Understanding the Dynamics of Inflation Volatility in Nigeria: A GARCH Perspective

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The estimation of inflation volatility is important to Central Banks as it guides their policy initiatives for achieving and maintaining price stability. This paper employs three models from the Generalized Autoregressive Conditional Heteroscedasticity (GARCH) family with a view to providing a parsimonious approximation to the dynamics of Nigeria's inflation volatility between 1996 and 2011. Of the competing models, the asymmetric TGARCH (1,1) provides an appropriate paradigm for explaining the dynamics of headline and core CPI volatilities in Nigeria, while the symmetric GARCH (1,1) was found to be adequate for food CPI. The results are quite revealing. Firstly, model outcomes indicate high persistence parameters for the core and food CPI, implying that the impacts of inflation shocks on their volatilities die away very slowly. However, the impact of inflation shocks on headline volatility die out rather quickly. Secondly, substantial evidence of asymmetric effect was found for both headline and core inflation types while the contrary was confirmed for food inflation. Thirdly, positive inflationary shocks yielded higher volatilities in headline and core inflation than negative innovations, implying the absence of leverage effect in them. The paper finds that periods of high inflation volatility are associated with periods of specific government policy changes, shocks to food prices and lack of coordination between monetary and fiscal policies.

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1.0 Introduction

In statistical terms, volatility is often regarded as variance and it is a measure of the dispersion of a random variable from its mean value. Thus, inflation volatility relates to the fluctuations (or instability) in a chosen measure of inflation (for further discussion, see Judson and Orphanides, 1999; Kontonikas, 2004; Samimi and Shahryar, 2009 and Pourgerami and Maskus, 1987). In Nigeria, for instance, monthly headline inflation is measured in terms of the year-on-year percentage change in the all-items Consumer Price Index (CPI) compiled by the National Bureau of Statistics (NBS) and fluctuations in such a measure characterizes inflation volatility in the country.

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The adverse effects of inflation volatility on the economy have been widely documented in countries of diverse economic structures and monetary policy frameworks. For example, it has been found to cause higher risk premia, hedging costs, unforeseen redistribution of wealth and ultimately a reduction in overall economic growth. This is in line with Friedman's (1977) conjecture that the harmful effect of inflation on growth is driven principally by inflation volatility. Additional evidences in this direction are provided by Judson and Orphanides (1999), Elder (2004), Byme and Davis (2004) and Elder (2005), Brunner and Hess (1993), Ungar and Zilberforb (1993), Baillie *et al.* (1996), Grier and Perry (1998), Rother (2004) and Caporale *et al.* (2010).

Internationally, the evidence for ARCH effects in inflation series is mixed, but there is strong evidence that countries with high inflation have significantly higher levels of volatility on average and such volatilities ultimately impacts on growth negatively. It is in recognition of this fact that most Central Banks of the world have incorporated price stability as part of their core mandates thereby mainstreaming policies that are capable of arresting the domestic drivers of high and unstable prices as well as anchoring inflation expectations at levels consistent with price stability. However, a crucial step in the achievement of this mandate or any serious price stabilization strategy for that matter involves proper estimation of inflation volatility as well as a firm understanding of its dynamics.

Over the years, the Generalized Autoregressive Conditional Heteroscedasticity (GARCH) methodology has become quite useful in modeling volatility of economic time series, including consumer price indices. As posited by Engle (1982), this methodology allows a conventional regression specification for the mean function with a variance which is permitted to change stochastically over the sample period. Within this framework, heteroscedasticity is seen as a variance that should be modeled in a time series perspective. Thus, the application of ARCH model introduced by Engle (1982) and its generalized extension (GARCH) proposed by Bollerslev (1986) in financial modeling have become very popular. An account of the variations and extensions to the GARCH model can be found in Hentschel (1995), Pagan (1996), Brooks (2008) and Xekalaki and Degiannakis (2010), among others. This study seeks to leverage on this area of methodology to understand the dynamics of inflation volatility in Nigeria in the last one and a half decades.

In Nigeria, some studies have been carried out in the area of modeling inflation volatility using GARCH methodology, most of which focused on estimating the conditional variance of the country's headline CPI series and investigating its impacts on other macro-economic variables. These studies include that of Idowu and Hassan (2010) who explore the relationship between headline inflation uncertainty and economic growth using quarterly headline CPI for the period 1970 to 2007. Also, Udoh and Egwaikhide (2008) employed the GARCH model to estimate headline inflation volatility and examined its impacts on foreign direct investment between 1970 and 2005, using annual data. Others include Adamgbe (2003) who fitted a symmetric GARCH (1,1) model to provide volatility estimates for Nigeria's headline CPI using annual data for the period 1970-2001. These studies assumed symmetric response of inflation volatility to positive and negative shocks as implied by the basic GARCH model. However, such a symmetric restriction in the GARCH model has been rejected by several empirical studies as inflation volatility was found to be more sensitive to positive inflation shocks than to negative shocks (Brunner and Hess, 1993).

A major implication of ignoring asymmetric considerations when modeling inflation volatility relates to either over-prediction or under-prediction of volatility levels depending on the nature of prevailing inflationary shocks. Also, the studies employed a rather low-frequency data for their analysis of headline inflation volatility. However, it has been argued in Natalia (2010) that using high frequency data increases the efficiency of extracting model-based estimates of volatility from economic time series. Finally, Idowu and Hassan (2010) obtain volatility estimates up to 2007 for headline inflation and this pre-dates the 2008 global financial crises.

In order to address the concerns highlighted above, this paper examines the volatility dynamics of not only headline CPI, but also food and core CPI series using monthly data. Also, the presence of volatility persistence and leverage effects in the three components of inflation are investigated. Thus, the broad objective of this paper is to model the time-varying volatility (σ_t^2) of Nigeria's inflation types between 1996 and 2011 using monthly data as well as explore its characteristics. To achieve this objective, a symmetric GARCH model and two asymmetric TGARCH and EGARCH models are fitted to each of the three inflation types and the best model for each type is selected based on selected information criterion[2].

[2] Akaike Information Criterion

For ease of exposition, the paper is structured into five sections; with section one as the introduction. Section two provides some historical perspective on Nigeria's inflation episodes. Section three discusses the analytical framework for the study as well as data sources. Section four presents the empirical analysis, while the final section concludes the paper.

2.0 Nigeria's Inflationary Episodes: Some Stylized Facts

Nigeria has had four major episodes of inflation in excess of 30 per cent since 1970. The first of these episodes was 1975, with an inflation rate of 33.7 per cent (tagged IE 1 in Fig. 1). The factors responsible for this development included drought in Northern Nigeria, which pushed up food prices as well as the excessive monetization of the large inflow of dollars that accrued from the crude oil boom. This period was also associated with high volatility as measured by the moving standard deviation of the year on year headline inflation rates (tagged VE 1 in Fig. 2). Some of the measures adopted to curb the situation included the reduction in import duties on a relatively large number of goods and raw materials, a conscious monetary policy targeted at encouraging banks to lend more to the productive sectors of the economy and the setting up of the Anti-Inflation Task Force, which recommended the establishment of the Productivity, Prices and Incomes Board. These explain the gradual decline in both the average inflation rate and its volatility during the period 1976 – 1983 (Fig. 1 & 2).

Also, 1984 represented another remarkable episode as inflation rate settled at a higher level of about 41.2 per cent, owing to the expectations of imminent devaluation of the domestic currency and monetary expansion. This period also witnessed increased inflation volatility as the computed 12 months moving standard deviation rose above 10.0 in 1984 and above 15.0 in 1985 (Fig. 2). In response, the military regime embarked on another round of price control, which led to a decline in the inflation rate to 5.5 per cent) in 1985 and 5.4 per cent in1986 and a decline in its standard deviation to less than 5 (Fig. 1 & 2).

The third episode of high inflation occurred during 1988 and 1989 caused by fiscal expansion of the 1988 budget, which was financed by credit from the CBN. Fig. 2 shows that the standard deviation of the headline inflation rate stood at 25 in 1988 before falling to about 7 in 1990, a period tagged VE3. Increased agricultural production helped to moderate inflationary pressures in 1990 as the inflation rate fell to 8.2 per cent.

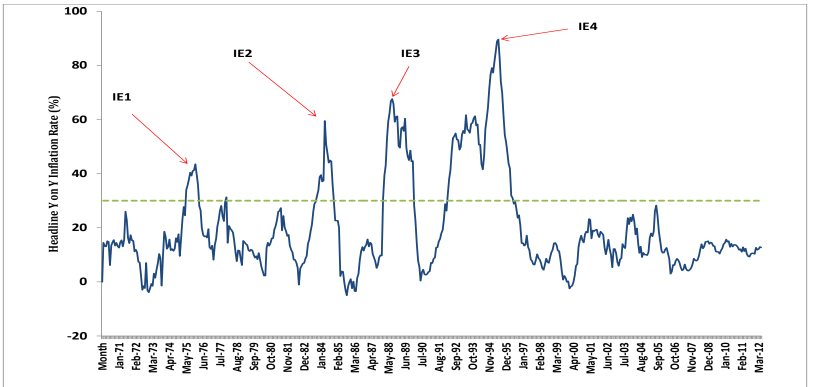

Fig 1: Plot of Nigeria's Y/Y Headline Inflation Rate

The fourth inflationary episode was the most turbulent in Nigeria's inflationary experience as it lasted about five years starting from 1992 and reaching an all-time high of over 80.0 per cent in 1995. The moving standard deviation was also relatively high, at about 15. Largely responsible for this development were monetary growth and fiscal expansion. As a response to the inflationary pressures of the period, the government strengthened its stabilization measures in the economy as it entrenched effective monetary policy, fiscal discipline as well as exchange rate stability.

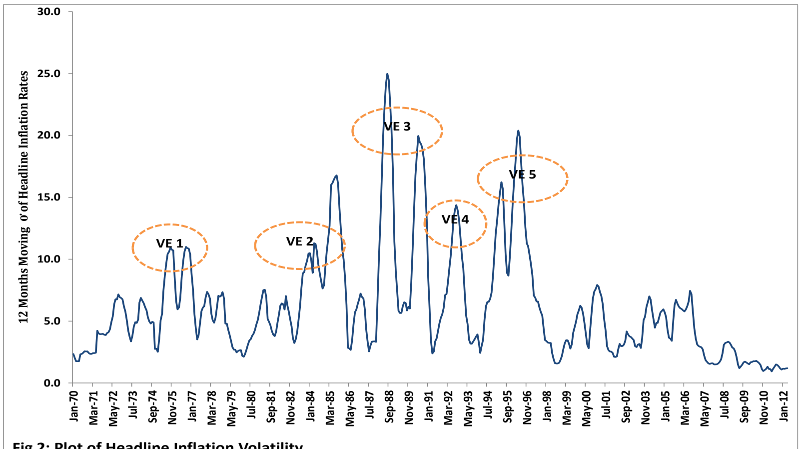

Fig 2: Plot of Headline Inflation Volatility

These measures resulted in a systematic decline in inflation rate from over 80.0 per cent in 1995 to 7.1 per cent in 2000. However, the last episode of inflation volatility was in 1996-97. From the foregoing analysis, we could infer that periods of high inflation are associated with periods of high inflation volatility.

3.0 Methodology

In developing the basic ARCH model, three distinct specifications are required, and these are for the: conditional mean equation, conditional variance equation, and conditional error distribution. For the purpose of this study, the conditional mean equation for each of the three inflation types shall follow an appropriate ARIMAX[3] process, which explains their behaviour overtime.

Table 1: List of Variables and their Definitions

S/N	Variable Symbol	Variable Definition
1	HCPI	Headline CPI
2	FCPI	Food CPI
3	CCPI	Core CPI
4	FUEL	Price of Petroleum Motor Spirit per Litre
5	GEXP	Central Government Expenditure
6	M	Broad Money Supply
7	OER	Official Nominal Naira Exchange Rate
8	RM	Reserve Money
9	R1C	Average Rainfall in Cereals Producing Zones [Northwest and Northeast Zones]
10	R2T	Average Rainfall in Tuber Producing Zones [North Central Zone]
11	R3V	Average Rainfall in Vegetables Producing Zone [Southern Zone]
12	CG	Credit to Central Government
13	EXRE	Gross External reserves
14	ER	Bureau-de-Change Nominal Naira Exchange Rate
15	μ	Autroregressive Term
16	ε	Moving Average Term

The literature is replete with theories of inflation, some of which include demand pull[4], cost push[5], Keynesian theory[6], quantity theory of money[7], purchasing power parity theory[8] and structural theory[9] (Jhingan, 2009). These theories guide the choice of variables used in this paper. Overall, the exogenous variables considered for inclusion in the mean models specified below are selected based on their theoretical, empirical and situational relevance. For instance, in addition to other variables suggested by theory, fuel price was incorporated in order to analyze the impact of government pronouncements of fuel price changes on inflation. Presented in Table 1 is the list of considered variables and their definition.

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[3] Autoregressive Integrated Moving Average with Exogenous Input

[4] This focuses on excess demand as a major determinant of inflation and highlights factors such as increased government, private and investment spending.

[5] This highlights factors such as increased money wages and higher prices of domestically produced or imported raw materials

[6] This combines both the demand pull and cost push factors and argues that money influences prices indirectly via interest rates.

[7] This posits that a change in money supply is accompanied by a proportionate change prices. Money supply is the key variable in this quantity theory model of inflation

[8] This emphasises the role of exchange rate in the inflationary process, especially in countries practicing flexible exchange rate regime.

[9] This explains that inflation can be caused by structural rigidities in the economy. These include land tenure, lack of storage facilities, poor harvest, overdependence on rainfall,

Thus, the mean equations for the headline (HCPI), food (FCPI) and core (CCPI) inflation types are specified respectively as:

$$HCPI_t = c_o + \sum_{i=0}^{v} A_i\, M_{t-i} + \sum_{i=0}^{w} B_i\, OER_{t-i} - \sum_{i=0}^{z} C_i\, R1C_{t-i} - \sum_{i=0}^{l} D_i\, R3V_{t-i} + \sum_{i=0}^{g} E_i\, ER_{t-i} + \sum_{i=0}^{m} F_i\, FCPI_{t-i} + \sum_{i=0}^{n} G_i\, CCPI_{t-i} + \sum_{i=1}^{p} H_i\, \mu_{t-i} + \sum_{i=1}^{q} I_i\, \varepsilon_{t-i} + \varepsilon_t \quad (1)$$

$$FCPI_t = c_o + \sum_{i=0}^{v} \psi_i\, M_{t-i} + \sum_{i=0}^{w} \pi_i\, OER_{t-i} - \sum_{i=0}^{z} \lambda_i\, R1C_{t-i} - \sum_{i=0}^{l} \varphi_i\, R3V_{t-i} + \sum_{i=0}^{g} \rho_i\, RM_{t-i} + \sum_{i=0}^{m} \nu_i\, CG_{t-i} - \sum_{i=0}^{n} \phi_i\, R2T_{t-i} + \sum_{i=0}^{u} \chi_i\, GEXP_{t-i} + \sum_{i=0}^{j} \upsilon_i\, EXRE_{t-i} + \sum_{i=0}^{h} \zeta_i\, ER_{t-i} + \sum_{i=1}^{p} \omega_i\, \mu_{t-i} + \sum_{i=1}^{q} \theta_i\, \varepsilon_{t-i} + z_t \quad (2)$$

and,

$$CCPI_t = c_o + \sum_{i=0}^{v} J_i\, M_{t-i} + \sum_{i=0}^{w} K_i\, FUEL_{t-i} - \sum_{i=0}^{z} L_i\, R1C_{t-i} - \sum_{i=0}^{l} M_i\, R2T_{t-i} + \sum_{i=0}^{g} N_i\, ER_{t-i} + \sum_{i=0}^{m} O_i\, FCPI_{t-i} + \sum_{i=1}^{p} R_i\, \mu_{t-i} + \sum_{i=1}^{q} S_i\, \varepsilon_{t-i} + k_t \quad (3)$$

where ε_t is assumed to be white noise $[\varepsilon_t \sim N(0, \sigma^2)]$, c_0 is a constant, ω_i*'s* are the autoregressive terms *(for i=1, 2, 3, ..., p)* and $\theta_{i's}$ are the moving average terms *(for i=1, 2, 3, ..., q)*. The residuals (ε_t) from equations (1), (2) and (3) are said to follow an ARCH (p) process if the conditional distribution of ε_t given its past values has zero mean and conditional variance σ^2_t. The coefficients of the exogenous variables are $A_i, B_i, C_i, D_i, E_i, F_i, G_i, \psi_i, \pi_i, \lambda_i, \varphi_i, \rho_i, \nu_i, \phi_i, \chi_i, \upsilon_i, \zeta_i, J_i, K_i,$ $L, M_i, N_i,$ and O_i with the subscript i on each of the parameters ranging from zero to their respective limits. The endogenous and exogenous variables are listed and defined in Table 1.

The conditional variance equations estimated in this study are broadly divided into two groups, namely: the symmetric model (GARCH)[10] and the asymmetric models (TGARCH and EGARCH)[11]. Starting with the symmetric model, Engle

[10] GARCH means Generalized Autoregressive Conditional Heteroscedasticity

[11] TGARCH means Threshold Generalized Autoregressive Conditional Heteroscedasticity and EGARCH means Exponential Generalized Autoregressive Conditional Heteroscedasticity.

(1982) introduced the ARCH (q) model to estimate the time-varying volatility of a series by expressing the conditional variance of the prediction error term as a function of the recent past values of the squared error as follows:

$$\sigma_t^2 = c_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-1}^2 \quad (4)$$

Such that $c_0 \geq 0$ and $\alpha_i \geq 0$ *for* $i = 0, 1, 2, ..., q$. σ^2_t denotes the conditional variance at time t, c_1 is a constant, α_i are the parameters of the ARCH terms of order q and ε_{t-i}^2 represent the lagged values of the squared prediction error for $i = 1, 2, 3, ..., q$. In order to provide solution to the problem of how many lags of the squared innovations should be included in the ARCH model, Bollerslev (1986) introduced a generalized version of the ARCH model by modeling the conditional variance as a function of its own lagged values as well as the lagged values of the squared innovations as follows:

$$\sigma_t^2 = c_0 + \alpha\varepsilon_{t-1}^2 + \beta\, \sigma_{t-1}^2 \quad (5)$$

where σ_t^2, c_0, α and ε_{t-i}^2 are as previously defined in equation (4), β is the GARCH coefficient and σ_{t-1}^2 represents the one period lag of the fitted variance from the model. To guarantee a well-defined GARCH (1,1) model, it is required that $\alpha \geq 0$ and $\beta \geq 0$, while $\alpha + \beta < 1$ suffices for covariance stationarity.

The TGARCH model introduced by Glosten *et al.* (1993) allows for asymmetric effects in volatility modeling. They extended the GARCH model by including an additional term γ, to capture possible asymmetries in the data. The TGARCH specification is given as:

$$\sigma_t^2 = c_0 + \alpha\varepsilon_{t-1}^2 + \gamma h_{t-1}\varepsilon_{t-1}^2 + \beta\, \sigma_{t-1}^2 \quad (6)$$

where h_{t-1} is an indicator function that takes the value of *1* if $\varepsilon_{t-1} < 0$ and *0* otherwise, γ is the asymmetric parameter and c_1, α and β are as defined in equation (5). Good news (positive shock) is obtained when $\varepsilon_{t-1} > 0$, while bad news (negative shocks) is obtained when $\varepsilon_{t-1} < 0$. Good news has an impact of $\boldsymbol{\alpha}$ while bad news has an impact of $\alpha + \gamma$ on the conditional variance. If $\boldsymbol{\gamma} \neq 0$, news impact is asymmetric and if $\boldsymbol{\gamma} > 0$, there is leverage effect as negative shocks increase volatility more compared with an equivalent amount of positive shocks. The TGARCH model reduces to the basic GARCH model if the asymmetric term (γ) is zero.

Nelson (1991) extends the GARCH model to efficiently capture volatility clustering and asymmetric effect. This model is known as the EGARCH is specified as:

$$log(\sigma_t^2) = c_0 + \alpha\left(\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}} - \sqrt{\frac{2}{\pi}}\right|\right) + \gamma\left(\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right) + \beta log(\sigma_{t-1}^2) \quad (7)$$

where c_0, α, β and γ are as defined in equation (6). The fact that the left-hand side of equation (7) is the log of the conditional variance implies that the leverage effect is exponential, rather than quadratic. Therefore, the forecasts of the conditional variance should be non-negative. The asymmetric effect of past shocks is captured by the $\boldsymbol{\gamma}$. If the asymmetric term is $\gamma \neq 0$, news impact is asymmetric and if $\gamma < 0$, there is leverage effect. The impact of conditional shocks on the conditional variance is measured by α. A positive shock in period $t-1$ has an effect of $\alpha + \gamma$ on the conditional variance whereas a negative shock has an effect of $\alpha - \gamma$. Usually ARCH/GARCH models are estimated under specific assumption about the conditional distribution of the error term. The normal distribution is assumed in this study[12].

There are various criteria for model selection in the literature. This paper employs the Akaike Information Criterion (AIC) as it helps to balance the trade-off between model-fit and complexity. It is defined as:

$$AIC = -2\left(\frac{L}{N}\right) + 2\left(\frac{K}{N}\right) \quad (8)$$

where L is the value of the log-likelihood function, K is the number of estimated parameters and N is the number of observations. In each class of model, different models are fitted and the one with the lowest AIC value is selected as the best for that class.

4.0 Data, Results and Discussions

This empirical study uses headline, food and core Consumer Price Indices (CPIs)[13], covering the period January 1996 to December 2011 as the dependent variables for the class of mean models estimated in this paper. Data on the other exogenous variables (listed in Table 1) for the same period are sourced from the Central Bank of Nigeria database.

[12] Estimation based on the student's t-distribution and generalized error distribution assumption of the prediction error term did not improve model results substantially.
[13] Downloadable from ***www.nigerianstat.gov.ng***

4.1 Stationarity Test

Checking the order of integration of included variables is crucial in any time series modeling. The Augmented Dickey Fuller (ADF) and Philips Perron tests are used to test for the stationarity properties of the data and Table 2 summarizes the results. Both tests rejected the null hypothesis of unit root in the un-differenced *FUEL and R1C* series while only the Phillips Perron test rejected same for *R2T*, *R3V* and *GEXP* at the at 5% level of significance. However, all other variables were integrated of order 1 (at 5% level of significance) and differencing them once ensured stationarity. Note that in Table 2 official and BDC exchange rates are denoted as OER and ER in the equations above.

Table 2: Results of Augmented Dickey-Fuller & Phillips-Perron Unit Root Test

Variables	Levels				First Difference			
	ADF^c	PP^c	ADF^{ct}	PP^{ct}	ADF^c	PP^c	ADF^{ct}	PP^{ct}
HCPI	2.7115	4.2623	-0.7000	-0.1432	-10.0938	-9.9460	-10.7184	-10.4352
FCPI	2.1490	2.9784	-0.7460	-0.3620	-10.8367	-10.7057	-11.2787	-11.0781
CCPI	2.0315	1.9530	-1.4821	-1.5482	-12.4267	-12.4297	-12.7222	-12.6828
FUEL	-16.4016	-16.5454	-16.3731	-16.5222	-10.7903	-235.0934	-10.7610	-236.9508
GEXP	0.9893	-7.9934	-1.3615	-12.4646	-11.6522	-51.3344	-11.8129	-56.7763
M2	2.7694	3.8744	-0.5268	-0.1239	-14.0763	-14.0670	-14.9602	-15.4506
OFFICIAL	-1.5302	-1.5330	-1.5798	-1.6740	-13.2569	-13.2604	-13.2690	-13.2706
CG	-1.3493	-1.4452	-1.3547	-1.5250	-14.8965	-14.9372	-14.8678	-14.9109
RM	3.4352	3.3941	1.6064	-0.5940	-10.4819	-18.7490	-9.4604	-20.3581
CPS	2.7808	3.1138	0.6371	0.4686	-4.4969	-11.9061	-5.3318	-12.3400
EXRES	-1.0800	-1.1042	-2.4280	-1.0940	-6.0129	-10.7670	-6.0253	-10.7812
R1C	-3.9181	-3.8362	-3.8795	-3.8013	-22.9769	-11.3045	-22.9488	-11.2837
BDC	-1.4511	-1.2488	-2.6607	-2.2381	-8.6052	-8.5364	-8.5827	-8.5132
R2T	-2.6394	-6.0965	-2.8352	-6.0791	-12.9205	-11.0370	-12.9150	-11.0146
R3V	-2.2764	-6.2736	-3.0907	-6.2554	-18.5953	-10.7922	-18.6041	-10.7741

ADF^c and PP^c represent unit root test with constant

ADF^{ct} and PP^{ct} represent unit root test with constant and trend

**MacKinnon (1996) critical values with constant are -3.4645 (1%), -2.8764 (5%) and -2.5748 (10%)*

**MacKinnon (1996) critical values with constant and trend are -4.0071 (1%), -3.4337 (5%) and -3.1407 (10%)*

4.2 Conditional Mean Equations

4.2.1 Conditional Mean Equation for Headline CPI:

From the results of the mean model for the headline CPI, which was selected based on the minimum AIC value, the estimated equation (1) can be expressed as:

$$\Delta HCPI_t = 0.0783 + 0.5776\Delta FCPI_t + 0.3187\Delta CCPI_t + 0.0142\Delta ER_t + 2.12 * 10^{-7}\Delta M_{t-5} + 0.0514\Delta OER_{t-12} - 0.0008R1C_{t-3} + 0.0007\Delta R3V_{t-4} - 0.2627\mu_{t-5} - 0.2157\mu_{t-6} - 0.4198\varepsilon_{t-1} - 0.0649\varepsilon_{t-12} + 0.5613\varepsilon_{t-18} \quad (9)$$

All the coefficients are statistically significant at the 1 per cent level. Equation (9) is well fitted and suggests that the monthly increase in headline CPI at time *t* is influenced by the monthly increases of food CPI and core CPI at the same period, a depreciation of the parallel market exchange rate at the same period, a depreciation of official exchange rate a year ago and increased money supply five months earlier.

4.2.2 Conditional Mean Equation for Food CPI

From the results of the mean model for the food CPI, which was based on the minimum AIC value, the estimated equation (2) can be expressed as:

$$\Delta FCPI_t = 0.7128 + 1.64 * 10^{-6}\,\Delta CG_t + 1.68 * 10^{-4}\Delta EXRE_{t-2} + 2.19 * 10^{-6}GEXP_{t-1} - 9.71 * 10^{-7}\Delta M_{t-9} - 0.1072\Delta OER_{t-12} + 2.37 * 10^{-6}\Delta RM_t - 0.0544\Delta ER_{t-14} + 0.0052R1C_t - 0.0039\Delta R2T_{t-2} - 0.0048\Delta R3V_{t-3} + 0.1766\mu_{t-5} + 0.2349\mu_{t-14} + 0.2152\varepsilon_{t-1} \quad (10)$$

All the coefficients are statistically significant at the 5 per cent level. Equation (10) is well fitted and suggests that monthly increase in food CPI in period *t* is largely explained by the expansion of reserve money in period *t*, increased credit to government in period *t* and government expenditure in period t-1. Also, increased gross external reserves in period t-2, and increased broad money supply in period t-9. Surprisingly, appreciation of both the official exchange rate and the parallel market exchange rate in periods t-12 and t-14 increase the food CPI in period *t*.

4.2.3 Conditional Mean Equation for Core CPI

From the results of the mean model for the core CPI, which was selected based on the minimum AIC value, the estimated equation (3) can be expressed as:

$$\Delta CCPI_t = 0.3021 + 0.0210FUEL_t - 0.1952\Delta FCPI_{t-4} - 1.57 * 10^{-6}\Delta M_t - 0059ER_{t-4} - 0.0034R1C_{t-8} + 0.0043\Delta R2T_{t-12} - 2234\mu_{t-9} + 0.1394\mu_{t-15} - 0.2203\mu_{t-31} - 0.1678\varepsilon_{t-19} \quad (11)$$

All the coefficients except the constant are significant at the 5 per cent level. Equation (11) is well fitted and suggests that an increase in core CPI in period *t* is determined by the price of petroleum motor spirit in period *t*, increase in broad money supply in period t, appreciation in parallel market exchange rate in period t-4 and a decline in the food index in period $t-4$. It is also affected by rainfall data and some of the autoregressive and moving average terms.

Table 3: Breusch-Godfrey Serial Correlation LM Test on the Residuals of the Mean Models

Model	F-Statistic Test		Chi-Square Test	
	F-Statistic	*Prob.*	*Obs*R-squared*	*Prob. Chi-Square*
Headline Inflation	0.3054	0.7372	0.6409	0.7258
Food Inflation	0.9937	0.3725	2.1603	0.3395
Core Inflation	0.1297	0.8785	0.2810	0.8689

The Breusch-Godfrey Lagrange Multiplier test for Serial Correlation was used to test for reliability of the estimated mean models in equations (9), (10) and (11). The test presented in Table 6 failed to reject the null hypothesis of no serial correlation in the residuals of the models. With the absence of serial correlation in the residuals, these estimated models could be used to forecast the CPI series.

4.3 Estimating the Volatility Models

The squared residuals in equations (9), (10) and (11) are tested for ARCH effect. The null hypothesis of homoscedasticity in the squared residuals of headline, food and core CPIs mean models was rejected at the 5 per cent level, implying the presence of ARCH effect. The result of the ARCH LM test presented in Table 4 leads to the conclusion that the headline, food and core models of equations (9), (10) and (11) possess time varying volatilities. Also, the plots of the autocorrelation function (ACF) and partial autocorrelation function (PACF) provided additional evidence for significant autoregressive conditional heteroscedasticity in the squared residuals as they revealed significant spikes at specific lags. Therefore, these mean models are subsequently used for the estimation of their volatilities.

Table 4: ARCH LM Test for Heteroscedasticity in the Squared Residuals of the Mean Models

Model	F-Statistic Test		Chi-Square Test	
	F-Statistic	*Prob.*	*Obs*R-squared*	*Prob. Chi-Square*
Headline CPI	10.8077	0.0012	10.3140	0.0013
Food CPI	3.6721	0.0275	7.1642	0.0278
Core CPI	6.0852	0.0029	11.5029	0.0032

4.3.1 Volatility Model for Headline CPI

The volatility models defined in equations (5), (6) and (7), namely the GARCH, TGARCH and EGARCH were estimated for the headline CPI. However, the model selection criterion indicates that the TGARCH (1,1) recorded the minimum AIC value and represents the best volatility model for headline CPI. The summary of the volatility models and their characteristics is presented in Table 5.

Table 5: Summary of the Headline CPI Volatility Models and their Characteristics

	GARCH	TGARCH	EGARCH
ω (Constant)	0.0267[a]	0.0310[a]	-1.8199[a]
α (ARCH)	0.2549[a]	0.4518[a]	0.8411[a]
β (GARCH)	0.4110[a]	0.3843[c]	0.5570[a]
γ (Asymmetry)	-	-0.4293[a]	0.0683[ns]
Impact of +ve Shocks	-	0.4518	0.9094
Impact of -ve Shocks	-	0.0225	0.7728
Persistence (α + β)	0.6659	0.8361	1.3981
AIC	0.3800	0.3705*	0.4031

P values are in Italics

a = Significant at 5% level, c = Significant at 10% level, ns = Not significant

From the results of the fitted TGARCH(1,1) model for the headline CPI, which was selected based on the minimum AIC value, the re-estimated equation (9) can be expressed as:

$$\Delta HCPI_t = 0.0867 + 0.5780\Delta FCPI_t + 0.3163\Delta CCPI_t + 0.0130\Delta ER_t + 1.85 * 10^{-7}\Delta M_{t-5} + 0.0513\Delta OER_{t-12} - 0.0009R1C_{t-3} + 0.0005\Delta R3V_{t-4} - 0.2232\mu_{t-5} - 0.1947\mu_{t-6} - 0.4268\varepsilon_{t-1} - 0.0554\varepsilon_{t-12} + 0.544\varepsilon_{t-18} \quad (12)$$

Equation (12) is well fitted and the coefficients are statistically significant at the 1 per cent level. The corresponding estimated volatility model is:

$$\sigma_t^2 = 0.0310 + 0.4518\varepsilon_{t-1}^2 - 0.4293h_{t-1}\varepsilon^2{}_{t-1} + 0.3843\,\sigma_{t-1}^2 \quad (13)$$

where $h_{t-1} = 1\ if\ \varepsilon_{t-1} < 0$, and *0* otherwise. Equation (13) shows that the ARCH and GARCH terms are significant at the 5% and 10% significant level, respectively. The persistence parameter is about 0.8361, which is much less than unity. This suffices for covariance stationarity and also indicates that impacts of shocks on headline volatility do die away rather quickly. The news impact is asymmetric and there is no leverage effect. Also, the asymmetric term is negative (-0.4293) and significantly different from zero. This indicates that positive inflation shocks, that is, news capable of inducing higher inflation, increases headline volatility than news capable of dampening inflation. For instance, positive inflation shocks increases headline inflation volatility by 0.4518, while negative shocks of the same magnitude transmit smaller volatility (0.0025).

4.3.2 Volatility Model for Food CPI

The volatility models estimated for the food CPI presented in Table 6 indicate that GARCH (1,1) model recorded the smallest AIC value, and is therefore more suitable for food CPI than the other two competing models.

Table 6: Summary of the Food CPI Volatility Models and their Characteristics

	GARCH	TGARCH	EGARCH
ω (Constant)	0.0024^{ns}	0.0021^{ns}	-0.7339^{a}
α (ARCH)	1.9910^{a}	2.0906^{a}	1.0100^{a}
β (GARCH)	0.1819^{a}	0.1873^{a}	0.6878^{a}
γ (Asymmetry)	-	-0.2524^{ns}	0.0123^{ns}
Impact of +ve Shocks	-	2.0906	1.0223
Impact of -ve Shocks	-	1.8382	0.9977
Persistence (α + β)	2.1729	2.2779	1.6978
AIC	3.0473*	3.0569	3.0854

P values are in Italics

a = Significant at 5% level, c = Significant at 10% level, ns = Not significant

From the results of the fitted GARCH(1,1) model for the food CPI, which was selected based on the minimum AIC value, the re-estimated equation (10) can be expressed as:

$$\Delta FCPI_t = 0.5009 + 1.36 * 10^{-6}\,\Delta CG_t + 1.52 * 10^{-4}\Delta EXRE_{t-2} + 1.11 * 10^{-6}GEXP_{t-1} - 1.53 * 10^{-6}\Delta M_{t-9} - 0.1226\Delta OER_{t-12} + 2.61 * 10^{-6}\Delta RM_t - 0.0284\Delta ER_{t-14} + 5.41 * 10^{-5}\,R1C_t - 0.0017\Delta R2T_{t-2} - 0.0016\Delta R3V_{t-3} + 0.1591\mu_{t-5} + 0.30899\mu_{t-14} + 0.3089\varepsilon_{t-1} \quad (14)$$

Equation (14) is well fitted and the coefficients are statistically significant at the 1 per cent level, except the rainfall coefficient. The corresponding estimated volatility model is:

$$\sigma_t^2 = 0.0024 + 1.9910\varepsilon_{t-1}^2 + 0.1819\sigma_{t-1}^2 \quad (15)$$

The volatility model of the food CPI suggests that both positive and negative inflation shocks confer similar effect on its volatility. However, there is evidence of volatility persistence, implying that the impacts of shocks to food inflation volatility die away very slowly.

4.3.3 Volatility Model for Core CPI

The volatility models estimated for core CPI and presented in Table 7 indicated that the TGARCH (1,1) is the best model for core CPI.

Table 7: Summary of the Core CPI Volatility Models and their Characteristics

	GARCH	TGARCH	EGARCH
ω (Constant)	0.1521[ns]	0.0256[ns]	-0.3428[a]
α (ARCH)	0.2049[a]	0.1097[a]	0.5524[a]
β (GARCH)	0.7055[a]	0.9934[a]	0.7016[a]
γ (Asymmetry)	-	-0.2342[a]	0.1067[ns]
Impact of +ve Shocks		0.1097	0.6591
Impact of -ve Shocks		-0.1245	0.4457
Persistence (α + β)	0.9104	1.1031	1.2540
AIC	3.2961	3.1846*	3.3030

P values are in Italics

a = Significant at 5% level, c = Significant at 10% level, ns = Not significant

From the results of the fitted TGARCH (1,1) model for the core CPI, which was selected based on the minimum AIC value, the re-estimated equation (11) can be expressed as:

$$\begin{aligned}\Delta CCPI_t = 0.292 + 0.0206FUEL_t - 0.1498\Delta FCPI_{t-4} - 9.89 * 10^{-7}\Delta M_t \\ - 0539ER_{t-4} - 0.0035R1C_{t-8} + 0.0047\Delta R2T_{t-12} - 0.1959\mu_{t-9} \\ + 0.0864\mu_{t-15} - 0.1727\mu_{t-31} \\ - 0.403\varepsilon_{t-19} \end{aligned} \quad (16)$$

Equation (16) is well fitted and the coefficients are statistically significant at the 5 per cent level, except the AR (15). The corresponding estimated volatility model is:

$$\sigma_t^2 = 0.0256 + 0.1097\varepsilon_{t-1}^2 - 0.2342\varepsilon_{t-1}^2 h_{t-1} + 0.9934\sigma_{t-1}^2 \quad (17)$$

where $\mathrm{h}_{t-1} = 1$ if $\varepsilon_{t-1} < 0$ and $h_{t-1} = 0,$ otherwise. The model defined in equation (17) confirms strong asymmetric response of core inflation volatility to inflation shocks as the asymmetric term is highly significant and negative. The negative coefficient of the asymmetric term connotes the absence of leverage effect and shows that the impact of positive innovations on core inflation volatility exceeds that of negative innovations. The ARCH and GARCH variables are also highly significant justifying their inclusion in the model. As in the other inflation types, the persistence parameter for core inflation volatility is high at 1.1031, indicating that the impact of shocks do die away very slowly.

For correctly specified variance models, the standardized residuals should contain no significant ARCH. The results of the ARCH LM test for ARCH in the residuals presented in Table 8 show that there is no remaining ARCH in the chosen variance equations and that the volatility models are adequate.

Table 8: ARCH LM Test for Remaining ARCH Effect in the Variance Models

Model	F-Statistic Test		Chi-Square Test	
	F-Statistic	*Prob.*	*Obs*R-squared*	*Prob. Chi-Square*
Headline Inflation (GJR-GARCH)	0.1459	0.7030	0.1474	0.7011
Food Inflation (GARCH)	0.3230	0.5706	0.3261	0.5680
Core Inflation (GJR-GARCH)	0.0059	0.9387	0.0060	0.9382

4.4 Dynamics of Inflation Volatility

The time series plot of estimated volatilities for headline, food and core CPI during the study period is presented in Fig. 3. It shows that food was the most volatile of the three inflation types, followed by core CPI and headline CPI in that order. In the case of headline CPI, the TGARCH variance estimates were low and stable between 1997 and the first half of 1998 (Fig. 4). This was brought about by successful measures put in place by the government against high and unstable prices. In addition, improved harvest of staples and exchange rate stability created an enabling environment for moderate and stable prices during the period. However, there were major volatility spikes in headline CPI during the third quarter of 1998 and core CPI during the fourth quarter, coinciding with a period of domestic and external imbalances in the economy (CBN, 1998). Sources of positive shocks to inflation during the period included the announcement effect of an upward review of the salary structure in the public sector, the continued scarcity of petroleum products and deteriorating infrastructures. However, proactive monetary policy interventions and favorable harvest of staples provided some dampening effects.

Following the volatility spikes of the second half of 1998, there was relative calm in headline, food and core CPIs during 1999 reflecting the moderation in inflationary pressure during the year (Fig. 3). This coincided with a period of favorable agricultural harvest and effective harmonization of monetary and fiscal policies. Also, interest rate policy (anchored on the Minimum Rediscount

Rate - MRR) was market based and responsive to market conditions thereby engendering some stability in the year.

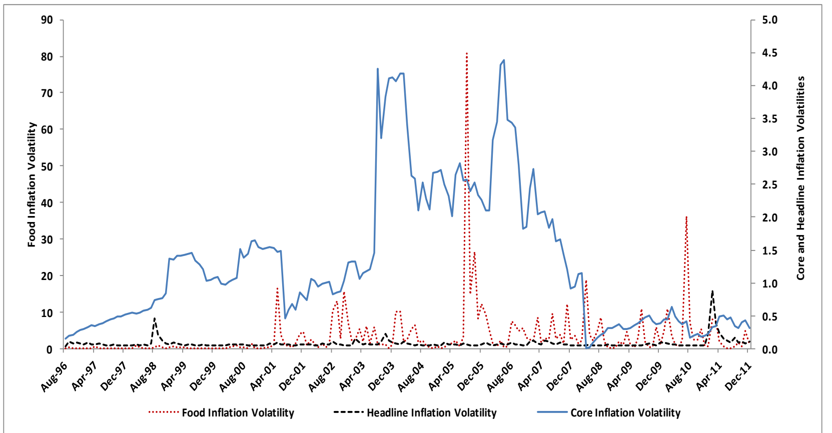

Fig. 3: Volatility Estimates for Headline, Food and Core CPI

The relative stability in prices witnessed in 1999 continued in first half of 2000. However, moderate increase in volatility was experienced during the third quarter of the year following the announcement of a hike in the price of fuel from ₦20/litre to ₦22/litre in June 2000 and the monetization of enhanced oil receipts. The instability in prices caused by these policy actions is reflected moderately in the volatility of headline CPI (Fig. 4) and noticeably in core CPI volatility (Fig. 5), while food CPI volatility remained quite low and stable (Fig. 6).

There were volatility spikes in the second quarter of 2001 in headline, food and core CPIs. This was followed by a period of relative stability, enabled by favorable agricultural harvest and tight fiscal and monetary policies. The TGARCH variance estimates for headline and core CPIs remained at low and moderate levels from the third quarter of 2001 to the beginning of 2003, with the exception of some spikes in August 2002 following the introduction of the RDAS in July, which saw the exchange rate depreciating from ₦118.49 per US dollar to about ₦123.72. Also, the monetization of US$1.5 billion external reserves in the last quarter of 2002 paved way for the inflationary pressure and turbulence recorded in the latter part of 2003.

The headline CPI variance estimate rose sharply in October 2003 (Fig. 4). Also, core CPI volatility reached its second highest point in August 2003 (Fig. 5) while food CPI volatility was relatively moderate (Fig. 6). The identified spikes in headline and core CPIs closely followed the announcement of an increase in pump price of petroleum products from ₦26/liter to ₦40/liter in June 2003.

In 2004, headline, food and core inflation volatility decreased steadily during the first two quarters of the year. During the year, inflationary pressure moderated due to fiscal prudence as the government adhered to the fiscal rule of the US$25.0/barrel oil benchmark price on which the budget was based. Also, tight monetary policy was implemented, anchored on continuous mopping up of excess liquidity and expansion of non-oil output.

In August 2005, however, food price volatility rose to its highest level during the study period. This coincided with the period of increased food export from the country and the restocking of the strategic grains reserves following food aid to Niger and Chad. These factors mounted inflationary pressure on food prices owing to limited supply. While core CPI volatility remained at high levels during the year, headline CPI volatility was low.

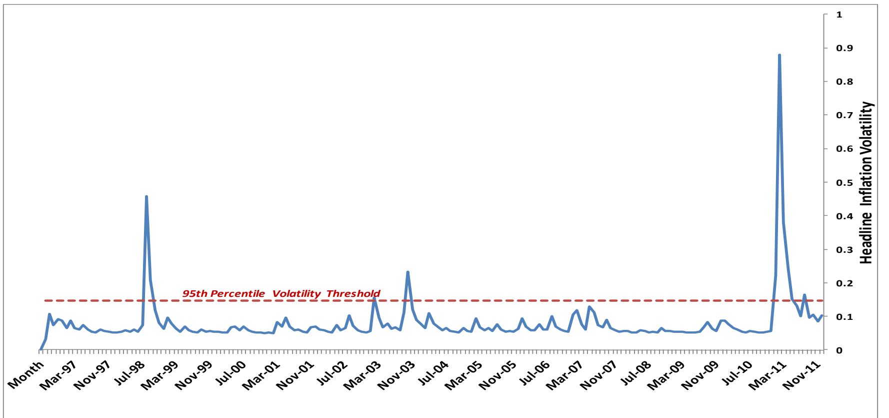

Fig 4: Volatility Estimate of Headline CPI

The volatility of headline and food CPIs remained at low levels in 2006. This was due to a number of factors, which included good harvests for most agricultural commodities, the appreciation and relative stability of the naira exchange rate and the implementation of sound monetary and fiscal policies. However, core CPI witnessed a sharp increase in its volatility in June 2006, the highest it ever got during the study period. In order to further maintain price and overall economic stability, a new monetary policy implementation framework (Monetary Policy Rate) was thus introduced in December 2006.

In 2007, there was less volatility in both headline, food and core inflation series as inflationary pressures were effectively contained due to sound monetary and fiscal policies, good agricultural harvest, stability in the prices and supply of petroleum products, as well as the relative stability in the naira exchange rate.

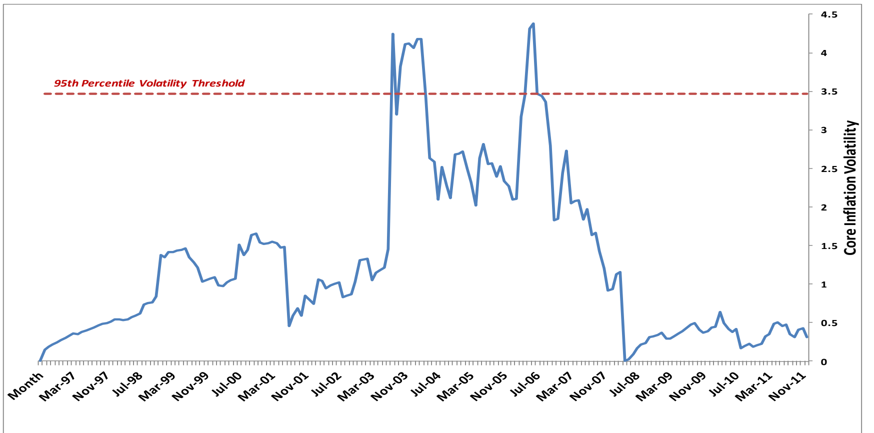

Fig 5: Volatility Estimate of Core CPI

The variance estimates for core inflation volatility declined steadily during the year probably due to the continued use of MPR as an anchor interest rate for moderating volatility in the interbank rates and improving monetary policy actions (Fig. 5). During the year, the MPR was reviewed appropriately to reflect monetary conditions. For instance, the MPR was reviewed downwards by 200 basis points in June, upwards by 100 basis points in October and upwards by 50 basis points in December, 2007.

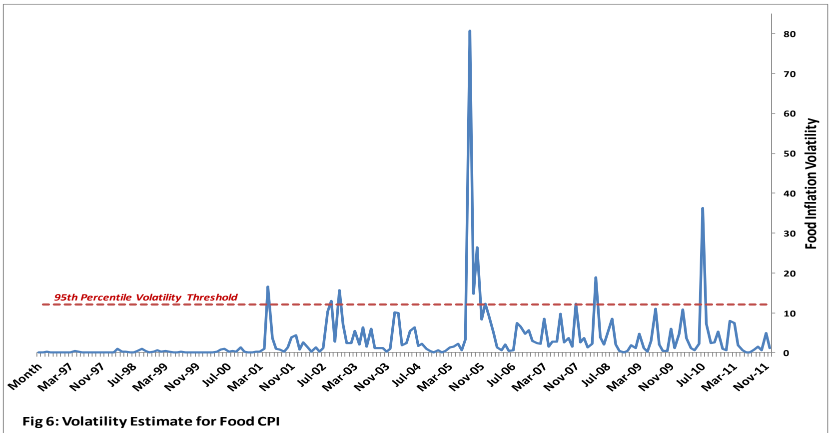

Fig 6: Volatility Estimate for Food CPI

The regime of low volatility of headline, food and core inflation continued in 2008, except for a spike recorded by food CPI in April reflecting the effect of the global food crisis that peaked in 2008 (Fig. 6). In response to the crisis, 64, 984.76 tonnes of grains were released from the strategic grains reserves to mitigate the effects of the food crisis during the year (CBN, 2008). Also, the

MPR was reviewed upwards by 50 basis points and 25 basis points in April and June and downwards by 50 basis points in September as a proactive and quick response to the contagion effect of the 2008 global financial crisis.

The impact of the 2008 crisis and other inflationary shocks were mitigated in 2009 through the proactive use of sound monetary and fiscal policies. Thus, headline, food and core inflation volatilities remained at low levels during the year (Fig. 3). However, moderate increase in volatility was recorded in the third quarter following some inflationary shocks, such as a surge in the prices of staples and the increase in price of petroleum products from ₦40/liter to ₦70/liter, which was later reduced back to ₦65/liter in June of the same year.

In 2010, the volatility of headline, food and core inflation remained at relatively low levels. During this period, inflationary pressures moderated due to increased agricultural production, relative stability in the supply and prices of petroleum products and very proactive and effective monetary policy decisions. Thus, there was relative calm in the first half of 2010. However, there was an increase in the volatility of food CPI in July, a period associated with increased demand for food by agro-processors, industrial users and neighboring countries (CBN, 2010). Headline CPI volatility got to its peak during the first quarter of 2011 reflecting inflationary pressures and instabilities preceding the April 2011 presidential elections. Food inflation also reached its peak for the year during the first quarter.

5.0 Summary and Conclusion

The study modeled inflation volatility in Nigeria's headline, food and core CPI series in order to understand the dynamics of inflation volatility between 1996 and 2011, using monthly data sourced from the National Bureau of Statistics (NBS) and the Central Bank of Nigeria (CBN). Most of the similar attempts made by different authors in the recent past employed the symmetric GARCH model using low frequency data. This paper however accommodates asymmetric considerations in its modeling approach, using recent and high frequency data set. Having modeled the conditional mean of the headline, food and core CPI individually as an ARIMAX process, the obtained residuals were tested for serial correlation and ARCH effects.

While no evidence of serial correlation was found, the squared residuals of the conditional mean models showed significant Autoregressive Conditional Heteroscedastic (ARCH) effect. For series with significant ARCH effects, the three inflation types were modeled as zero-mean, serially uncorrelated process with non-constant variances conditional upon the past. In this regard, a symmetric GARCH model and two asymmetric GARCH models were fitted to each of the three inflation types with a view to coming up with the best model for obtaining reliable estimates of their conditional variances. Based on AIC model selection procedure, the TGARCH (1,1) model was found appropriate for headline and core CPI, while the symmetric GARCH was selected for food CPI.

The variance models confirmed the presence of volatility persistence in headline, food and core CPI, implying that while the effect of inflation shocks on headline do die away rapidly, the effects on food and core do die away rather slowly. However, a higher persistence parameter was recorded for food CPI (2.2) compared with core CPI (1.1) and headline CPI (0.8). Also, the asymmetric term for the headline and core CPI variance models were significant, confirming the asymmetric response of their volatilities to inflation shocks. However, no evidence of leverage effect was found for the two series as their conditional volatility are more responsive to positive shocks than negative innovations. In the case of food CPI, the asymmetric term was insignificant and the symmetric GARCH was found appropriate. Thus, positive and negative inflation shocks confer similar effects on food CPI volatility.

Based on the 95^{th} percentile point of the variance estimates during the study period, episodes of high inflation volatilities in headline, food and core inflation were identified. Thus, three major periods of high volatility of headline CPI were identified and these are August 1998, October 2003 and February 2011 (Fig. 4). In the case of food inflation volatility, six episodes were identified during the periods May 2001, November 2002, August-November 2005, November 2007, April 2008 and June-August 2010 (Fig. 6). August-November 2005 represented the peak of food inflation volatility and this coincided with the period of the global food crisis. Lastly, three episodes of high core inflation volatility were found corresponding to the periods July-August 2003, October 2003 - March 2004 and May-June, 2006 (Fig. 5). Of the three inflation types, food inflation was found most volatile followed by core and headline inflation, respectively.

Economic developments surrounding the periods of high inflation volatility were discussed in the paper. However, major positive inflationary shocks during the study period include, among others, announcement of fuel price hikes, announcement of an upward review in the wages of public sector workers, food crisis and exchange rate instability. An analysis of the volatility dynamics of the series in a time series perspective showed that periods of high inflation volatility were associated with periods of specific government policy changes, shocks to food prices and lack of coordination between monetary and fiscal policies. The study therefore recommends the strengthening of the current market-based interest rate regime, strategic intervention for improved agricultural productivity and effective harmonization of monetary and fiscal policies as a way of maintaining price stability in the country.

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