Monetary Policy and Inflation Dynamics in Nigeria: A Bayesian DSGE Approach

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This study examines monetary policy shock and inflation dynamics in Nigeria within an open economy Bayesian DSGE model framework, employing data from 2000Q1 to 2023Q1. It applies different price measures across the pre-COVID/Russia-Ukraine war era and the entire sample. Findings reveal a significant impact of monetary policy shock on inflation, irrespective of the price measure adopted. Remarkably, the results also reveal a marginal decline in the potency of monetary policy in the COVID/Russisa-Ukraine War era, compared to the pre- COVID/Russisa-Ukraine War era. The study recommends the adoption of GDP deflator as the measure of inflation that anchors inflation expectations as it is most responsive to monetary policy innovations. It also recommends complementing monetary policy with supply-side policies when faced with inflationary pressures occasioned by supply chain disruptions.

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1. Introduction

In the wake of the COVID-19 pandemic and the Russia Ukraine war, the global economy plunged into a high inflation regime, with global inflation rising to 8.88 per cent in 2022 from 3.5 per cent in 2019. The surge in prices is largely attributed to the attendant supply chain disruptions arising from the global shocks in addition to demand pressures emanating from the stimulus measures to dampen the effect of the Pandemic on households and businesses (IMF, 2022). While these inflation drivers are global, the impact varies across countries and dependent on the structure of each economy and their respective levels of exposure to global inflation shocks. Consequently, monetary authorities across the globe reversed the accommodative policy stance adopted in the wake of the 2008/09 global financial crisis (GFC), and entered a tightening cycle (IMF, 2022).

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In Nigeria, headline inflation rose to 21.91 per cent in February 2023, from 11.98 per cent in December 2019. Similarly, core and food inflation rose to 18.84 per cent and 24.35 per cent, from 9.33 per cent and 14.67 per cent, respectively. To rein-in inflation the Monetary Policy Committee (MPC) of the Central Bank of Nigeria (CBN), beginning in May 2022, raised the monetary policy rate (MPR) six times, cumulatively 650 basis points to 18.0 per cent and increased the cash reserve ratio (CRR) by 500 basis points to 32.5 per cent. Despite the hawkish stance of the CBN, inflationary pressures remain unabated, presenting a price puzzle.

The literature is replete with attempts to analyse the nexus between monetary policy and inflation and to understand the price puzzle. These include the use of quantile regression models (Iddrisu & Alagidede; 2020, Nkang *et al.*, 2022), variants of VAR models (Akram, 2009; Tule *et al.*, 2015; Bhattacharya and Jain, 2020), Autoregressive distributed lag models (Ekong & Ukoha, 2018; Adelakun & Yousfi, 2020), dynamic stochastic general equilibrium (DSGE) models (Woodford, 2003; Smet & Wouters, 2004; Adebiyi & Mordi, 2016; Tawose et al, 2021, Asuzu *et al.,* 2022). Policy insights from these efforts are particularly useful in advancing evidence-based monetary policymaking and guiding monetary policy decisions at the central bank. Consequently, many central banks maintain a suite of macroeconomic models to analyse policy impacts and evaluate the effectiveness of monetary policy decisions (Olofin *et al.,* 2014).

Dynamic Stochastic General Equilibrium (DSGE) models have become a work horse in central banks. They address price puzzle in the macroeconomic literature and are known to outperform alternative modelling approaches in accounting for the role of expectations in decision making; thus, resolving the Luca's Critique (Woodford, 2003; Gertler *et al.*, 2008; Asuzu *et al.,* 2022). DSGE models account for the inter-temporal nature of economic agents by incorporating the combination of forward-looking and backward-looking price-setting behaviour (Adebiyi & Mordi, 2016; Asuzu *et al.,* 2022). They can also reflect rate-setting behaviour of central banks by accommodating an interest rate smoothing parameter that captures how interest rate adjustments are made in series of relatively small steps in the same direction (Gali & Gertler, 1999; Gertler *et al.*, 2008).

Despite the merits of DSGE models, Storm (2021), argues that these models are too complex and unrealistic, and that they do not account for the role of institutions and other factors that affect the economy. Notwithstanding, the review of the Nigerian DSGE literature reveals a dearth of studies that captures the effect of structural breaks such as the COVID-19 pandemic and the Russia-Ukraine Crisis on the monetary policy-inflation nexus. For DSGE models to adequately inform the decision-making process, they should capture the impact of monetary policy shocks on the price level during crisis and non-crisis periods.

Furthermore, the emphasis of the literature has largely been on aggregate price measures such as headline inflation and the GDP deflator (Woodford 2003; Adebiyi & Mordi, 2016; Asuzu *et al.*, 2022). However, several studies (Johnson, 1999; Mishkin, 2007) have argued in favour of core inflation since it captures the underlying rate of inflation and prevents monetary authorities from responding too strongly to transitory movements in inflation. These concerns emphasize the need for an adequately specified open-economy DSGE model that can provide the central bank with information on the effects of policy shocks on alternative inflation measures to inform appropriate policy responses to inflation.

The objective of this paper is to examine the impact of monetary policy shock on headline, core and food inflation considering the COVID-19 pandemic and the Russia-Ukraine war. The study employed an open-economy Bayesian DSGE model due to its ability to provide efficient estimations of the model parameters and more consistent estimates of the shocks driving economic developments amid a limited data environment (Smet & Wouters, 2004).

The study is one of the earliest attempts to employ Bayesian DSGE to provide evidence of changes in the monetary policy-inflation nexus pre-COVID, and in the Russia-Ukraine war era. The understanding of this relationship is an important contribution to the literature as it provides guidance to central banks and researchers on the impact of pandemics and geo-political tensions on monetary policy-inflation nexus. The framework features an augmented New Keynesian Phillips curve equation that accounts for both backward-looking and forward-looking and price-setting behaviour, as in Gali and Gertler (1999) to capture inter-temporality of choice.

The rest of the study is structured as follows: Section 2 presents the review of related literature, Section 3 outlines the study design and methods, Section 4 discusses the findings while Section 5 concludes the study with some policy recommendations.

2. Literature Review

The literature is replete with studies on the impact of monetary policy shocks on inflation using DSGE models. However, a number of studies standout, such as Woodford (2003), that adopted a small DSGE model to provide the theoretical foundation for rule-based monetary policy. Smet and Wouters (2004), extended the Bayesian DSGE model to incorporate habit formation, costs of adjustment in capital accumulation and variable capacity utilization, when analysing business cycles in Europe. Christiano *et al.*, (2005), developed a DSGE model with staggered wage and price contracts to model the nominal rigidities that account for the observed inertia in inflation and persistence in output, which has become a mainstay in modelling nominal rigidities.

Employing a dual state DSGE model, Lyu *et al.*, (2023) examined conventional and unconventional monetary policy in the UK. Quantitative easing was modeled by expanding the Bank of England's bond purchases using the monetary base to reduce the credit spread at the zero lower bound. The findings revealed that financial shocks are significant, and productivity shocks slowed the recovery for the 2009-2012 period. Shah and Garg (2023) used a Bayesian New Keynesian DSGE model to test the effectiveness of fiscal and monetary policy in India during COVID-19. They found monetary policy to be effective in improving growth from both the demand and supply side while fiscal policy was only effective from the supply side.

Studies for Nigeria include, Adebiyi and Mordi (2010), which employed a Bayesian DSGE framework to examine the channels of monetary policy transmission in a managed float exchange rate regime, incorporating forward-looking and backward-looking components in headline inflation determination. Mordi *et al.*, (2013), built on Adebiyi and Mordi (2012), to specify a Bayesian DSGE model that estimated the exchange rate passthrough and sacrifice ratio in Nigeria. The study established a hump-shaped effect of monetary tightening on headline inflation. Omotosho (2019) evaluated the impact of oil price shocks and fuel subsidies on the Nigerian economy using a Bayesian DSGE model. He found that a negative oil price shock increases inflation, reduce aggregate demand and depreciates the exchange rate. Similarly, Oladunni (2020) within a new Keynesian DSGE framework assessed the impact of oil price shocks on macroeconomic indicators in an oil exporting emerging economy. The findings indicate that a positive oil price shock increases oil output and employment and, reduces total output. Tawose *et al.* (2021) employed a maximum likelihood (ML) based closed economy-DSGE model to analyse the impact of monetary policy and productivity shocks on key macroeconomic variables. However, the assumption of a closed economy and the lack of informative priors ML-based DSGE models rendered their findings suboptimal.

The jury on the impact of monetary policy shocks on the sub-aggregate measures of inflation and the recent COVID-19 pandemic and Russia-Ukraine war in the analyses is still out in the recent literature. This impresses the need for an adequately specified open economy DSGE model that appropriately captures the behaviour of the different economic agents in the society. This study fills this gap by specifying an open-economy Bayesian DSGE model that evaluates the monetary policy-inflation relationship before and during the COVID-19 pandemic and Russia-Ukraine war shocks.

3. Model, Data and Estimation

3.1 A Brief Specification of the Model

The study extended the Woodford (2003) model to incorporate backward-looking price setting (Olofin *et al.,* 2014), interest rate smoothing (Asuzu *et al.,* 2022) and exchange rate (representing the external sector) (Olofin *et al.,* 2014). The effect of interest rate smoothing is captured by including the first lag of the policy rate as an additional regressor in the policy rule in Equation (3c). The backward-looking price setting behaviour is adopted as several studies suggest that it is a better estimation of reality than forward-looking behaviour (Fuhrer, 1997; Linde, 2002). In this study, Nigeria is presented as a small open economy with evidence of backward-looking price setting behavior and interest rate smoothing (Olofin *et al.,* 2014; Asuzu *et al.,* 2022). In addition to accounting for monetary policy shocks, the productivity and demand shocks are also included in the model for completeness, though not the focus of this study.

The choice of the Bayesian approach stems from its ability to provide efficient estimations of the model parameters and more consistent estimates of the shocks driving economic developments amid limited data (Smet & Wouters, 2004). The estimations are established on the likelihood functions produced by the DSGE models and prior distributions to include additional information into the parameter estimation (An & Schorfheide, 2007). This approach also emphasizes the dynamic relations between several interrelated blocks, portraying the effects of previous actions on todays and future outcomes. The households, firms, and the Central Bank are the blocks included in this study. Consequently, the Bayesian model is employed to analyse the effect of monetary policy shock on inflation in Nigeria as well as to reflect the backward-looking price setting and interest rate smoothing characteristics of the CBN (Asuzu *et al.,* 2022). The blocks are briefly presented below.

3.1.1 Households

The optimization function of households is represented by the Euler equation which states the intertemporal first-order condition for a dynamic choice problem facing the representative household. This specification assumes that households make consumption and labor supply decisions based on their expectations of future income and prices (Woodford, 2003). Equation 1a states that the current output Y_t is a function of expected output Y_{t+1}, and expected inflation Π_{t+1}.

$$\frac{1}{Y_t} = \beta E_t\left(\frac{1}{Y_{t+1}}\frac{1}{\Pi_{t+1}}\right) \tag{1a}$$

Assume that the current nominal interest rate is the interest rate that households pay on loans and earn on savings. A higher nominal interest rate will make it more expensive for households to borrow, and it will also make it less attractive for saving. As a result, a higher nominal interest rate will tend to reduce current output (see Appendix for additional model specification). Equation 1a can be respecified to capture current nominal interest rate (R_t) as follows:

$$\frac{1}{Y_t} = \beta E_t\left(\frac{1}{Y_{t+1}}\frac{R_t}{\Pi_{t+1}}\right) \tag{1b}$$

The shock process is expressed in (1c), where g_t is a first-order autoregressive state variable.

$$g_{t+1} = \rho_g g_t + \xi_{t+1} \tag{1c}$$

3.1.2 Firms

Assuming that the final domestic good is composed of a range of i differentiated goods, supplied by different firms. Given the time varying inflation in the central bank's model, we permit interest rate inertia in the current inflation target in addition to inflation expectation in the Phillips curve. Thus, firms are represented in the price equation with the Phillips curve. This equation outlines the relation between the ratio of actual output Y_t to the natural level of output Z_t and the current deviation of inflation from its steady-state $(\Pi_t - \Pi)$ to the expected value of the deviation of inflation from its steady-state in the future $E_t(\Pi_{t+1} - \Pi)$.

$$(\Pi_t - \Pi) + \frac{1}{\phi} = \phi\left(\frac{Y_t}{Zt}\right) + \beta E_t(\Pi_{t+1} - \Pi) \tag{2a}$$

ϕ and β represent the pricing decision of firms and discount factor, respectively. Π_t denotes inflation in the domestic sector. Note that Π_t represents GDP deflator inflation in the benchmark model but will also represent other measures of inflation such as headline, core, and food CPI inflation when each is used to replace GDP deflator inflation to capture their unique response to shocks. Equation 2a assumes that firms pricing decisions are determined by expected inflation and real marginal costs represented by the output gap. The backward-looking price setting behaviour is also captured in the firm's equation.

Given that Nigeria is a small open economy, the exchange rate also determines prices as such equation 2a can be restated as:

$$(\Pi_t - \Pi) + \frac{1}{\phi} = \phi\left(\frac{Y_t}{Zt}\right) + \beta E_t(\Pi_{t+1} - \Pi) + \vartheta e_t \tag{2b}$$

where $\boldsymbol{\vartheta}$**,** captures the effect of exchange rate on current inflation and $\boldsymbol{e_t}$ is the naira per dollar exchange rate. We extend the model by adding an AR(1) for the unobserved state variable (es_t) and an equation that links the unobserved variable to the observed variable (e_t). This solution defines a control variable that is state variable which models the exogenous process. As such, the identity in (6) holds

$$e_t = es_t \tag{2c}$$

where, e_t is modelled as an exogenous variable. The evolution of exchange rate es_t shock as a state variable with an AR(1) process is defined as:

$$es_{t+1} = \rho_{es} es_t + v_{t+1} \tag{2d}$$

3.1.3 The Central Bank

Similar to Omotosho (2019), the linearized monetary policy rule is given by Taylor's rule which outlines the reaction of the monetary authority in response to inflation.

$$R_t = \frac{1}{\psi}\Pi_t + u_t \tag{3a}$$

R_t is the steady-state value of the interest rate and u_t represents a state variable that captures all changes in the interest rate not driven by inflation. $\frac{1}{\psi}$ is the degree to which the central bank responds to inflation.

Equation 8 is altered to include interest rate smoothing effects as shown in Equation (9).

$$R_t = \rho_r R_{t-1} \frac{1-\rho_r}{\psi}\Pi + u_t \tag{3b}$$

where R_{t-1} represents the interest rate smoothing effect and ρ_r is a state variable. This effect is captured as the Nigerian monetary authority tends to adjust its rate in a sequence of relatively small steps in the same direction (Salisu *et al.,* 2022). A backward-looking price-setting component is also included to ensure determinacy and test whether the nominal interest rate responds aggressively or otherwise to past inflation rates (Carlstrom & Fuerst, 2000). To capture other price measures relevant to this study, Π_t, which is the GDP deflator inflation will be substituted with other measures of inflation in the monetary policy rule to evaluate the impact of monetary policy shocks on food and core inflation. The monetary policy shock which follows an AR(1) process is specified as follows:

$$u_{t+1} = \rho_u u_t + \epsilon_{t+1} \tag{3c}$$

3.1.4 Structural Shocks

The structural model captures the effect of three shocks, namely, monetary policy shock (u_t), productivity shock (g_t), and demand shock (es_t) represented by equations 4, 5, and 6, respectively. The equations for these state variables in logarithm form are as follows:

$$lnU_{t+1} = \rho_u lnU_t + e_{t+1} \tag{4}$$

$$lnG_{t+1} = \rho_g lnG_t + \epsilon_{t+1} \tag{5}$$

$$lnES_{t+1} = \rho_{es} lnES_t + v_{t+1} \tag{6}$$

This block is significant as it completes the model, illustrating the evolution of the state variables (U_t, G_t and ES_t). The variables e_{t+1}, ϵ_{t+1} and v_{t+1} are shocks to the state variables and are used to determine the appropriate response of the central bank to monetary policy, productivity, and demand shocks, respectively.

3.2 Estimation Procedure

The Markov chain Monte Carlo (MCMC) method is the simulation method employed in this study with the number of iterations measured by an MCMC size of 46,000 draws for robustness and convergence and a burn-in size of 6,000, producing an MCMC sample size of 40,000. The Metropolis-Hastings sampling algorithm is also used.

3.3 Data Sources, Description, and Summary Statistics

Data were sourced from the Central Bank of Nigeria (CBN) database covering the 2000Q1 to 2023Q1 period. The interest rate, proxied by the maximum lending rate is measured in percentage, while the nominal effective exchange rate (NEER), sourced from the International Finance Statistics (IFS) database is measured in growth rate. All price proxies are measured in units except the GDP deflator. The units are converted to inflation rates during estimation. The details of data selection, processing, and sources are shown in Table 1.

The summary statistics in Table 2 suggest significant variations in the consumer price measures as revealed by the substantial difference between the minimum and maximum values. Comparatively, the standard deviation reveals that the GDP deflator is the least volatile followed by the core inflation measure. The food inflation measure is the most volatile, lending further credence to the argument for its removal from monetary policy analysis. The interest rate exhibits a relatively lower level of volatility with a standard deviation of 4.14, while the exchange rate measure recorded a standard deviation of 38.71. All these data characteristics provided the guide for the determination of the prior distribution process.

Distributions of the Priors

The distribution of the priors employed in this study are determined by theory and institutional knowledge as outlined in Table 3. Conventionally, the beta should range between 0 and 1, with common values ranging between 0.90 and 0.99. Typically, kappa is assumed to be small and positive. The autocorrelation parameters must also lie between -1 and 1 but are usually assumed to be positive and closer to 1 than to 0. To maintain stability, the coefficient of inflation to monetary policy rate should range between 0 and 1 (Asuzu *et al.*, 2022; Smets & Wouters, 2007; Woodford, 2003). The priors were chosen to match the theoretical considerations highlighted above.

Table 1: Variable definition and measurement

Variable	Measurement	Data Source
Interest rate	In percent (%)	CBN
GDP Deflator	$\frac{nominal\ GDP}{real\ GDP} * 100$	CBN
NEER	Growth rate (%)	IFS
Headline CPI	In units	CBN
Core CPI	In units	CBN
Food CPI	In units	CBN

Table 2: Summary Statistics

	Interest rate	GDP Deflator	NEER	HCPI	CCPI	FCPI
Mean	25.12	120.16	99.03	163.17	154.15	174.96
Standard deviation	4.14	69.41	38.71	123.98	104.89	146.25
Minimum	17.99	28.61	40.86	30.06	31.86	29.78
Maximum	31.95	288.69	182.37	526.98	441.97	626.70
Observation	93	93	93	93	93	93

Note: NEER, HCPI, CCPI and FCPI denote Nominal Effective Exchange Rate, Headline Consumer Price Index, Core Consumer Price Index and Food Consumer Price Index, respectively.

Table 3: Distribution of the Priors

Parameter	Interpretation	Range	Density function	Para(1)	Para(2)
ρ_r	Interest rate smoothing parameter	(0,1)	Beta	0.70	0.30
φ	Coefficient of inflation to monetary policy rate	(0,1)	Beta	0.50	0.50
ρ_p	Backward-looking price setting	(0,1)	Beta	0.30	0.70
β	Discount factor	(0,1)	Beta	0.95	0.05
κ	Price adjustment parameter	(0,+∞)	Beta	0.30	0.70
ϕ	Pricing decision of the firm	(0,+∞)	Beta	0.30	0.70
ρ_u	AR(1) for the monetary policy shock	(-1,1)	Beta	0.75	0.25
ρ_g	AR(1) for the productivity shock	(-1,1)	Beta	0.75	0.25
ρ_e	AR(1) for the demand shock	(-1,1)	Beta	0.75	0.25
σ_u	Standard deviation of the monetary policy shock	(0,+∞)	Inverse-gamma	0.01	0.01
σ_g	Standard deviation of the productivity shock	(0,+∞)	Inverse-gamma	0.01	0.01
σ_{es}	Standard deviation of the demand shock	(0,+∞)	Inverse-gamma	0.01	0.01

4. Results and Discussion

4.1 The Full Sample (2000Q1 – 2023Q1)

The posteriors show that the persistence value of the monetary policy shock is 0.60%, productivity shock is 0.79%, and demand shock is 0.66%. This indicates that the impact of a productivity shock is more persistent in Nigeria followed by exchange rate and monetary policy shocks. This is because the Nigerian labour market is characterized by rigidities or slow adjustment processes, thus, productivity gains or losses have a prolonged impact on employment and wage dynamics, contributing to the persistence of productivity shocks. Nigeria is also an importing economy, consequently, exchange rate shocks are also persistent. The persistence level of monetary policy shock could be attributed to the low level of financial inclusion and relatively low level of consumer credit. These findings are similar to Asuzu *et al.,* 2022.

Table 4: Results for GDP Deflator Inflation

Parameter	Model (without block)		Model (with block)	
	Mean	95% interval	Mean	95% interval
ρ_r	0.8777	[0.8603, 0.8944]	0.8824	[0.8330, 0.9208]
φ	0.7914	[0.7355, 0.8414]	0.5732	[0.4849, 0.6571]
ρ_p	0.0912	[0.0643, 0.1212]	0.1426	[0.0978, 0.1952]
β	0.7341	[0.6873, 0.7777]	0.9482	[0.8962, 0.9829]
κ	0.3911	[0.3149, 0.4683]	0.3263	[0.2444, 0.4135]
ϕ	0.1952	[0.1368, 0.2597]	0.2498	[0.1756, 0.3349]
ρ_u	0.5920	[0.5545, 0.6334]	0.6044	[0.5604, 0.6522]
ρ_g	0.9783	[0.9695, 0.9857]	0.7913	[0.7275, 0.8509]
ρ_e	0.3944	[0.3306, 0.4644]	0.6564	[0.5608, 0.7525]
σ_u	2.9491	[2.8429, 3.0528]	4.6243	[3.0731, 6.7692]
σ_g	0.5873	[0.4870, 0.6915]	4.5209	[2.6780, 7.1936]
σ_{es}	3.4678	[3.2690, 3.6685]	5.9773	[5.1827, 6.8938]
Log-MLH	-1045.421		-899.3936	
Acceptance rate	0.2051		0.4256	

Note: MCMC runs of 46,000 iterations with 6,000 burn-ins were used. Log-MLH stands for log marginal-likelihood and the acceptance rate is the random-walk Metropolis-Hastings sampling.

When the GDP deflator is used to measure inflation, the model reveals that the CBN smoothens interest rate by 0.88%. This supports how interest rate adjustments are made in series of relatively small steps in the same directions after a shock. The impulse response function in Figure 1 shows that the initial effect of monetary policy shock on inflation is significant as price declines by over 20% given an increase in monetary policy rate. This also reveals the absence of the price puzzle. In line with apriori expectation, both demand and productivity shocks have lower initial inflationary impact compared to the monetary policy shock. Notably, their effects die out before the 4^{th} quarter following the introduction of the shock, compared to the monetary policy shock which lasts until the 7^{th} quarter.

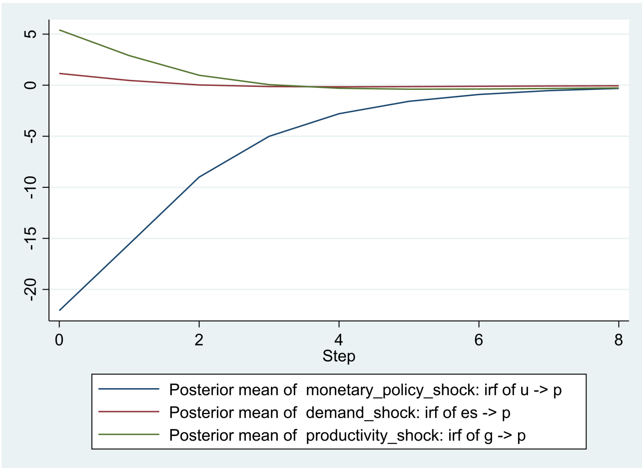

Figure 1: The response of GDP deflator inflation to shocks emanating from monetary policy, demand, and productivity

Pre-COVID-19/Russia-Ukraine War Sample (2000Q1 – 2019Q4)

The results obtained for the pre-COVID era are presented in Table 5 and are similar to the estimates for the entire sample, albeit with marginal differences. The productivity shock remained the most persistent followed by the exchange rate and monetary policy shocks. However, the exchange rate and monetary policy estimates from the pre-COVID 19 model are marginally larger than the estimates from the full sample. This suggests that monetary and exchange rate shocks were marginally more persistent in the Pre-COVID/Russia-Ukraine War era. Conversely, productivity shocks became more persistent in the COVID-19 era.

The interest rate smoothening parameter was also marginally lower in the pre-COVID-

19 era, recording 0.8797%, relative to 0.8824% recorded in the full sample. Like the full sample results, the impulse responses show that monetary policy shock has a high initial effect on inflation as price declines by over 20% given an increase in monetary policy rate. Specifically, inflation initially declines by 22.38% in the pre-COVID era compared to 22.07% in the full sample. This suggests that monetary policy shocks were more potent in the pre-COVID era. This could be attributed to the nature of the supply-side inflationary pressures that preceded the COVID-19 pandemic and the Russia-Ukraine war, given that monetary policy traditionally influences demand side pressures. Noteworthy is the fact the differences observed across samples may be more pronounced if the comparative analysis covered only the pre and COVID-19 pandemic and Russia-Ukraine War eras. This is because there are more observations in the pre-COVID era data compared to the COVID era, which could have contributed in dampening the effects of the dynamics of the COVID era in the full sample analysis.

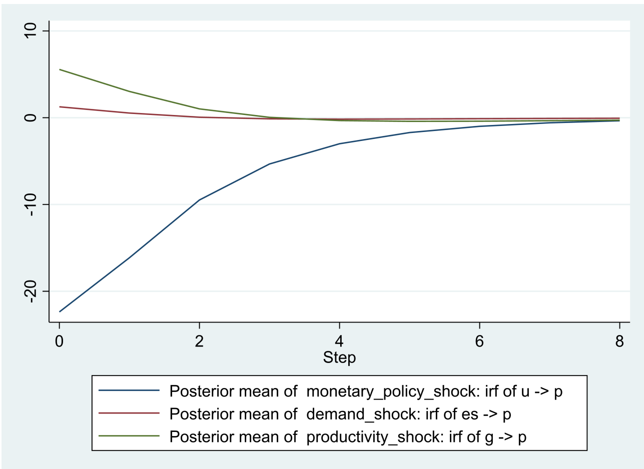

Figure 2: The response of GDP deflator inflation to shocks emanating from monetary policy, demand, and productivity

Table 5: Model Estimation Results for GDP deflator

Parameter	Model (without block)		Model (with block)	
	Mean	95% interval	Mean	95% interval
ρ_r	0.9366	[0.9254, 0.9464]	0.8797	[0.8289, 0.9179]
φ	0.5049	[0.4291, 0.5932]	0.5710	[0.4846, 0.6565]
ρ_p	0.1231	[0.0885, 0.1599]	0.1513	[0.1037, 0.2073]
β	0.9755	[0.9505, 0.9918]	0.9469	[0.8945, 0.9829]
κ	0.6616	[0.6076, 0.7114]	0.3128	[0.2351, 0.3964]
ϕ	0.1759	[0.1209, 0.2372]	0.2551	[0.1808, 0.3382]
ρ_u	0.4572	[0.4251, 0.4892]	0.6111	[0.5660, 0.6576]
ρ_g	0.9616	[0.9451, 0.9750]	0.7828	[0.7155, 0.8455]
ρ_e	0.5220	[0.4440, 0.6037]	0.6653	[0.5686, 0.7629]
σ_u	2.3729	[2.2138, 2.5303]	4.843	[3.2353, 7.0533]
σ_g	1.1169	[0.8704, 1.2854]	4.9739	[2.8966, 7.7926]
σ_{es}	3.8257	[3.5202, 4.1460]	6.2926	[5.3545, 7.3956]
Log-MLH	-897.5126		-786.5889	
Acceptance rate	0.2342		0.416	

Note: MCMC runs of 46,000 iterations with 6,000 burn-ins were used. Log-MLH stands for log marginal-likelihood and the acceptance rate is the random-walk Metropolis-Hastings sampling.

4.3 Alternative Measures of Inflation

4.3.1 Headline Inflation

When headline inflation is used to replace GDP deflator inflation in the full-sample model, the results remained unchanged. Specifically, using headline inflation the persistence level of the monetary policy, productivity and demand shocks were 0.62%, 0.80% and 0.66%, respectively, compared to GDP deflator where monetary policy shock persistence is 0.60%, productivity shock is 0.79%, and demand shock is 0.66%. This suggests that the results are robust to different aggregate price measures. Interestingly, the monetary policy shocks and productivity shocks are more persistent with headline inflation.

The interest rate smoothening parameter is relatively smaller in the headline inflation model, compared to that of GDP deflator. Considering the impulse responses in Figure 3, the results are similar to the estimates from the GDP deflator model in terms of direction, significance and persistence. However, in terms of magnitude, the initial impact of a monetary policy shock is relatively smaller in the headline inflation model, as inflation initially declines by about 12%, compared to about 22% in the GDP deflator model. This suggests that monetary policy is more potent in influencing the GDP deflator-based price measure than the CPI based-price measure.

Table 6: Model Estimation Results for Headline Inflation

Parameter	Model (without block)		Model (with block)	
	Mean	95% interval	Mean	95% interval
ρ_r	0.8418	[0.8238, 0.8596]	0.8482	[0.7922, 0.8935]
φ	0.4918	[0.4515, 0.5364]	0.5539	[0.4653, 0.6425]
ρ_p	0.1741	[0.1331, 0.2144]	0.1888	[0.1358, 0.2496]
β	0.9578	[0.9165, 0.9859]	0.9468	[0.8947, 0.9822]
κ	0.2683	[0.2052, 0.3350]	0.3269	[0.2461, 0.4150]
ϕ	0.2866	[0.2157, 0.3614]	0.2278	[0.1601, 0.3057]
ρ_u	0.6615	[0.6274, 0.6972]	0.6161	[0.5685, 0.6645]
ρ_g	0.9047	[0.8872, 0.9222]	0.7968	[0.7339, 0.8537]
ρ_e	0.5349	[0.4574, 0.6165]	0.6588	[0.5601, 0.7568]
σ_u	4.6341	[4.2625, 5.0301]	3.3537	[2.3461, 4.6914]
σ_g	2.0612	[1.9568, 2.1703]	3.4444	[2.1821, 5.2502]
σ_{es}	4.1625	[3.8604, 4.4854]	5.9974	[5.1564, 6.9786]
Log-MLH	-874.8849		-829.1368	
Acceptance rate	0.2722		0.4399	

Note: MCMC runs of 46,000 iterations with 6,000 burn-ins were used. Log-MLH stands for log marginal-likelihood and the acceptance rate is the random-walk Metropolis-Hastings sampling.

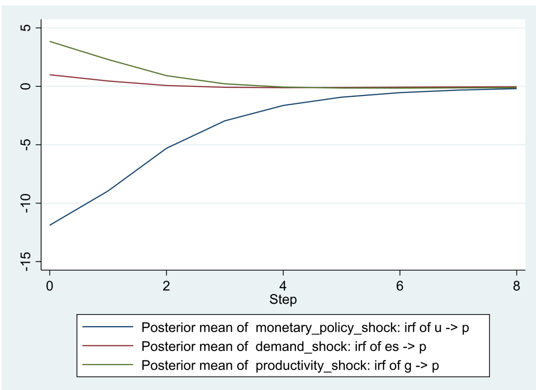

Figure 3: The response of headline inflation to shocks emanating from monetary policy, demand, and productivity

4.3.2 Core Inflation

The core inflation results are similar to the headline inflation estimates, with the persistence of monetary policy, productivity and demand shocks being 0.61%, 0.80% and 0.66%, respectively. This suggests that these shocks evoke similar responses in terms of persistence across all three measures of inflation.

Despite the apparent similarities between the headline inflation results and core inflation estimates, the monetary policy shock exerts a larger impact on core inflation than headline inflation. Specifically, the initial impact of the shock on core inflation is about 15%, whereas the impact on headline inflation is about 12%. This suggests that core inflation is more responsive to monetary policy rate adjustments, lending further credence to the proposition that monetary policy should focus more on core inflation and not headline inflation. The variation in estimates could be attributed to the inclusion of non-core elements in headline inflation which are more impervious to monetary policy shocks.

Table 7: Model Estimation Results for Core Inflation

Parameter	Model (without block)		Model (with block)	
	Mean	95% interval	Mean	95% interval
ρ_r	0.8653	[0.8456, 0.8845]	0.8542	[0.8019, 0.8964]
φ	0.5651	[0.5346, 0.6005]	0.5574	[0.4670, 0.6458]
ρ_p	0.1498	[0.1116, 0.1906]	0.1702	[0.1216, 0.2259]
β	0.9357	[0.8800, 0.9764]	0.9452	[0.8926, 0.9818]
κ	0.2905	[0.2323, 0.3564]	0.3145	[0.2355, 0.4022]
ϕ	0.2699	[0.2086, 0.3419]	0.2287	[0.1616, 0.3055]
ρ_u	0.6144	[0.5770, 0.6508]	0.6063	[0.5577, 0.6517]
ρ_g	0.8854	[0.8656, 0.9051]	0.8019	[0.7396, 0.8570]
ρ_e	0.5232	[0.4638, 0.5759]	0.6592	[0.5613, 0.7556]
σ_u	3.4985	[3.2618, 3.7592]	4.0687	[2.9217, 5.6978]
σ_g	2.0738	[1.9081, 2.2332]	3.3854	[2.1851, 5.1919]
σ_{es}	5.4664	[4.8365, 6.2050]	5.9806	[5.1729, 6.9878]
Log-MLH	-873.1572		-850.8203	
Acceptance rate	0.1799		0.4071	

Note:MCMC runs of 46,000 iterations with 6,000 burn-ins were used. Log-MLH stands for log marginal-likelihood and the acceptance rate is the random-walk Metropolis-Hastings sampling.

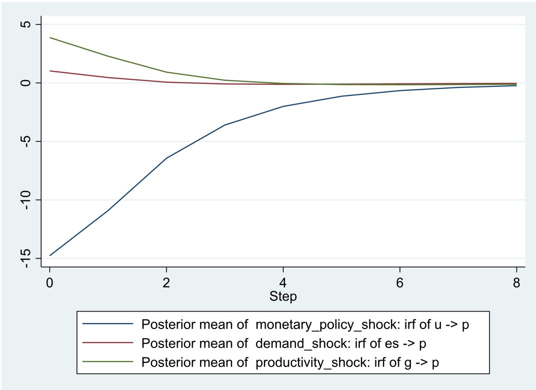

Figure 4: The response of core inflation to shocks emanating from monetary policy, demand, and productivity

4.3.3 Food Inflation

The food inflation estimates exhibits similar characteristics to the previous results, with the persistence levels of the monetary policy, productivity and demand shocks recording 0.62%, 0.79% and 0.66%, respectively. The impulse response results further reveal the similarity of the food inflation estimates to the other price measures. Interestingly, the initial response of food inflation is higher than that of headline inflation and core inflation, as it declined by about 18% compared to 15% for core inflation and 12% for headline inflation. This is not out of place as food inflation is traditionally higher than core inflation and headline inflation in Nigeria. This implies that food inflation is more responsive to monetary policy shocks.

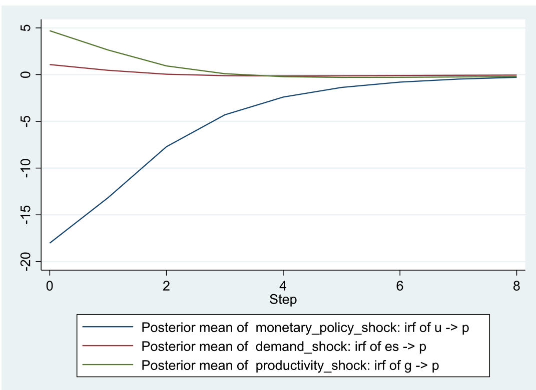

Figure 5: The response of food inflation to shocks emanating from monetary policy, demand, and productivity

Table 8: Model Estimation Results for Food Inflation

Parameter	Model (without block)		Model (with block)	
	Mean	95% interval	Mean	95% interval
ρ_r	0.8633	[0.8493, 0.8772]	0.8706	[0.8213, 0.9123]
φ	0.6689	[0.6253, 0.7153]	0.5655	[0.4774, 0.6516]
ρ_p	0.0947	[0.0684, 0.1229]	0.1671	[0.1176, 0.2247]
β	0.9557	[0.9152, 0.9845]	0.9479	[0.8960, 0.9831]
κ	0.3297	[0.2770, 0.3834]	0.3294	[0.2496, 0.4141]
ϕ	0.1953	[0.1434, 0.2508]	0.2403	[0.1682, 0.3232]
ρ_u	0.5850	[0.5538, 0.6166]	0.6192	[0.5732, 0.6643]
ρ_g	0.9623	[0.9491, 0.9741]	0.7911	[0.7259, 0.8492]
ρ_e	0.5240	[0.4582, 0.5868]	0.6586	[0.5604, 0.7506]
σ_u	3.6296	[3.4520, 3.8217]	4.1230	[2.7913, 5.8263]
σ_g	0.8197	[0.7596, 0.8773]	4.0606	[2.5128, 6.6123]
σ_{es}	3.6932	[3.5066, 3.9022]	5.9886	[5.1387, 7.0198]
Log-MLH	-953.4585		-870.3953	
Acceptance rate	0.2171		0.4225	

Note:MCMC runs of 46,000 iterations with 6,000 burn-ins were used. Log-MLH stands for log marginal-likelihood and the acceptance rate is the random-walk Metropolis-Hastings sampling.

5. Conclusion

This study examined the impact of monetary policy shocks on inflation in Nigeria for the period 2000Q1-2023Q1, using different aggregate and sub-aggregate price measures. The study also employed sub-samples to evaluate the impact of monetary policy shocks on inflation dynamics in Nigeria before and during the COVID-19 pandemic and the Russia-Ukraine war by extending the seminal Woodford (2003) DSGE open economy model to include demand shock and to account for interest rate smoothing and backward-looking price setting.

Findings revealed that monetary policy exerted significant impact on inflation in Nigeria irrespective of the price measure employed (GDP deflator, headline inflation, core inflation or food inflation) or the period considered (pre-COVID/Russisa-Ukraine War era or COVID/Russisa-Ukraine War era), revealing the robustness of the results. However, the GDP deflator was found to be the most responsive price measure, followed by food inflation, core inflation and headline inflation.

Remarkably, the results also revealed a marginal decline in the potency of monetary policy in the COVID/Russisa-Ukraine War era, compared to the pre- COVID/Russisa-Ukraine War era, which was attributed to the supply chain disruptions associated with the exogenous shocks. This implies that the employment of supply-side policy measures may significantly contribute to dampening inflationary pressures during supply shocks. This is particularly useful considering the prevailing supply side shocks (PMS Subsidy removal and exchange rate unification) in Nigeria.

The study recommends the inclusion of GDP deflator inflation among the price measures considered by the CBN, to better anchor inflation expectations, since it is most responsive to monetary policy shocks. It also recommends the employment of supply-side policies alongside interest rate adjustments when faced with supply shocks which dampen the efficacy of monetary policy. The study also recommends the deployment of policies which could curtail adverse productivity and exchange rate shocks, due to the substantial level of persistence of their impact on the economy.

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Appendix
Appendix 1: Additional Model Description

Following Woodford (2003), we rewrite equations 1-3 such that X_t=Y_t/Z_t defines the output gap:

$$1 = fi E_t \left(\frac{X_t}{X_{t+1}} \frac{1}{G_t} \frac{R_t}{\Pi_{t+1}} \right) \tag{1A}$$

$$\frac{R_t}{R} = \left(\frac{\Pi_t}{\Pi} \right)^{\frac{1}{fi}} \tag{2A}$$

$$\frac{R_t}{R} = \left(\frac{\Pi_t}{\Pi} \right)^{\frac{1}{fi}} U_t \tag{3A}$$

where $G_t = Z_{t+1}/Z_t$ is a state variable that captures Z_t. The linear forms of the adjustments that represents the final equations for each segment of the economy are expressed below:

$$x_t = E_t(x_{t+1}) - r_t - E_t(\Pi_{t+1}) - g_t \tag{1B}$$

$$\Pi_t = æ_p \Pi_{t-1} + \left(1 - æ_p\right) [fi E_t(\Pi_{t+1}) + ˇ x_t + Œ es_t] \tag{2B}$$

$$r_t = æ_r r_{t-1} \frac{1 - æ_r}{´} \Pi_t + u_t \tag{3B}$$