Fuel Subsidy Removal and Monetary Policy Adjustments in an Oil-Producing Emerging Economy[*]

Junior Maih[†]   Babatunde S. Omotosho[‡]   Bo Yang[§]

November 21, 2025

Abstract

This paper examines the implications of fuel subsidy removal in an oil-producing economy, focusing on the central bank's response to volatile oil prices. Using a Markov-switching dynamic stochastic general equilibrium (DSGE) model, we analyze the welfare effects of this policy change under different regimes of oil price volatility and monetary policy. Our empirical findings, based on data from Nigeria (2000:2 - 2021:4), reveal time-varying switches in oil price fluctuations and monetary policy adjustments that synchronize with states of high oil price volatility. We also find that subsidy removal has welfare-reducing and heterogeneous effects on households, especially when implemented in an environment of heightened volatility. The efficacy of monetary policy in mitigating the impacts of subsidy removal depends on the ability of the central bank to design a flexible framework capable of adapting to economic shifts, while balancing its stabilization objectives. Furthermore, the observed policy switching in response to different states of oil price shocks suggests a need for the central banks of oil-producing emerging economies to consider the prospects of a dual-mandate regime.

[†]Norges Bank, Bankplassen 2, 0151 Oslo, Norway. E-mail: junior.maih@norges-bank.no

[‡]Statistics Department, African Development Bank, Avenue Joseph Anoma 01 BP 1387 Abidjan 01, Cote d'Ivoire. E-mail: b.omotosho@afdb.org

[§]Department of Economics, School of Social Sciences, Swansea University, Singleton Park, Swansea, SA2 8PP, United Kingdom. E-mail: bo.yang@swansea.ac.uk (corresponding author)

1 Introduction

Fuel consumption subsidies remain at the center of global debates, especially in resource-rich emerging economies exposed to high international commodity price volatility. This paper addresses two related questions: (i) What is the optimal monetary policy response to fuel subsidy removal in an oil-exporting emerging economy under different regimes of oil price volatility? (ii) How can central bank policy rules be optimized to stabilize macroeconomic outcomes following subsidy removal, particularly during periods of heightened oil price volatility?

Many studies have focused on assessing the implications of fuel subsidy reforms under the assumption of Gaussian shock distributions. However, relatively little work exists on the optimal interaction between monetary policy and the economic consequences of oil price volatility within a micro-founded small open economy (SOE) framework, and no consensus has emerged in the literature. Existing studies primarily focus on macroeconomic responses to subsidy reforms but often overlook the dynamic nature of economic conditions, including the possibility of regime shifts.

Past research is also relatively silent on the mechanisms through which oil price volatility affects the macroeconomy, through, for example, central bank actions and the connection between regime switching and monetary policy. To fill this gap, we incorporate regime-switching dynamics into a dynamic stochastic general equilibrium (DSGE) model. Within this framework, we model oil price heteroskedasticity to account for distinct volatility regimes and the uncertainty policymakers face. Our approach, directly linking the significant increase in volatility and the behavior of policymakers responding to these dynamics, is novel in the context of an estimated regime-switching DSGE model. Our objectives include evaluating optimal monetary policy responses to an oil price shock, assessing welfare implications of alternative policy scenarios, examining historical implications of subsidy policies, and understanding the macroeconomic impacts of reforms.

Fuel consumption subsidies, a widespread global phenomenon, have been used to stimulate production, reduce inequality, alleviate energy poverty, and stabilize domestic prices (Estache and Leipziger, 2009; Taylor, 2020). In 2017, 191 countries accounted for global fossil fuel subsidies amounting to USD 5.2 trillion (6.5% of global GDP), rising to USD 7 trillion in 2022 (Coady *et al.*, 2019). Oil-producing developing countries accounted for 48.3% of pre-tax global subsidies in 2017. However, concerns surrounding fiscal burdens and negative externalities have led to calls for reforms (Clements *et al.*, 2013b; Coady, 2015; Taylor, 2020). Fuel subsidies involve sizeable fiscal costs that hinder growth, especially in oil-producing developing countries. Ineffective subsidies distort domestic price signals and complicate monetary policy.

The complete removal of fuel subsidies in Nigeria in May 2023 has intensified policy debates, reflecting the challenge of balancing macroeconomic stability with the imperative for reform. Historically, subsidy reforms have been among the most difficult fiscal adjustments for governments due to complex political-economy considerations (Inchauste and Victor, 2017). The reluctance to implement reforms stems from potential socio-political implications, especially in the absence of safety nets. In Nigeria, calls for the removal of subsidies have been driven by inefficiencies, fiscal costs, and concerns about wealth disparities and the public debt profile. While there is uncertainty as to the macroeconomic implications of subsidy removal, it is clear that the debate on the appropriateness of necessary complementary policies to support the reform continues to evolve.

We focus on Nigeria, a large net oil exporter, for two main reasons. First, Nigeria is representative of a typical resource-rich emerging market and remains heavily dependent on oil, with

limited diversification toward non-oil exports and industrialization.[1] Thus, the economy is vulnerable to oil price fluctuations, and its mono-product export structure makes macroeconomic outcomes susceptible to global oil market conditions. Second, monetary policy plays a central stabilizing role. Resource abundance can contribute to weak institutions and economic mismanagement, particularly on the fiscal side. Given budgetary constraints and limited diversification, macroeconomic stabilization may largely fall on the monetary authority.

Furthermore, large external price shocks have been a major force behind recent inflationary pressures in Nigeria, given the economy's openness and its fuel import requirements. Heightened volatility in relative prices, which feeds into inflation expectations, has made it difficult for the central bank to achieve price stability while supporting growth. The volatile process governing crude oil prices, therefore, poses major challenges for policymakers, as uncertainty about future prices appears to be increasing.

To achieve our objectives, we employ empirical analysis based on data from 2000:2–2021:4. The parameterization accounts for distinctive features of oil-producing emerging economies to capture dynamic interactions among oil price innovations, economic variables, and policy interventions. The model features an oil producer and a fiscal authority that governs the level of fuel subsidies. To examine the interactions between oil price volatility and monetary policy adjustments, our model incorporates stochastic regime shifts in both volatility and the policy rule coefficients. Thus, we make contributions to the existing literature by discussing a range of practical and theoretical implications, shedding more light on the underlying mechanism that guides policy choices for a successful fuel subsidy reform.

We start by examining dynamic monetary policy responses. The paper finds empirical support for time-varying switches between major volatile episodes in oil prices and monetary policy adjustments that synchronize with states of high oil price volatility. These episodes include 2008–2009, 2014–2016, and 2020–2021, corresponding to the US credit crisis, the supply-driven collapse in oil prices leading to Nigeria's 2016 recession, and the pandemic.

Next, we discuss estimation results and the extent to which the central bank adjusts its behavior in response to oil price volatility. During highly volatile periods, the central bank becomes less sensitive to movements in headline inflation and exchange rate stabilization, while placing greater emphasis on the output gap and adjusting interest rates more aggressively.

We then compare economic performances under the estimated policy with a counterfactual scenario in which subsidies were not in place historically. The macroeconomy would have been more volatile with the realized shocks and policy rule. With additional income available, consumption rises initially, but low-income consumers experience comparatively smaller increases.

To further understand the implications of removing fuel subsidies, we solve the model for given policy parameters and evaluate welfare using the resulting solution. A complete, one-off removal is welfare-reducing in an environment with recurrent periods of volatile oil price shocks. Differences in private consumption and future retail prices help explain these welfare outcomes.

Finally, the optimal policy that accommodates regime shifts prescribes a more aggressive inflation response during high-volatility states, helping mitigate some of the adverse effects of subsidy removal. The impulse responses of interest rates under the realized rule differ from those under the optimal policy. When shocks are large and volatile, the optimal response prescribes an initial interest rate cut. Monetary policy faces a less severe trade-off between price stability and output stabilization following subsidy removal, but high-volatility periods worsen these trade-offs.

---

[1]According to the Central Bank of Nigeria (CBN) Statistical Bulletin, since 2000, the oil and gas sector in Nigeria has accounted for about 40% of GDP, 72% of government revenue, and 95% of exports earnings.

The rest of the paper is organized as follows. Section 2 reviews related literature. Section 3 outlines the baseline model and introduces the Taylor-type monetary policy rule. Section 4 presents the model parameterization and the implications for filtering. Section 5 discusses historical and counterfactual implications of subsidy policies. Section 6 details the central bank's role and optimal monetary policy results. Section 7 discusses broader policy implications, and Section 8 concludes.[2]

2   Related literature

There are three strands of literature related to our paper. Additionally, we discuss the contrast between these relevant pieces of literature and our approach to further clarify the contribution of this paper.

2.1   Nonlinearities of oil price shocks

The first strand is a largely econometrics literature studying oil price shocks, which have been known to generate macroeconomic instability in many resource-rich countries. This strand of literature explores the econometric aspects of oil price shocks, dissecting their asymmetric output effects and state dependence. Notable studies such as Barsky and Kilian (2004), Kilian (2009), Ramey and Vine (2011), Riggi and Venditti (2015) and Caldara et al. (2019) delve into the sources of these shocks, while others such as Rahman and Serletis (2010), Holm-Hadulla and Hubrich (2017), Pellegrino (2021), Hwang and Zhu (2024) and Gazzani et al. (2024) investigate central banks' responses, accounting for time-varying impacts.

Although useful for understanding the degree of macroeconomic co-movements, nonlinear multivariate models and dynamic factor models do not provide much information about the mechanisms through which oil shocks affect the macroeconomy. Furthermore, to be useful for optimal policy design, we must require a data-based DSGE model that provides the structural investigation from the richer dynamics and model-implied moments behind the estimated parameters. Invariably, the contradicting findings earlier mentioned allude to the importance of a need to ascertain the appropriate mechanisms through which oil price shocks affect both the oil and non-oil sectors of the economy in order to proffer optimal policies using open economy DSGE models.

2.2   Episodic switches in DSGE frameworks

The second piece of literature focuses on episodic switches in DSGE frameworks, introducing Markov chains for macroeconomic volatility and structural parameters. Empirical studies, including Schorfheide (2005) and Liu et al. (2011), employing regime-switching DSGE models, reveal substantial evidence of structural shifts.[3]

A number of recent papers are related to the present paper. Bjornland et al. (2018) estimate a regime-switching model that studies the roles of oil prices and monetary policy in the US economy for the timing of the Great Moderation. Best and Hur (2019) evaluate monetary policy with time-varying volatilities of non-policy shocks. Maih et al. (2021) investigate asymmetric monetary policy rules for the Euro area and the US based on a sample that encompasses periods

---

[2]Online Appendices provide additional details including the data sources, the statistical validation of the model, and explore robustness of the results based on posterior simulations.

[3]Recent applications also include Liu and Mumtaz (2011), Bianchi (2013), Davig and Doh (2014), Bianchi and Ilut (2017), Bianchi and Melosi (2017) and Kapetanios et al. (2019), among others.

of financial distress. Alstadheim *et al.* (2021) study how central banks in small open-economies respond to exchange rate movements with multiple structural changes. Chang *et al.* (2021) examine the observed US monetary policy shifts through a latent factor in a threshold-switching DSGE framework.

In our paper, we study the macroeconomic implications under different policy scenarios affected by changing oil price volatility and modeling uncertainties based on a model tailored to incorporate unique economic features for an oil-rich emerging economy. The paper elects to stay closer to the current consensus on synchronized-switching models, but offers a number of innovations that address the new challenges. In contrast to the previous papers, the stochastic switch in our model assumes that responses of the real economy depend on the volatility and persistence of oil price shocks. In addition, we implement a hybrid, flexible framework to bridge the time-varying behavior of policy and heteroskedasticity in oil price shocks, which allows us to differentiate between the dynamics of normal times and those generated by stress or crisis episodes and to model the interaction between monetary policy and uncertainty in a parsimonious manner. This is particularly relevant to the behavior of monetary policy adjustments that is affected by significant increases in oil price volatility.

2.3 Macroeconomic effects of fuel subsidy reforms

Empirical evidence initiated by Hamilton (2003) and recent studies, such as Clements *et al.* (2013a), Siddig *et al.* (2014), Dennis (2016), Rentschler *et al.* (2017) and Coady *et al.* (2019), delves into the macroeconomic effects of fuel subsidy reforms. Notably, Fan and Wang (2022) assess the net social welfare effect of China's petroleum pricing mechanism reform. Siddig *et al.* (2014) study the effect of subsidy reduction on consumption, income and fiscal planning in Nigeria. Using an overlapping generations model calibrated to Egypt, Glomm and Jung (2015) study the welfare consequences of subsidy reduction.

Most empirical studies find non-trivial implications for the response and volatility of macroeconomic variables. The main predictions of these studies show that fuel subsidy reforms could cause inflation, reduce economic welfare, distort fiscal planning, reduce household income, increase unemployment in the informal sector, and worsen the problem of inequality (see Dartanto, 2013; Couharde and Mouhoud, 2020; McCulloch *et al.*, 2021, among others).[4] However, research within a general equilibrium framework remains limited.[5]

Our paper departs from previous studies by evaluating potential subsidy reforms within a DSGE framework that incorporates fuel subsidies and is closely related to the work of Omotosho and Yang (2024). These papers examine the pass-through effects of oil prices on domestic prices, investigating macroeconomic volatility and dynamics. However, this literature lacks an exploration of policy formulation and welfare implications in the context of potential subsidy reforms, considering dynamic interactions between stochastic regime shifts in the nature of oil prices and time-varying central bank adjustments, and subsidy reforms – a gap addressed by this paper.

---

[4]See also Ozili and Obiora (2023) for an overview.

[5]Simulating a general equilibrium model calibrated to the Euro area, Bartocci *et al.* (2024) study the effect of reducing excise taxes on fossil fuels on monetary policy, while Yau and Chen (2021) focus on a calibrated energy-importing economy and the welfare consequences of energy price subsidies. Using computable general equilibrium (CGE) simulations, Dartanto (2013), Lin and Jiang (2011), Dennis (2016) and Antimiani *et al.* (2023) study the impacts of subsidy removal on fiscal balance, household welfare and carbon pricing.

2.4 Outline of contributions

In light of this review, our paper makes the following three main contributions to the literature. First, methodologically, our paper emphasizes the crucial importance of the assumption of heteroskedasticity in oil price shocks in studying the behavior of monetary policy adjustments. Second, our paper estimates a benchmark form of an open economy micro-founded macroeconomic model that captures key features of oil-producing emerging economies. Third, in our application, we study simple Taylor-type monetary policy rules that are 'operational', in the sense that they are easy for the public to monitor, whilst approximating the stabilizing properties of complex optimal rules. Indeed, our empirically based approaches have properties that make them particularly suitable for policy analysis and the design of monetary frameworks that exhibit flexibility and adaptability. In addition to providing the important insights into optimal policy responses and welfare consequences drawn from Nigeria's subsidy removal, our paper offers the core guiding principles to implement fuel subsidy reforms for similar economies facing similar challenges.

3 The Regime-switching DSGE model

As in Omotosho and Yang (2024), the model features the SOE and the foreign economy and presents the regime-switching monetary policy. There are four categories of firms operating in the economy: the final goods firm, the intermediate goods producing firms, the foreign goods importing firms, and the oil-producing firm. The economic environments in which the first three categories of firms operate are standard. For the oil sector that is owned by the government and foreign investors, there are three departures from the standard open economy model that lead to interesting results. First, oil enters firms' production technology and results in a direct impact of oil shocks on the supply side (Ferrero and Seneca, 2019). Second, in the oil market, the government sells the imported fuel based on a fuel pricing rule that connotes an implicit subsidy regime (Allegret and Benkhodja, 2015). Third, there are frictions in the financial markets facing households as in Gabriel *et al.* (2023) and in the form of non-Ricardian households to capture credit constraints.[6] Furthermore, we allow for the law of one price (LOP) gap in imports and by implication assume incomplete exchange rate pass-through into import prices (Monacelli, 2005; Senbeta, 2011).[7] We assume that our model can switch exogenously between regimes of oil price volatility and the monetary policy rule over time.[8]

3.1 Oil production and pricing

The oil firm's profit maximization problem is similar to that of Ferrero and Seneca (2019) and Algozhina (2022). The firm is owned by the government and foreign investors and combines

---

[6]The presence of rule-of-thumb non-Ricardian households who have no access to formal financial services and credit to smooth out consumption should improve the model fit for an emerging economy in the type of volatile economic environment that has been described so far (see Gabriel *et al.*, 2016 and Gabriel *et al.*, 2023, among others).

[7]As supported by empirical literature on Nigeria, there is incomplete exchange rate pass-through of imports to domestic prices. Various studies have estimated the level of exchange rate pass-through for Nigeria (see, for example, Oyinlola and Adetunji, 2009 and Adebiyi and Mordi, 2012).

[8]As is standard in most DSGE models, we assume that wages as well as prices of domestically produced goods are sticky. Also, an investment adjustment cost is incorporated into the model to generate hump-shaped investment response to shocks. For simplicity, the main elements of the model including the behaviors of the oil firm and analogous 'foreign' variables are largely omitted in the exposition. We refer to Online Appendices A - D for full details of the micro-foundations.

materials sourced from the domestic economy, M_t, and oil-related capital, $K_{o,t}$, to produce oil output, $Y_{o,t}$, which is exported to the rest of the world at a price, $P_{o,t}^*$, determined in the international crude oil market, using the following Cobb-Douglas technology

$$Y_{o,t} = A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m} \tag{1}$$

where $A_{o,t}$ represents the oil technology. α_o^k and $\alpha_o^m \in (0,1)$ represent the elasticities of oil output with respect to $K_{o,t}$ and M_t, respectively. The former is accumulated by foreign direct investment (FDI), FDI_t^*, as follows

$$K_{o,t} = (1 - \delta_o) K_{o,t-1} + FDI_t^* \tag{2}$$

where δ_o is the depreciation rate. The intuition of (2) follows closely the assumption made in Melina *et al.* (2016) and Algozhina (2022). The natural resource sector in oil-exporting developing and emerging countries attracts capital inflows from the rest of the world in the form of FDI. Melina *et al.* (2016) argue that the decisions for resource production and developments in these countries typically happen via negotiations between governments and foreign multinational firms. As a result, FDI can be thought of as the outcome of these negotiations and is accumulated to create $K_{o,t}$ used in (1).[9] FDI inflows to the oil sector respond to the real international price of oil, $P_{o,t}^*$, as follows

$$FDI_t^* = \left(FDI_{t-1}^* \right)^{\rho_{fdi}} \left(P_{o,t}^* \right)^{1 - \rho_{fdi}} \tag{3}$$

where ρ_{fdi} measures the extent of inertia in the accumulation of FDI_t^*.

The oil firm receives its revenues net of royalties levied by the government on production quantity at a rate τ as follows

$$\Pi_{o,t} = (1 - \tau) \varepsilon_t P_{o,t}^* Y_{o,t} \tag{4}$$

where ε_t is the nominal exchange rate. The oil firm's profits are fully taxed. It is clear that a shock to $P_{o,t}^*$ affects the firm's production and demand for capital and materials.

We assume that $P_{o,t}^*$ and $A_{o,t}$ evolve according to the following $AR(1)$ processes

$$P_{o,t}^* = \left(P_{o,t-1}^* \right)^{\rho_{P_o^*}(s_t^{vol})} \exp\left(\sigma_{P_o^*}(s_t^{vol}) \xi_o^{P^*} \right), \quad A_{o,t} = (A_{o,t-1})^{\rho_{A_o}} \exp\left(\sigma_{A_o} \xi_t^{A_o} \right) \tag{5}$$

where $\xi_t^{A_o} \sim N(0, \sigma_{A_o}^2)$ is i.i.d.

In order to capture possible nonlinearities in the response of the economy to the unpredictability of future oil price movements, we allow the volatility of the oil price shock, $\sigma_{P_o^*}(s_t^{vol})$, to change from one regime to another: $s_t^{vol} \in \{High, Low\}$. To take into consideration the possibility where the responses of the real economy may depend also on the persistence of the shock, we also restrict the persistence parameter, $\rho_{P_o^*}(s_t^{vol})$, to follow a Markov chain that switches at the same time, but not necessarily in the same direction, given the unpredictable nature of oil markets.

---

[9]The role of FDI inflows aimed at oil and gas resource production is important in countries and regions that are new to resource development and may have weak institutions and tax systems. Previous literature that investigates the importance of FDI in the natural resource sector finds a significant correlation between FDI and resource endowments and studies the role and regulations of host governments in supporting large-scale resource developments with foreign investments. See, for example, Asiedu and Lien (2011), Teixeira *et al.* (2017) that apply the dynamic panel data analysis, and Goldwyn and Clabough (2020) that use the narrative approach based on case studies.

3.2 Fuel subsidy and fiscal policy

We assume that the government respects a budget constraint given by

$$TX_t + OR_t + B_t = P_{g,t}G_{c,t} + OS_t + \frac{B_{t+1}}{R_t} \tag{6}$$

where (6) shows that an increase in government expenditure, $G_{c,t}$, consisting of imported goods and domestically produced goods, can be financed either by increasing per-capita lump-sum taxes levied on households, TX_t, generating more oil revenues collected from oil royalties, OR_t, or issuing more debt, B_t. On the payment side of (6), $\frac{B_{t+1}}{R_t}$ represents the interest payments on B_t. When the need arises, the government makes refined oil subsidy payments, OS_t, within a framework that allows for the stabilization of domestic fuel price. $P_{g,t}$ is the deflator of government expenditure (see Online Appendix C).

Following Allegret and Benkhodja (2015), we assume that aggregate refined oil, O_t, is produced abroad and imported into the SOE at a landing price, $P_{lo,t}$, by the government. In turn, the government sells the imported fuel to households and domestic firms, at a regulated price, $P_{ro,t}$, based on a fuel pricing rule given by

$$P_{ro,t} = P_{ro,t-1}^{1-\nu} P_{lo,t}^{\nu} \tag{7}$$

where $0 \leq \nu \leq 1$ governs the extent to which the government subsidizes fuel consumption. When $\nu = 1$, the implicit subsidy regime ceases to exist, whereas $\nu = 0$ implies complete price regulation. $P_{lo,t}$, expressed in domestic currency, is given by[10]

$$P_{lo,t} = \varepsilon_t \frac{P_{o,t}^*}{P_t^*} \Psi_t^o \tag{8}$$

where Ψ_t^o is the LOP gap associated with the import price of fuel, and P_t^* is aggregate consumer price index of the foreign economy.

Thus, the implicit fuel subsidy payment is given by the difference between the value of fuel imports expressed in domestic currency and the amount realized from fuel sales in the domestic economy as follows

$$OS_t = (P_{lo,t} - P_{ro,t}) O_t \tag{9}$$

where total imported fuel (O_t) comprises fuel consumption by households, $C_{o,t}$, and consumption by domestic firms, $O_{h,t}$.

On the revenue side of the budget constraint, (6), the amount of oil revenues, OR_t, accruing to the government are given by

$$OR_t = \tau \varepsilon_t P_{o,t}^* Y_{o,t} \tag{10}$$

Following Bergholt *et al.* (2019) and Algozhina (2022), we consider backward looking fiscal policy reaction functions that allow government consumption and taxes to respond to lagged

---

[10]This is similar to the specification in Poghosyan and Beidas-Strom (2011).

debt, OR_t and OS_t[11]

$$\frac{G_{c,t}}{\bar{G}} = \left(\frac{G_{c,t-1}}{\bar{G}}\right)^{\rho_g} \left[\left(\frac{Y_{o,t}}{\bar{Y}_o}\right)^{\omega_{yo}} \left(\frac{B_{t-1}}{\bar{B}}\right)^{-\omega_b} \left(\frac{OR_t}{\overline{OR}}\right)^{\omega_{or}}\right]^{1-\rho_g} \exp\left(\sigma_{gc}\xi_t^{gc}\right) \qquad (11)$$

$$\frac{TX_t}{\overline{TX}} = \left(\frac{G_{c,t}}{\bar{G}}\right)^{\varphi_g} \left(\frac{B_{t-1}}{\bar{B}}\right)^{\varphi_b} \left(\frac{OS_t}{\overline{OS}}\right)^{\varphi_{os}} \left(\frac{OR_t}{\overline{OR}}\right)^{-\varphi_{or}} \exp\left(\sigma_{tx}\xi_t^{tx}\right) \qquad (12)$$

where $\rho_g \in [0,1]$ represents the degree of smoothing in the government spending rule. ω_{yo}, ω_b and ω_{or} are the government consumption feedback coefficients with respect to oil output, lagged domestic debt and OR_t, respectively. In (12), lump-sum taxes respond to government consumption, lagged debt, OS_t and OR_t with the feedback parameters, φ_g, φ_b, φ_{os} and φ_{or}, respectively. The tax shock, ξ_t^{tx}, and government spending shock, ξ_t^{gc}, are given by an $AR(1)$ exogenous process.

3.3 Monetary policy and the switching Taylor rule

To compute optimized simple rules for periods of varying economic conditions, our modified version of the model introduces a hybrid monetary rule to account for heteroskedasticity in oil price shocks. In setting the short-term nominal interest rate, R_t, the central bank follows a simple time-varying Taylor rule by gradually responding to aggregate inflation, $\pi_t = \frac{P_t}{P_{t-1}}$, domestic output, $Y_{h,t}$, and the exchange rate depreciation, $\Delta\varepsilon_t$,[12] and faces challenges in making policy decisions due to the heightened uncertainty in oil price movements

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_r(s_t^{vol})} \left[\left(\frac{\pi_t}{\bar{\pi}}\right)^{\omega_\pi(s_t^{vol})} \left(\frac{Y_{h,t}}{\bar{Y}_h}\right)^{\omega_y(s_t^{vol})} \left(\frac{\Delta\varepsilon_t}{\overline{\Delta\varepsilon}}\right)^{\omega_\varepsilon(s_t^{vol})}\right]^{1-\rho_r(s_t^{vol})} \exp\left(\sigma_r\xi_t^r\right) \qquad (13)$$

where $\rho_r \in [0,1]$ is the interest rate smoothing parameter capturing monetary policy inertia. ω_π, ω_y and ω_ε are the policy coefficients with respect to inflation, domestic output and the exchange rate, respectively. These parameters are assumed to be governed by the same Markov process described in Section 3.1 and switch together with $\sigma_{P_o^*}(s_t^{vol})$, which directly impacts uncertainty and the central bank's ability to manage inflation and stabilize the economy. The monetary policy shock, $\xi_t^r \sim N(0, \sigma_r^2)$, is i.i.d.

To bridge the behavior of policy and the heteroskedasticity in oil price shocks, we implement a hybrid framework

$$\rho_r(s_t^{vol}) = \bar{\rho}_r + \hat{\rho}_r(s_t^{vol}) \qquad (14)$$

$$\omega_x(s_t^{vol}) = \bar{\omega}_x + \hat{\omega}_x(s_t^{vol}) \qquad (15)$$

where $x = \pi, y, \varepsilon$. This specification postulates that the behavior of policy responses is made up of a systematic component, $\bar{\rho}_r$ and $\bar{\omega}_x$, and a regime-dependent component, $\hat{\rho}_r(s_t^{vol})$ and

---

[11]In order to accommodate varying behavior of the government subject to the state of the economy, and as a robustness check, we estimate a linearized fiscal policy rule accommodating potential regime shifts for policy responses to lagged debt and oil price volatility, allowing the policy parameters to switch with the volatility chain, in line with the treatment of the monetary rule. Following studies such as Leeper (1991), Bianchi and Ilut (2017) and Jin and Xiong (2021), we focus on tax policy response regimes. We do not find any evidence of stochastic regime shifts in fiscal policy during oil price shocks.

[12]The modeling of monetary policy is consistent with the operations of the CBN which currently adopts a monetary targeting framework, uses the Monetary Policy Rate (MPR) as a key instrument for signalling monetary policy stance, and has recently moved to a regime of market-based exchange rate determination.

$\hat{\omega}_x(s_t^{vol})$. The setup is very flexible and nests as special cases the structures which characterize the systematic response of monetary policy that is consistent regardless of the regimes of oil price volatility[13] and those which are typically thought to motivate the assumption of regime shifts in policy stance in the presence of heteroskedasticity in macroeconomic data. By focusing on the latter, our setup captures the dynamic adjustments that policymakers must make when faced with fluctuating and uncertain oil prices, which are a defining characteristic of resource-dependent economies.

Indeed, the monetary authority in Nigeria has responded differently to the macroeconomic fluctuations arising from oil price shocks – our assumption of the synchronized-switching model is based on the observation. While other avenues of relaxing time-constancy of the policy rule are possible, e.g., by defining a Wicksellian rule as in Trehan and Wu (2007) and Curdia et al. (2015) or alternatively allowing for time-varying coefficients as in Kim and Nelson (2006), our setup is particularly suitable to capture changes in the CBN's approach to inflation and macroeconomic stability management within our sample period because it encompasses major volatile episodes in oil price fluctuations and multiple crisis episodes. This method ensures that the policy rule can capture the shifts in macroeconomic behavior without distorting the overall results. In doing so, it not only gives an explicit role to oil price volatility, capturing the increasing uncertainty faced by policymakers and making these variances affect the behavior of policy directly, but also allows us to take an agnostic approach in regime-switching of volatility and policy adjustments, making them a crucial factor for understanding how subsidy removal interacts with monetary policy.

3.4 Perturbation solution of the model

The generic problem of our rational expectations nonlinear DSGE model with Markov-switching can be written as

$$E_t \sum_{s_{t+1}=1}^{h} p_{s_t,s_{t+1}} (\mathcal{I}_t) f_{s_t} \left(x_{t+1} (s_{t+1}), x_t (s_t), x_{t-1}, \theta_{s_t}, \theta_{s_{t+1}}, \epsilon_t \right) = 0 \qquad (16)$$

where E_t is the expectation operator. $p_{s_t,s_{t+1}} (\mathcal{I}_t)$ is the transition probability of going from state s_t in the current period to state s_{t+1} in the next period. f_{s_t} is a vector of (potentially) nonlinear functions. $x_t (s_t)$ is a vector of all the endogenous variables in the current regime s_t. θ_{s_t} contains the parameters in the current regime. $\epsilon_t \sim N (0, I)$ is a vector of stochastic shocks.

In this paper, we follow Maih (2015), who proposes a solution method that computes the equilibrium using a Newton algorithm for solving the general Markov-switching framework set out in (16). This approach also develops a perturbation solution technique that allows us to approximate the decision rules and is suitable for large systems such as our model. The exact solution can be returned in the form of a first-order vector autoregression (VAR), utilizing the idea of a minimum state variable solution of the form

$$x_t = \mathcal{T}_{s_t}(x_{t-1}, \epsilon_t) \qquad (17)$$

As the solution also depends on the regime s_t, a p-th order perturbation of $x_t = \mathcal{T}^{s_t} (z_t)$

---

[13]For example, Leduc and Sill (2004) study how systematic monetary policy accounts for the movements in real output following an oil price shock.

yields the following solution that approximates the decision rule in (17)

$$\mathcal{T}^{s_t}(z_t) \simeq \mathcal{T}^{s_t}(\bar{z}_{s_t}) + \mathcal{T}_z^{s_t}(z_t - \bar{z}_{s_t}) + \frac{1}{2!}\mathcal{T}_{zz}^{s_t}(z_t - \bar{z}_{s_t})^{\otimes 2} + ... + \frac{1}{p!}\mathcal{T}_{z^{(p)}}^{s_t}(z_t - \bar{z}_{s_t})^{\otimes p} \quad (18)$$

where $z_t \equiv \begin{bmatrix} x'_{t-1} & \chi & \epsilon'_t \end{bmatrix}'$ is a vector of state variables, $\bar{z}_{s_t}$ is the steady-state values of the state variables in s_t, and χ is the perturbation parameter.

4   Parameterization and filtration implications

We compute a first-order solution to (18) and estimate θ_{s_t} by Bayesian methods using the RISE toolbox in Matlab, which also includes the procedure we use for filtering the regime-switching model.[14] The data sample (2000:2 - 2021:4) and the corresponding measurement equations for the observables are the same as in Omotosho and Yang (2024). The domestic variables include real GDP growth ($\Delta y_{h,t}$), real consumption growth (Δc_t), real investment growth ($\Delta i_{no,t}$), real effective exchange rate (q_t), headline CPI inflation (Δp_t), core CPI inflation ($\Delta p_{no,t}$), the nominal interest rate (R_t), oil output ($\Delta y_{o,t}$), growth rate of government debt (Δb_t), change in tax revenue (Δtx_t) and government consumption growth ($\Delta g_{c,t}$). The foreign variables are trade-weighted real GDP growth (Δy_t^*), aggregate CPI inflation (Δp_t^*), the interest rate (R_t^*), and log growth in the international oil price ($\Delta p_{o,t}^*$).[15]

4.1   Bayesian estimation

The joint posterior distribution of the estimated parameters is then obtained in two steps. First, the posterior mode and the Hessian matrix are obtained via standard numerical optimization routines. Using the information from the latter, we report mode curvature as a diagnostic tool to assess how well the model parameters are identified in Online Appendix G. No major identification weaknesses are detected from the posterior simulations. Second, we carry out a sensitivity analysis that explores the robustness of the results based on posterior distributions (see Online Appendix H).

Table 1 reports the prior and posterior distributions of the estimated parameters and 90% high posterior density intervals (HPDI). Based on Section 3.2, the estimated ν implies about 53% pass-through of international oil price to domestic prices and that the government subsidizes just over half of the fuel consumption. It is interesting to note that the estimated values of the key switching parameters are very different between regimes. The standard deviation of the oil price shock, $\xi_t^{P_o^*}$, is estimated to be over two times higher in the high-volatility regime ($s_t^{vol} = H$) than in the low-volatility regime ($s_t^{vol} = L$). The probability of moving from $s_t^{vol} = L$ to $s_t^{vol} = H$ ($1 - p_{LH}^{vol}$) is higher than $1 - p_{HL}^{vol}$ but the periods of major oil price fluctuations do not tend to be long-lasting. For the US and a number of commodity-exporting countries, Bjornland $et\ al.$ (2018) and Alstadheim $et\ al.$ (2021) also find strong evidence for time-varying policy rule and oil shocks.

To understand the central bank behavior, our empirical analysis evaluates the extent of its adjustments that interact with the varying oil price volatility. There is no prior information

---

[14]See Maih (2015) for further details.

[15]To set up the model for policy analysis, it is solved by linearizing about the steady state. The lower case variables denote the deviations of these variables from their steady state. Online Appendix E provides more precise information about the sources of our data, including links to publicly available databases where applicable. Details of the calibration are also appended to the paper in Online Appendix F.

Parameter		Prior distribution			Posterior distribution		
		Density	Mean	SD/DoF	Mode	Median	90% HPDI
Ricardian consumers	γ_R	$\mathcal{B}$	0.60	0.10	0.811	0.807	[0.739: 0.877]
Labour supply elasticity	φ	$\mathcal{G}$	1.45	0.10	1.424	1.397	[1.252: 1.547]
Relative risk aversion	σ	$\mathcal{IG}$	2.00	0.40	1.271	1.304	[1.021: 1.549]
External habit	ϕ_c	$\mathcal{B}$	0.70	0.10	0.388	0.400	[0.281: 0.503]
Investment adjustment cost	χ	$\mathcal{G}$	4.00	3.00	16.866	18.050	[17.043: 18.619]
Fuel pricing parameter	ν	$\mathcal{B}$	0.30	0.10	0.526	0.522	[0.387: 0.625]
Oil-core consumption elasticity	η_o	$\mathcal{G}$	0.20	0.10	0.151	0.189	[0.059: 0.318]
Foreign-domestic consumption elasticity	η_c	$\mathcal{G}$	0.60	0.20	0.560	0.586	[0.435: 0.784]
Foreign-domestic investment elasticity	η_i	$\mathcal{G}$	0.60	0.20	0.561	0.586	[0.257: 0.807]
Calvo - domestic goods	θ_h	$\mathcal{B}$	0.70	0.10	0.616	0.621	[0.557: 0.678]
Calvo - imported goods	θ_f	$\mathcal{B}$	0.70	0.10	0.691	0.664	[0.498: 0.822]
Calvo - exports goods	θ_{hf}	$\mathcal{B}$	0.70	0.10	0.716	0.717	[0.522: 0.867]
Monetary policy: systematic							
Taylor rule - inflation	$\bar{\omega}_\pi$	$\mathcal{G}$	1.50	0.25	3.492	3.234	[2.831: 3.719]
Taylor rule - output	$\bar{\omega}_y$	$\mathcal{G}$	0.125	0.05	0.108	0.115	[0.051: 0.186]
Taylor rule - exchange rate	$\bar{\omega}_\varepsilon$	$\mathcal{G}$	0.125	0.05	0.177	0.199	[0.087: 0.341]
Interest rate smoothing	$\bar{\rho}_r$	$\mathcal{B}$	0.50	0.25	0.162	0.146	[0.020: 0.272]
Monetary policy: regime-dependent							
Taylor rule - inflation (Low)	$\hat{\omega}_\pi(s_t^{vol}=L)$	$\mathcal{N}$	0.00	0.25	0.609	0.632	[0.378: 0.923]
Taylor rule - inflation (High)	$\hat{\omega}_\pi(s_t^{vol}=H)$	$\mathcal{N}$	0.00	0.25	0.206	0.011	[-0.360: 0.302]
Taylor rule - output (Low)	$\hat{\omega}_y(s_t^{vol}=L)$	$\mathcal{N}$	0.00	0.25	-0.077	0.008	[-0.144: 0.200]
Taylor rule - output (High)	$\hat{\omega}_y(s_t^{vol}=H)$	$\mathcal{N}$	0.00	0.25	0.161	0.029	[-0.151: 0.258]
Taylor rule - exchange rate (Low)	$\hat{\omega}_\varepsilon(s_t^{vol}=L)$	$\mathcal{N}$	0.00	0.25	0.866	1.071	[0.844: 1.327]
Taylor rule - exchange rate (High)	$\hat{\omega}_\varepsilon(s_t^{vol}=H)$	$\mathcal{N}$	0.00	0.25	0.363	0.152	[-0.167: 0.433]
Interest rate smoothing (Low)	$\hat{\rho}_r(s_t^{vol}=L)$	$\mathcal{N}$	0.00	0.25	0.002	0.030	[-0.090: 0.131]
Interest rate smoothing (High)	$\hat{\rho}_r(s_t^{vol}=H)$	$\mathcal{N}$	0.00	0.25	-0.092	-0.009	[-0.191: 0.189]
Fiscal policy							
Government consumption - output	ω_{yo}	$\mathcal{N}$	0.40	0.50	-0.388	-0.388	[-0.440: -0.322]
Government consumption - fiscal debt	ω_b	$\mathcal{N}$	0.30	0.50	0.079	0.086	[0.000: 0.178]
Government consumption - oil revenue	ω_{or}	$\mathcal{N}$	0.80	0.50	0.778	0.758	[0.603: 0.929]
Government consumption smoothing	ρ_{g_c}	$\mathcal{B}$	0.50	0.25	0.310	0.307	[0.161: 0.466]
Tax - fiscal debt	φ_b	$\mathcal{N}$	0.40	0.50	0.205	0.207	[0.006: 0.384]
Tax - government consumption	φ_g	$\mathcal{N}$	0.95	0.50	0.630	0.680	[0.507: 0.853]
Tax - subsidies	φ_{os}	$\mathcal{N}$	0.10	0.50	0.531	0.604	[0.239: 0.809]
Tax - oil revenue	φ_{or}	$\mathcal{N}$	0.30	0.50	0.077	0.130	[0.007: 0.241]
Standard deviation and persistence of shock							
Oil price - standard deviation (Low)	$\sigma_{P_o^*}(s_t^{vol}=L)$	$\mathcal{IG}$	0.10	4.00	0.100	0.126	[0.114: 0.137]
Oil price - standard deviation (High)	$\sigma_{P_o^*}(s_t^{vol}=H)$	$\mathcal{IG}$	0.01	4.00	0.226	0.325	[0.214: 0.475]
Oil price - persistence (Low)	$\rho_{P_o^*}(s_t^{vol}=L)$	$\mathcal{B}$	0.50	0.28	0.994	0.957	[0.907: 0.999]
Oil price - persistence (High)	$\rho_{P_o^*}(s_t^{vol}=H)$	$\mathcal{B}$	0.50	0.28	0.548	0.587	[0.371: 0.888]
Transition probability							
[Low, High]	p_{LH}^{vol}	$\mathcal{B}$	0.50	0.28	0.045	0.043	[0.006: 0.084]
[High, Low]	p_{HL}^{vol}	$\mathcal{B}$	0.50	0.28	0.178	0.280	[0.103: 0.476]

Table 1: **Prior and Posterior Distributions**

Notes: Two chains of 100,000 draws are generated and the first half of these draws is discarded. The variance-covariance matrix of the perturbation term for the jumping distribution in the Metropolis-Hastings algorithm is adjusted so that an acceptance rate of 0.2469% is obtained. In the estimation the number of draws that we choose is sufficient to allow for convergence. To formally check the convergence of the parameters, we use the convergence indicators such as the scale reduction factor statistic recommended by Brooks and Gelman (1998).

about the regime-dependent policy parameters which are assumed to be normally distributed and centered at 0 with standard deviations of 0.25. Our posterior maximization identifies several observed switches in monetary policy. During highly volatile periods ($s_t^{vol} = H$) faced by policymakers, the central bank is less sensitive to movements in headline inflation, focuses less on exchange rate stabilization, but places greater emphasis on the output gap and adjusts interest rates more aggressively. This heightened uncertainty can lead to more aggressive and adaptive monetary policy responses, as reflected in our regime-switching estimation.

4.2 Smoothed transition probabilities

There is ample evidence in favor of stochastic regime switches in the parameters. Figure 1 plots the smoothed state probabilities for being in $s_t^{vol} = H$, based on the posterior mode, and clearly shows recurrent spikes in the oil price movements that contribute to their nonlinear effect on the real economy. The economy has stayed in $s_t^{vol} = H$ with a high probability of occurrence which is mostly responsible for the macroeconomic instability that we observe and coincides with the time-varying monetary policy adjustments. We account for multiple episodes by allowing for heteroskedasticity in the model, which enables us to capture the shifts in volatility that occur during such episodes.
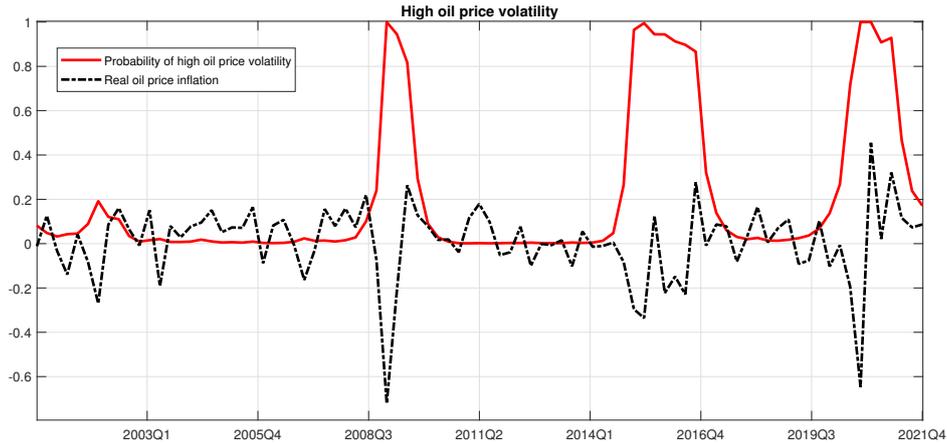

Figure 1: **Smoothed Probability of High-Volatility Regime** ($s_t^{vol} = H$)

Notes: The figure presents the smoothed probabilities for being in the high oil price volatility regime in the model that allows synchronized switching in the standard deviations of the oil price shock and in the monetary policy parameters. Their priors are assumed to be inverse gamma with $(0.1, 4)$ and normal with $(0, 0.25)$, respectively, between the high- and low-volatility regimes. Observed data: log growth in the international oil price.

Interestingly, major volatile episodes in oil prices are observed during 2008–2009, 2014–2016, and 2020–2021. These high-volatility states are mostly related to historical events and are clearly triggered by a plunge in oil prices in these distinct periods. The first period of a huge price swing coincides with the US credit crisis of 2008. The second episode of heightened volatility saw crude oil spot prices drop from as high as USD 115 a barrel in June 2014 to a low of USD 45 in January 2015.[16] This may be explained by the booming US shale oil production causing the sharp and persistent price fall starting from the third quarter of 2014 that culminated into an economic recession in Nigeria in 2016.[17] The third break date is estimated to occur in

---

[16]Source: U.S. Energy Information Administration.

[17]Beyond the oil price movements in 2014-2016, oil revenue in Nigeria was subject to heightened volatility due to production shutdowns and supply disruptions, and was affected by the peculiar market demand conditions associated with the shale oil and gas revolution. As a result, the country recorded reduced patronage of its crude

2019/2020. We find that oil prices have displayed a more recent surge of volatility since then, coinciding with the demand-driven collapse in oil prices starting from the fourth quarter of 2019 due to the COVID-19 outbreak.

The monetary authority has responded differently to different oil price shocks depending on the size and persistence of the shock and the state of the economy prior to the shock.[18] It appears to have been less sensitive to movements in headline inflation since the US credit crisis as the MPR was more persistent before the period.[19] This appears to be in tandem with the transition to a multiple-mandate regime of the CBN, which has been involved in quasi-fiscal operations aimed at boosting output, with the belief that its interventions positively impact the supply-side drivers of inflation, especially in times of economic crises (Kormilitsina, 2011; Benmelech and Tzur-Ilan, 2020; Omotosho and Yang, 2024). This shows the benefits of monetary-fiscal coordination in maintaining macroeconomic stability, particularly in periods of stress and high volatility.

5 Macroeconomic implications

Before conducting our policy exercises, we simulate the model based on the posterior estimates under a condition of complete pass-through of international oil price to the retail price of fuel to assess how the economy would have responded in the absence of the subsidy program.

5.1 Responses of subsidy removal

A value of $\nu = 1$ in (7) provides us this alternative case where the subsidy regime ceases to exist. In Figure 2, we simulate the model based on the parameterization in Section 4 and report the impulse responses (henceforth IRFs) comparing the transmission mechanism of a negative oil price shock when the subsidy program is in place or 'turned off'.[20]

The projected outcomes are in line with the findings of Siddig *et al.* (2014) and Omotosho and Yang (2024). In particular, there are marked differences in IRFs when the economy moves from $s_t^{vol} = L$ to $s_t^{vol} = H$. Overall, the effects are generally stronger and more persistent in $s_t^{vol} = H$. The decline in firms' real marginal cost is more fully reflected by the removal effects, causing more downward adjustment in the prices of domestically produced goods which is exacerbated if the shock is large and volatile. Given an oil price shock in $s_t^{vol} = H$, the alternative economy ($\nu = 1$) is associated with a large decline in total inflation and, facing no inflationary pressures following a fall in oil prices, its central bank would cut interest rates in the bid to boost aggregate demand. As a result, it would ameliorate the contractionary effects of the negative shock. Interestingly, the model also predicts an amplification effect in the output dynamics in $s_t^{vol} = H$ where the estimated policy reacts strongly to output stabilization.

Following a negative oil price shock, better outcomes are recorded for GDP, non-oil GDP and private consumption in the economy without fuel subsidies, especially if high volatility in oil prices persists. This suggests that the removal of subsidies can free up financial resources for the development of critical public infrastructure (Glomm and Jung, 2015), such as the

---

oil, and more so, increased disinvestment of oil-related capital by foreign investors.

[18] For instance, the factors such as the prevailing dominant macroeconomic objectives of the government or the availability of robust external reserves may cause the central bank to respond to oil shocks in a nonlinear way.

[19] According to the CBN Statistical Bulletin, the correlation between the headline inflation rate and the MPR, which was 0.43 pre-2009, declined significantly to 0.04 in the post-2009 period.

[20] A negative oil price shock (an unanticipated fall in oil prices) can be strongly correlated with domestic output and capital inflows. The frailties in emerging market countries can lead to sudden and sharp reversals of capital inflows during a negative oil price shock (the 'sudden stops' highlighted in Calvo, 1998).
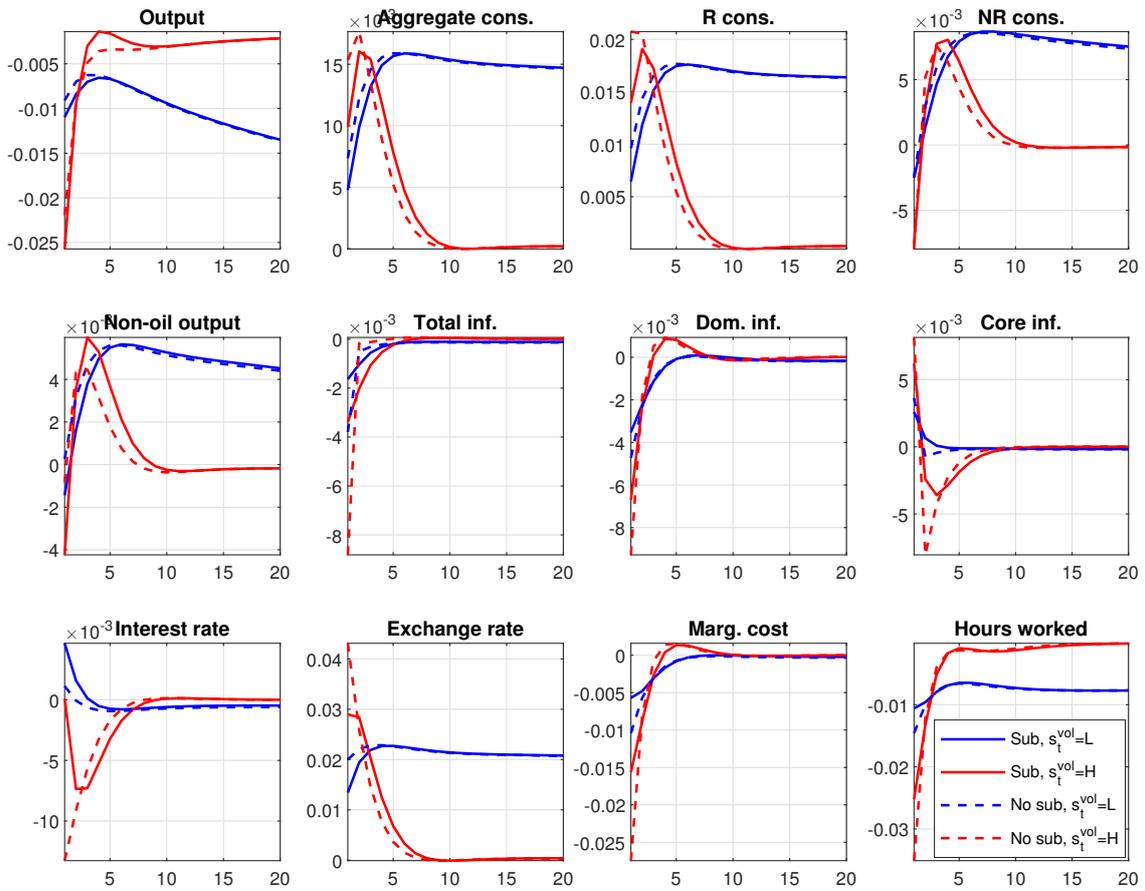
Figure 2: **Responses to a Negative Oil Price Shock**

Notes: The figure plots the response corresponding a *negative* one standard deviation of the oil price shock's innovation. Each response is for a 20 period (5 years) horizon. $s_t^{vol} = L \rightarrow$ Low oil price volatility state; $s_t^{vol} = H \rightarrow$ High oil price volatility state. Subsidy: $\nu = 0.526$; No subsidy: $\nu = 1$.

reinvigoration of Nigeria's domestic refineries (Bazilian and Onyeji, 2012), and other sectors, such as agriculture, healthcare and education, that require significant government interventions and funding, as well as reducing the current budget deficit and government borrowing and spending on petroleum imports (Ozili and Obiora, 2023). Such savings could ease the pressure on the exchange rate and improve trade balances.

As our model features Ricardian and non-Ricardian households (rich and poor), we depict the responses of consumption of both types of households (R and NR, respectively). Removing the subsidy program introduces more amplified responses into the model, driving a bigger wedge between the responses of the two economies in aggregate consumption and the consumption of R households than those in the consumption of NR households. This implies that the increase in aggregate consumption is mostly associated with that from the R households, arising from additional income that is available to the latter. Additionally, the magnitude of the increase is larger in $s_t^{vol} = H$ where the shock is more volatile and therefore the precautionary saving motive is stronger. Clearly, this suggests that potential (uncompensated) fuel subsidy reforms would have mainly benefited the upper-income households exacerbating wealth inequality between these households and the working poor that are credit-constrained. This result is in line with the findings in Siddig *et al.* (2014), Dennis (2016), and McCulloch *et al.* (2021), where the latter, using household survey data, show that subsidy removal widens the wealth and income gap.

These results are useful in helping us understand the issues of different welfare consequences in different policy scenarios. Our results show that a negative oil price shock impacts more on R households, especially during periods of oil price volatility. Monetary policy actions would impact more on R households because fiscal shocks in a no-subsidy economy have different effects on R and NR households. As the former have access to financial assets and wealth, the Ricardian equivalence hypothesis amplifies the negative wealth effect of private consumption to a positive fiscal spending shock. While we emphasize the importance of coordinated policy responses, the issue of fiscal transparency and the way the fiscal authority finances subsidies are crucial for designing the optimized monetary rule.

5.2   Economic performances under counterfactual scenarios

What would the economy look like if the central bank does not change its policy when the subsidy is removed? Table 2 corresponds to the standard deviations of observed domestic variables in the alternative economy ($\nu = 1$) and the estimated benchmark, respectively. With the estimated Taylor rule, this leads to higher volatility in most of the key economic indicators. The alternative economy is associated with higher volatility in headline, core, domestic and imported inflation. Table 3 reports the cross-correlations of the observable variables *vis-à-vis* output. The alternative economy also performs poorly in capturing the countercyclicality of inflation, generating the wrong sign.

std. dev.	$\Delta y_{h,t}$	Δc_t	$\Delta i_{no,t}$	π_t	R_t	q_t	$\pi_{c,t}$	$\Delta y_{o,t}$	Δb_t	Δtx_t	$\Delta g_{c,t}$
Benchmark	0.146	0.182	0.092	0.109	0.429	0.143	0.107	0.457	0.551	0.444	0.233
$\nu = 1$	0.147	0.186	0.092	0.113	0.432	0.159	0.109	0.458	0.550	0.454	0.235

Table 2: **Standard Deviation of Domestic Observables**

What would be the stabilization properties of the estimated policy had the subsidy removal been implemented over the last two decades? Figure 3 provides an additional comparison of the economic performances under the counterfactual scenario where subsidies were not in place

cross-corr.	$\Delta y_{h,t}$	Δc_t	$\Delta i_{no,t}$	π_t	R_t	q_t	$\pi_{c,t}$	$\Delta y_{o,t}$	Δb_t	Δtx_t	$\Delta g_{c,t}$
Benchmark	-	0.324	0.033	0.015	-0.069	0.241	0.042	0.543	0.610	0.152	0.444
$\nu = 1$	-	0.341	0.034	-0.020	-0.081	0.272	0.057	0.543	0.608	0.176	0.455

Table 3: **Co-Movement of Domestic Observables**

historically. To this end, we plot the simulated time series from the benchmark model based on the smoothed shocks and compare those with the simulated economy from the counterfactual scenario. With the realized policy rule, Figure 3 provides some interesting result that shows that the central bank had done well and achieved better performances in terms of stabilizing inflation and exchange rate movements and smoothing out fluctuations in output, especially during the early periods of the sample during which oil prices were relatively stable, in the presence of subsidies. In the counterfactual scenario ($\nu = 1$), the macroeconomy (particularly in terms of the three policy target variables) would have been more volatile with the realized shocks and policy rule.
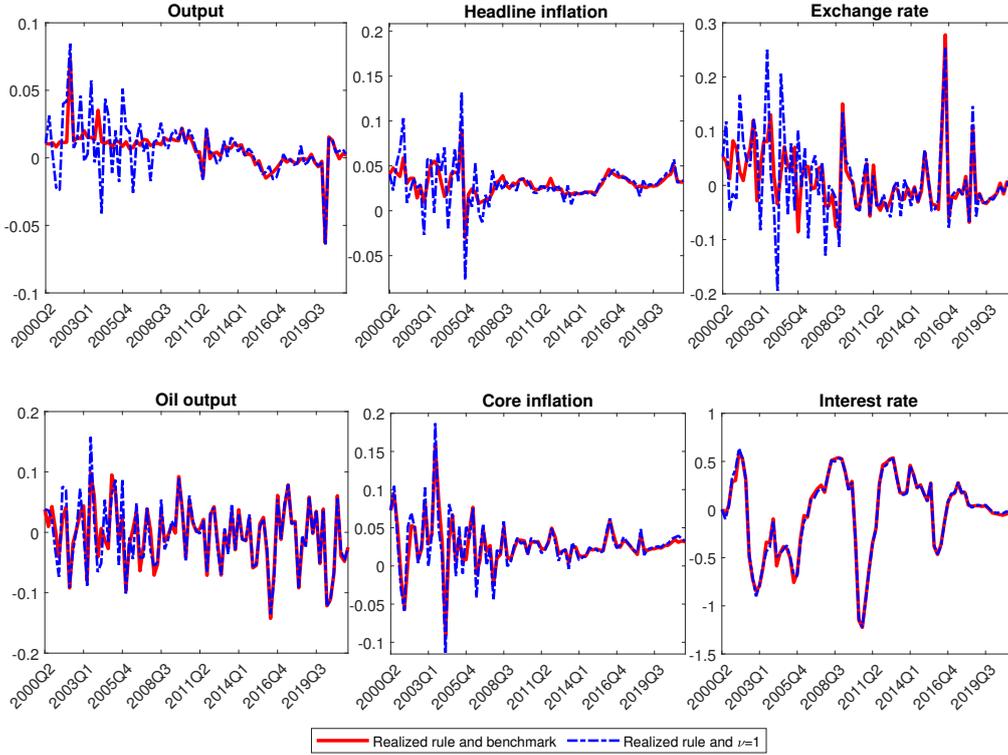

Figure 3: **Simulated Economies with Realized Rule and Shocks**

The results of our counterfactual simulations indicate that the extant fuel subsidy regime has non-trivial implications for the economy's response to an oil price shock. In view of the macroeconomic instabilities observed under the counterfactual economy, a successful fuel subsidy reform must necessarily encompass the deployment of well-designed policy interventions. Subsidy removal, particularly under high oil price volatility, due to its effect on disposable income, production costs, logistics, and price setting, could translate to weak aggregate demand, leading to lower levels of production thereby widening the output gap, and slow the rate of economic growth. Siddig *et al.* (2014) show that a subsidy reduction can have a detrimental impact on household income.

6 Macroeconomic stabilization and optimal policy

The estimated structural model set out above is well-suited for the study of policy options. In this section, we move to optimal monetary policy exercises. The policymaker may be constrained to simple rules even with commitment, thus, for transparency, information available for communications, and ease of implementation, we focus on the optimized simple Taylor-type commitment rule that minimizes an expected inter-temporal loss at time t.

6.1 The central bank's role

The central bank sets out to maximize a general discounted welfare criterion subject to the constraints of the DSGE model. In a no-subsidy economy, the reason why monetary policy is more important for stabilizing economic activity is three-fold. First, we do not know whether the central bank has behaved optimally, in terms of a Taylor rule model. Second, agents are more vulnerable to oil price fluctuations which can be exacerbated by fuel subsidy removal. Third, the central bank may better shield the economy from future oil price shocks and volatility by adopting a regime-specific policy stance.

There are generally two approaches to optimally evaluate policies for welfare analysis in DSGE models. The welfare loss function can be either utility-based or derived through a standard ad-hoc quadratic loss function. We examine the potential consequences of removing fuel subsidies from the viewpoint of a central banker, focusing on their role in managing the adverse effects of oil price shocks and subsidy removal. Therefore, we opt for the latter approach and evaluate policy rules based on the linearized model of (16) with a simple quadratic loss function that penalizes variability in an observed subset of key macroeconomic variables (i.e., welfare-relevant variables).

The estimated structural parameters, other than the monetary policy parameters, are used to seek optimized simple monetary policy rules, based on the time-varying Taylor interest rate rule set out in Section 3.3, that can accommodate the Markov-switching parameters. We consider the standard ad-hoc quadratic period loss function in deviation form given by

$$
\begin{aligned}
\Omega_0 &= (1-\beta)E_0\left[\sum_{t=0}^{\infty}\beta^t(\lambda_\pi\pi_t^2 + \lambda_y y_{h,t}^2 + \lambda_r\Delta R_t^2 + \lambda_\varepsilon\Delta\varepsilon_t^2)\right] \\
&\simeq \lambda_\pi\text{var}(\pi_t) + \lambda_y\text{var}(y_{h,t}) + \lambda_r\text{var}(\Delta R_t) + \lambda_\varepsilon\text{var}(\Delta\varepsilon_t) \text{ as } \beta \to 1 \quad (19)
\end{aligned}
$$

where the variances above are unconditional variances of the target variables and the period utility Ω_0 is an unconditional welfare loss function where $\beta \to 1$. We also carry out a search over a grid on a range of different weights on the variances in terms of $(1, \lambda_y, \lambda_r, \lambda_\varepsilon)$. We compare the result with counterfactual simulations in terms of their abilities in stabilizing inflation, output and exchange rates, assuming that, like agents in the model, the central bank can observe the different regimes (i.e., they observe s_t).

6.2 Optimized Taylor rules

To optimize the parameters in (13), we set bounds (priors) to discipline the process with the wide 90% ranges within which the optimization searches for the parameters. Our focus is on linear-quadratic problems that are available for different forms of policy, and we use the ad-hoc approach for the (central bank's) loss as the welfare criterion assuming that they dislike inflation, output gap, and exchange rate movements to assess the welfare-reducing effects implied by the

model features. Table 4 uses the same prior densities as in Table 1 but imposes more prior uncertainty and uses quantiles of the distributions, allowing such priors to have more diffuse distributions.

We carry out the policy simulations that compare the expected inter-temporal losses and macroeconomic volatilities for periods of varying macroeconomic conditions (time-varying variances of oil prices), and for cases of zero or partial subsidy. In a sense, we have designed and derived 'robust' simple policy rules with respect to exogenous uncertainties incorporated into the autoregressive shock process of oil prices for the estimated model and an alternative policy scenario ($\nu = 1$).

Parameter	Prior distribution			Posterior mode		
	Density	Lower quartile	Upper quartile	Estimated rule	OSR $\nu = 0.526$	OSR $\nu = 1$
$\bar{\omega}_\pi$	$\mathcal{G}$	1	10	3.492	6.782	6.897
$\bar{\omega}_y$	$\mathcal{G}$	0.1	4	0.108	0.153	0.144
$\bar{\omega}_\varepsilon$	$\mathcal{G}$	0.1	4	0.177	0.824	0.801
$\bar{\rho}_r$	$\mathcal{B}$	0.5	0.95	0.162	0.783	0.781
	Density	Mean	SD			
$\hat{\omega}_\pi(s_t^{vol} = L)$	$\mathcal{N}$	0	0.5	0.609	0.060	0.060
$\hat{\omega}_\pi(s_t^{vol} = H)$	$\mathcal{N}$	0	0.5	0.206	0.023	0.024
$\hat{\omega}_y(s_t^{vol} = L)$	$\mathcal{N}$	0	0.5	-0.077	-0.036	-0.047
$\hat{\omega}_y(s_t^{vol} = H)$	$\mathcal{N}$	0	0.5	0.161	-0.008	-0.012
$\hat{\omega}_\varepsilon(s_t^{vol} = L)$	$\mathcal{N}$	0	0.5	0.866	0.115	0.114
$\hat{\omega}_\varepsilon(s_t^{vol} = H)$	$\mathcal{N}$	0	0.5	0.363	0.044	0.043
$\hat{\rho}_r(s_t^{vol} = L)$	$\mathcal{N}$	0	0.5	0.002	-0.345	-0.351
$\hat{\rho}_r(s_t^{vol} = H)$	$\mathcal{N}$	0	0.5	-0.092	-0.232	-0.235
Ω_0				0.0417	0.0251	0.0262

Table 4: **Estimated and Optimized Simple Rule Coefficients**

Notes: $s_t^{vol} = L \rightarrow$ Low oil price volatility state; $s_t^{vol} = H \rightarrow$ High oil price volatility state. $\nu = 0.526$: estimated partial subsidy; $\nu = 1$: zero subsidy. We assume that $\lambda_\pi = 1$, $\lambda_y = 0.2$, $\lambda_r = 0.1$ and $\lambda_\varepsilon = 0.1$ in (19) for the policymaker's linear-quadratic problem. Following Chen and Macdonald (2012), we carry out a search over a grid on a range of different weights. We allow (λ_y, λ_r) to vary over a grid of $[0, 1]$ and compute the optimized simple rules and the unconditional variances of the target variables which compares the output-inflation volatilities associated with each set of (λ_y, λ_r) used. Our result shows that a conservative banker's policy preference increases the variance of output and clearly faces a policy trade-off which moves to the upper-left corner when λ_r increases. To derive an optimal monetary policy rule, we also choose the above parameter configuration in the loss function that generates a low level of exchange rate volatility, whilst keeping the output-inflation volatility low at the same time.

In Table 4, we benchmark the optimized simple rules (OSR) against the estimated policy rule. The OSR prescribes larger responses to all three target variables and has a much higher degree of interest rate smoothing compared to the realized rule. These results suggest that, had the central bank acted optimally, it would more aggressively respond to fluctuations in inflation and exchange rates and be much more inertial whether subsidies are in place or not. Such a rule would achieve the best welfare outcome under the subsidy program (i.e., we use $\Omega_0 = 0.0251$ as our performance metric). In addition, the OSR responses are more symmetric between regimes so that under the OSR the central bank behaviors are relatively systematic regardless of regime shifts, except for stabilizing exchange rates.

This paper proposes that optimal behavior by the central bank in the no-subsidy economy would stabilize prices and exchange rates, focusing on preserving price stability and anchoring inflation expectations. If high volatility in oil prices persists, then the central bank could focus less on stabilizing exchange rates which could moderate the transmission of an oil shock to the domestic economy by supporting the local currency more effectively. For instance, under a managed float exchange rate regime, the foreign exchange accretion from exported petroleum

products would strengthen the domestic currency against the US Dollar, thereby mitigating the exchange rate depreciation (Akinola, 2018; Ozili and Obiora, 2023; Omotosho and Yang, 2024). This is interesting as Alstadheim *et al.* (2021) find that monetary policy in commodity exporters has responded strongly to exchange rate movements during periods of high volatility.

6.3   Unconditional standard deviations

Under different optimized rules, aggregated standard deviations of the key domestic variables are computed by re-weighting the system with appropriate probabilities (i.e., the ergodic distribution of the regimes) and presented in Table 5 with one exception: the bottom row indicates the scenario where the regime-specific volatilities are computed. It shows the level of macroeconomic instabilities conditional on regimes, for example, if the economy had stayed in the high-variance state ($s_t^{vol} = H$).

	sd($\Delta y_{h,t}$)	sd(Δc_t)	sd($\Delta i_{no,t}$)	sd($\Delta y_{no,t}$)	sd(π_t)	sd($\pi_{c,t}$)	sd($\pi_{d,t}$)	sd($\pi_{f,t}$)	sd(R_t)	sd($\Delta\varepsilon_t$)
Estimated rule	0.146	0.182	0.092	0.190	0.109	0.107	0.111	0.091	0.429	0.204
OSR $\nu = 0.526$	0.142	0.178	0.092	0.186	0.068	0.070	0.088	0.064	0.388	0.168
OSR $\nu = 1$	0.144	0.183	0.092	0.186	0.070	0.072	0.088	0.064	0.392	0.177
OSR $\nu = 1$, $\lambda_y = 0.5$	0.144	0.182	0.092	0.186	0.072	0.073	0.089	0.064	0.391	0.158
OSR $\nu = 1$, $s_t^{vol} = H$	0.145	0.181	0.092	0.183	0.079	0.079	0.089	0.065	0.383	0.194

Table 5: **Standard Deviation of Macroeconomic Variables**

Notes: $\nu = 0.526$: estimated partial subsidy; $\nu = 1$: zero subsidy. $s_t^{vol} = H \rightarrow$ High oil price volatility state. $\lambda_y = 0.5$ is the weight on the output gap variance. The variables include real GDP growth ($\Delta y_{h,t}$), real consumption growth (Δc_t), real investment growth ($\Delta i_{no,t}$), non-oil output growth ($\Delta y_{no,t}$), headline inflation (π_t), core inflation ($\pi_{c,t}$), domestic inflation ($\pi_{d,t}$), imported inflation ($\pi_{f,t}$), nominal interest rate (R_t), real effective exchange rate ($\Delta\varepsilon_t$).

The first two rows of Table 5 compute the cost of following the estimated rule relative to the optimal rule in the benchmark economy (OSR $\nu = 0.526$). In line with the results that compare the welfare losses (Table 4), which represent the expectation of all future outcomes, the computed OSR in the alternative economy (OSR $\nu = 1$) is able to more effectively stabilize the economy, compared to the estimated rule in the benchmark economy, with the exception of consumption. However, full subsidy removal is welfare-reducing as it increases macroeconomic instability compared to the benchmark OSR. Similar findings based on CGE-simulations show how uncompensated removal of subsidies lowers household welfare (Lin and Jiang, 2011; Dennis, 2016).

The channels through which external shocks are propagated is key to understanding the sources of the welfare differences. The fuel subsidy distorts price signals in the domestic economy and affects the response of monetary policy to inflationary developments. This is because the subsidy affects not only direct fuel consumption, but also the cost of logistics for non-oil goods. In addition, fuel is an input in the production function of non-oil firms, and it features in their real marginal cost and price setting behavior (i.e. through (B.27) and (B.28) in Online Appendix B.2); thus, the regulation of retail fuel price by the fiscal authority also affects domestic prices indirectly and the addition of this feature is non-trivial, which, allied to heightened volatility in oil prices, can then potentially impact on business cycles and monetary policy.

Table 5 also presents a scenario under which we can achieve better policy outcomes than the estimated rules when $\nu = 1$. To do so, the central banker sets the weight on the output gap variance to $\lambda_y = 0.5$. This result shows the potential welfare gains from eliminating business cycle fluctuations in the alternative economy with the OSR. Putting a higher weight on controlling output volatility increases inflation variance. Nevertheless, this policy scenario

generates an optimized Taylor rule that can achieve better policy outcomes than the estimated rules in the $\nu = 1$ economy.

Finally, we investigate the level of macroeconomic instabilities that is regime-specific (OSR $\nu = 1$, $s_t^{vol} = H$). Full subsidy removal generally reduces welfare, with the effects being particularly pronounced during periods of high oil price volatility (typically due to persistent movements in inflation that materialize in the absence of subsidies). The OSR in this economy generates significantly higher volatility for both headline and core inflation and exchange rate movements. The lower foreign demand, following a negative oil shock, dampens domestic employment, causing exchange rate depreciation which may also have implications for welfare.

Based on our optimized rules, we argue that fuel subsidies are important for oil price shock transmission which, in the event of a prolonged, volatile oil shock, produce higher support for macroeconomic stabilization and welfare. If higher volatility in oil prices persists, then the welfare cost of business cycles requires the central bank to place greater emphasis on these welfare-relevant variables and the optimal choice for the degree of government intervention in price setting in the context of implementable Taylor rules.

6.4 Heterogeneous household effects in high- and low-volatility periods

Uncertainty induces consumers to smooth their consumption (if they are able to) and the effect on NR households is different compared to that on R households in the absence of subsidies. Table 6 shows the volatility changes from subsidy removal by examining household heterogeneity in both high- and low-volatility periods. In doing so, we explicitly link macroeconomic fluctuations to the distinction between R and NR households.[21] We compute the regime-specific volatilities for the domestic variables in Table 5 and investigate whether the presence of NR households aggravates the macroeconomic fluctuations associated with subsidy removal.

Regime-specific rules	NR	$\text{sd}(\Delta y_{h,t})$	$\text{sd}(\Delta c_t)$	$\text{sd}(\Delta i_{no,t})$	$\text{sd}(\Delta y_{no,t})$	$\text{sd}(\pi_t)$	$\text{sd}(\pi_{c,t})$	$\text{sd}(\pi_{d,t})$	$\text{sd}(\pi_{f,t})$	$\text{sd}(R_t)$	$\text{sd}(\Delta \varepsilon_t)$
OSR $\nu = 1$, $s_t^{vol} = L$	Yes	0.144	0.204	0.097	0.166	0.068	0.070	0.103	0.070	0.396	0.170
OSR $\nu = 1$, $s_t^{vol} = H$	Yes	0.146	0.202	0.097	0.163	0.079	0.079	0.104	0.072	0.385	0.181
OSR $\nu = 1$, $s_t^{vol} = L$	No	0.146	0.191	0.088	0.171	0.068	0.069	0.080	0.063	0.387	0.154
OSR $\nu = 1$, $s_t^{vol} = H$	No	0.148	0.189	0.088	0.168	0.085	0.084	0.082	0.068	0.372	0.173
% change in $s_t^{vol} = L$		1.44%	-6.31%	-8.97%	2.97%	-0.03%	-0.96%	-22.32%	-9.52%	-2.11%	-9.42%
% change in $s_t^{vol} = H$		1.11%	-6.30%	-8.94%	3.01%	7.13%	5.81%	-21.35%	-5.77%	-3.20%	-4.33%

Table 6: **Percentage Change in Macroeconomic Volatility Based on Household Types**

Notes: We investigate two alternative economies, i.e., with and without NR households. To focus our exercise on a scenario with a significant amount of NR consumers, we compute the regime-specific volatilities assuming an economy in which 50% of households are rule-of-thumb.

Our results show that, in the absence of subsidies, most variables are less volatile under the model without NR households. In other words, the oil-producing emerging economy with a significant amount of NR households is likely to experience greater macroeconomic instabilities in the aftermath of a subsidy removal. Under optimized rules, volatility increases in high shock volatility regimes and the economy inhabited by Ricardian households benefits more from subsidy removal in low-volatility periods due to higher disposable income and the ability to smooth out consumption. As is consistent with our earlier results, subsidy removal in high-volatility periods amplifies the negative wealth effect of private consumption, exacerbating inequality in

---

[21] As noted in Sections 6.1 and 6.2, this paper focuses on appropriate policy responses to an oil price shock and subsidy removal. A complete welfare ranking, as in Glomm and Jung (2015) and Ferrero and Seneca (2019), would require a second-order solution based on the utility of the representative household which is an avenue for future research.

the short term. However, allowing for heterogeneity in the household sector helps to dampen this amplification as some households do have the ability to be forward-looking and are able to smooth out consumption by trading in financial assets.

During high-volatility periods, the divergent impacts by household types could be exacerbated by the inflation effect, especially for the poor and vulnerable, through a significant reduction in their purchasing power. This can lead to increased income uncertainty and broader inflation. This result highlights that transparency is key in any subsidy reforms or targeted transfer policies (Ozili and Obiora, 2023; McCulloch *et al.*, 2021). For example, it is obligatory that public authorities publish information on the roll-out of palliatives and other welfare-enhancing initiatives to support the vulnerable households affected by the volatile prices immediately after subsidy removal. Such transparency obligations should be designed to pursue specific policy objectives in order to remedy an identified market failure or address an equity rationale – such as social difficulties, distributional concerns, changes in economic behavior and societal norms, and local or regional disadvantages.

6.5 Implications of optimized rules for output-inflation volatility

As in Section 6.3, we allow λ_y to vary and compute the optimized simple rules and the unconditional variances of the target variables in Table 7 which compares the output-inflation volatilities associated with $\lambda_y = 0.1$ and $\lambda_y = 0.5$, respectively. By increasing λ_y, we show that the central banker's policy preference decreases the variance of output growth, whilst facing a clear policy trade-off which generates a higher level of inflation volatility. For this exercise, our focus is on comparing the following four cases: the benchmark economy ($\nu = 0.526$), the alternative economy ($\nu = 1$), the benchmark economy staying in the high-variance state ($s_t^{vol} = H$), and the alternative economy staying in the high-variance state.

$\lambda_y = 0.1$	$\mathrm{sd}(\Delta y_{h,t})$	$\mathrm{sd}(\pi_t)$	$\lambda_y = 0.5$	$\mathrm{sd}(\Delta y_{h,t})$	$\mathrm{sd}(\pi_t)$	$\downarrow \mathrm{sd}(\Delta y_{h,t})$	$\uparrow \mathrm{sd}(\pi_t)$
Benchmark	0.14226	0.06838	Benchmark	0.14210	0.06950	0.00016	0.00112
Alternative	0.14423	0.07027	Alternative	0.14397	0.07171	0.00026	0.00143
Benchmark in $s_t^{vol} = H$	0.14387	0.07690	Benchmark in $s_t^{vol} = H$	0.14377	0.07780	0.00010	0.00090
Alternative in $s_t^{vol} = H$	0.14496	0.07930	Alternative in $s_t^{vol} = H$	0.14478	0.08051	0.00018	0.00121

Table 7: **Output-Inflation Volatility for Optimized Simple Rules**

Notes: $\nu = 0.526$: estimated partial subsidy; $\nu = 1$: zero subsidy. $s_t^{vol} = H \rightarrow$ High oil price volatility state. $\lambda_y = 0.1, 0.5$ is the weight on the output gap variance. The policy variables are real GDP growth ($\Delta y_{h,t}$) and headline inflation (π_t).

Our results indicate that monetary policy trade-offs become less severe under optimized rules, particularly when the central bank adopts an aggressive response to inflation following fuel subsidy removal. However, during periods of high oil price volatility, these trade-offs become more pronounced, requiring careful calibration of policy. This result is in line with the finding in Natal (2012) who makes a similar argument that oil price volatility operates as a source of monetary policy trade-off amplification. If efficiently implemented, fuel subsidies typically encourage greater consumption of such fuels leading to increased economic output thereby closing the output gap. If high volatility persists, then the appropriate monetary policy to adopt in the presence of market-determined prices and costly price adjustments is sensitive to the relative importance of maintaining price stability and output stabilization.

6.6 Impulse responses to a negative oil price shock

Insights into the working of optimal policy and of the transmission mechanism can be obtained by deriving posterior IRFs following an unanticipated 1% negative international oil price shock. The aim of this exercise is two-fold. First, we are interested in comparing the transmission of the shock when the subsidy program is 'turned on' and 'turned off'. This way, we assess the impact of imposing/removing the program on different model dynamics under different monetary policy rules. Second, we investigate the importance of shocks to the endogenous variables of interests in order to gain a better understanding of the model uncertainties faced by policymakers and the source of welfare differences. In Figures 4 and 5, we plot the IRFs for the low- ($s_t^{vol} = L$) and high-volatility regimes ($s_t^{vol} = H$), respectively. The policy rules presented are the estimated rule under the benchmark model, an OSR derived based on the posterior mode, and an OSR when we remove the subsidy program in the same model economy.
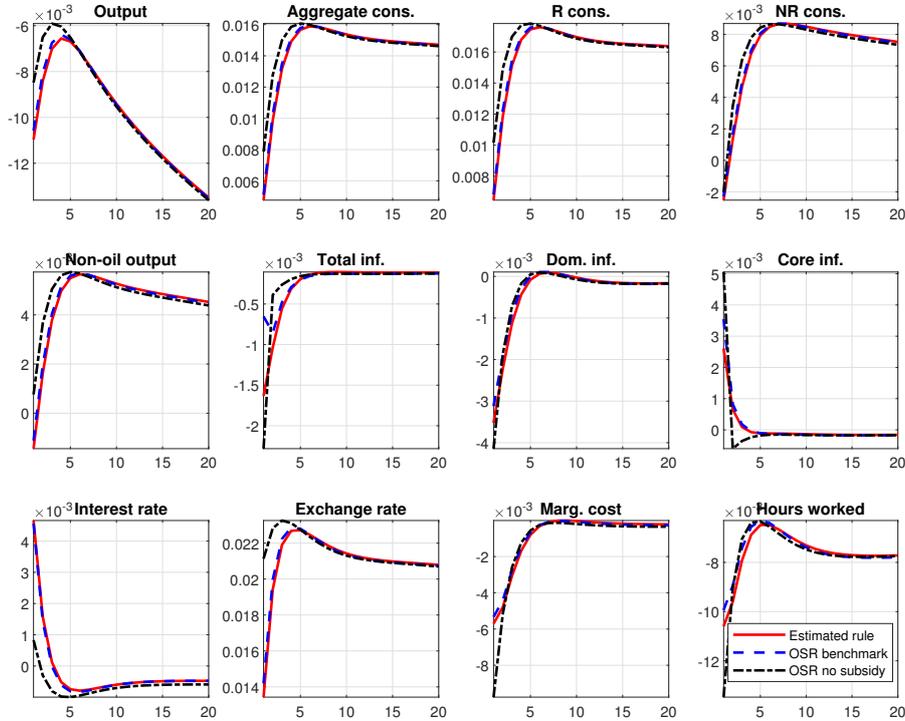
Figure 4: **Responses to a Negative Oil Price Shock with** $s_t^{vol} = L$

Qualitatively, the IRFs are broadly similar under the different monetary policy rules and under the volatility-switching assumption. Only the qualitative responses of total inflation and interest rate differ depending on the subsidy regulation. Following a negative oil price shock, output immediately falls and domestic inflation falls. This effect in turn leads to a reduction in equilibrium labor. The supply-side shock results in a fall in the marginal cost, and the fall is larger in the absence of subsidies. Consumption rises due to the depreciating real exchange rate and the resultant improvement in the terms of trade.

The optimal policy (when the subsidy is in place) is to raise the interest rate a little initially to contain inflation (the headline or core measure), but then to commit to a sharp monetary relaxation before gradually returning to the steady state. The same trajectory is depicted by the estimated policy. Contrary to the situation in which the government subsidizes the fuel consumption, but similarly to Figure 2, the OSR predicts an initial cut in the interest rate
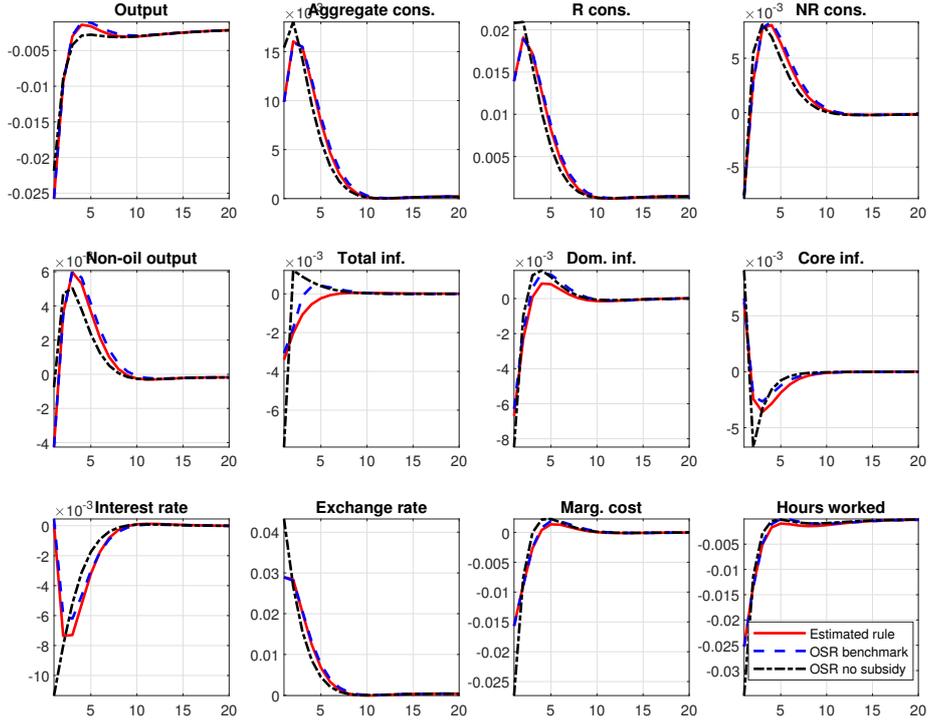
Figure 5: **Responses to a Negative Oil Price Shock with $s_t^{vol} = H$**

in the counterfactual case in response to the falling headline inflation rate, ameliorating the contractionary effects of a negative oil price shock on aggregate GDP. As is consistent with Table 4, the responsiveness of the initial monetary expansion to inflation is stronger in the no-subsidy case (if we compare the magnitude of their responses under the two optimal rules).

As expected, the reaction to the shock is less aggressive in $s_t^{vol} = L$. The three policy rules, in particular, OSR no subsidy, generate less contractionary effects on output and are better at containing inflation and mitigating the real exchange rate depreciation in this regime. It should be noted that, while the magnitude of the interest rate responses under the OSR is slightly larger in $s_t^{vol} = H$, the target variables exhibit generally much larger responses to the shock in $s_t^{vol} = H$ compared to in $s_t^{vol} = L$ (especially those of output and aggregate inflation). This suggests that the optimal policy has a more aggressive reaction function to variations in these variables in $s_t^{vol} = L$ – a result consistent with our Table 4 above. These state-dependent effects of monetary policy are also qualitatively in line with the findings in Pellegrino (2021).

As oil is an input to both production and consumption, our results can also reveal more evidence for the central bank's trade-off and that the severity of this dilemma depends on volatility (uncertainty) and the impact of subsidy removal. For example, when the central bank tends to respond to increased uncertainty about future prices during an episode of persistent inflationary pressures (Figure 5) by raising the interest rate (a small rate increase), the OSR and realized policy rule predict a more severe decline in output than under the low-volatility regime. Similarly, as noted, the responsiveness of the initial monetary expansion to inflation is stronger in the case when the subsidy is removed, from a central bank whose objective is to smooth out fluctuations in output, thus this helps prevent the economy from contracting drastically following the shock.

Finally, as discussed initially in Section 5.1, the policy IRFs provide more interesting results. With additional resources available to consumers (which, as discussed, would mainly benefit R

households), under the OSR, consumption rises initially but NR households see this happening with a *much smaller and delayed* increase in their consumption (decreases in real expenditure as also shown in Figure 2). This is similar to the results in Glomm and Jung (2015) who study the heterogeneous wealth effects between working and retired households. The responses of real variables - output, hours and consumption - differ considerably between the benchmark OSR and the OSR in the no-subsidy economy, and between the low- and high-volatility regimes, following the shock, which explains the large welfare differences (for all shocks combined). Furthermore, the OSR policy derived in both regimes of price volatility and in the no-subsidy economy sees a larger increase in both output and consumption on impact and in the short run. This is a major source of the expected welfare differences noted previously.

7   Implications for macroeconomic policy

By generating important dynamics in the data, the results presented in the paper can be used to derive some concrete policy recommendation for an oil-producing emerging economy. Our analysis is normative, aiming to suggest that the central bank may better shield the economy from future crises and changes in the volatility distribution of shocks by adopting a regime-specific policy stance.

On the design of monetary policy frameworks, we find that, for a welfare-maximizing central bank, the best policy rules are aggressive on inflation and exchange rates and are much more inertial whether fuel subsidies are implemented or not. The trade-offs faced by the central bank in balancing objectives such as price stability and output stabilization are less severe when the subsidy is removed, but they become larger in regimes of high oil price volatility. Due to increased economic volatility, the challenges of the central bank intervention in mitigating the impacts of subsidy removal when responding to contractionary supply shocks lie in designing a flexible framework capable of adapting to economic shifts while balancing its stabilization objectives.

In terms of building capacity around crisis response in times of uncertainty, disentangling the impact responses from shocks whose variances are time-varying is helpful for developing the policy coordination scenarios in the context of exploring the potential benefits of coordination between monetary and fiscal authorities in achieving economic stability, particularly in periods of stress and high volatility. Our results indicate that monetary policy becomes more expansionary in an economy without fuel subsidies during high-volatility periods. This is useful for policymakers to give careful consideration to the consequences of combinations of fiscal and monetary policy for jointly stabilizing the economy through scenario analysis. Furthermore, the observed switches in monetary policy suggest a need for a policy transition to a multiple-mandate regime.[22] Fiscal operations (quasi-fiscal activities) aimed at boosting output would positively impact the supply-side drivers of inflation suggesting that the best policy framework required to effectively respond to abrupt changes in global economic conditions should exhibit flexibility and adaptability.

---

[22]Omotosho and Yang (2024) and Online Appendix H discuss such a transition of the central bank that has been involved in quasi-fiscal operations aimed at boosting output and may explain the observed switch in the monetary policy regime in the aftermath of the financial crisis (see also Kumar *et al.*, 2024 for a discussion about the fiscal spillover and financial channel in emerging economies following the crisis). We also acknowledge that the implementation of this policy could however face resistance due to the institutional context, including political pressures, the nature of the central bank as an institution, potential lack of expertise, and other structural weaknesses. These and the socio-political challenges to subsidy removal, such as governance issues and political resistance, are indeed the practical challenges that Nigeria might face in executing the policy reforms.

Our paper is also, albeit indirectly, related to the literature studying uncertainty shocks and uncertainty-dependent effects of monetary policy (see, for example, Bloom, 2009; Kumar et al., 2021; Pellegrino, 2021; Corrado and Silgado-Gomez, 2022, among others). By modeling heteroskedasticity in oil price shocks and interpreting it structurally through an estimated New Keynesian framework, we disentangle monetary policy into systematic and regime-dependent components and have estimated spikes in macroeconomic uncertainty after some noticeable events. The estimation of heightened uncertainties influences monetary policy response differently. Under our optimal policy, in the absence of subsidies, the central bank responds to heightened uncertainty by lowering the policy rate. This supports the real activity and mitigates some of the adverse effects of subsidy removal, highlighting improved monetary policy decisions following an inflationary supply shock.

Finally, broader institutional and socio-economic factors influence policy reforms. In terms of the socio-economic implications of subsidy reforms, our empirical results and policy simulations indicate that the vast majority of the subsidy and benefits of its removal goes to better-off households. This explains why, especially during periods of high oil price volatility, subsidy reductions could widen the wealth and income gap, and be a major source of the different welfare consequences previously noted in the analysis.[23] Potential adjustments to interest rates, reserve requirements, or other policy tools that could be used to counteract the contractionary effects on income and wealth distribution could be helpful to inform future policy design and implementation, particularly in navigating regime-switching dynamics in uncertain environments.[24]

8 Concluding remarks and future research

We estimated a regime-switching DSGE model of an oil-producing emerging economy. In this model, the fiscal authority sells the imported fuel using a pricing rule that connotes an implicit subsidy program and the monetary authority responds to stochastic regime shifts in shocks to oil prices. We studied the impact of fuel subsidy removal on central bank behavior and optimal monetary policy. We have three major findings.

A general finding is that monetary policy adjustments are time-varying and synchronize with states of high oil price volatility. In the high-volatility state, the central bank policy rule delivers a lower degree of interest rate smoothing and places greater emphasis on the output gap relative to inflation, compared to the low-volatility state. Our study strengthens the connection between regime-switching dynamics and monetary policy responses in times of uncertainty.

A second finding is that a complete, one-off removal of fuel subsidy may lead to welfare losses due to increased macroeconomic volatility, highlighting the need for careful policy consideration. The optimal monetary rules are aggressive on inflation and exchange rates regardless of the subsidy arrangement in place, and prescribe an initial monetary expansion in the absence of subsidies during highly volatile periods. The result suggests that central bank interventions may be crucial in mitigating the welfare-reducing impact, underscoring the importance of coordinated

---

[23]The similar results can be found from previous empirical studies, such as Siddig et al. (2014), that have focused on examining the implications of fuel subsidy for the Nigerian economy, and Bartocci et al. (2024) who assess the effect of changing excise taxes on fossil fuels on macroeconomic policy and non-Ricardian households in the Euro area.

[24]For example, we acknowledge that the cash reserve ratio requirement in Nigeria (45%) is a significant policy instrument and the CBN's monetization of fiscal expenditure also impacts inflation. However, studying these features would introduce additional layers of complexity that go beyond the primary focus of the present paper which is providing a clear and tractable framework for analyzing the monetary policy dimension of subsidy removal. We leave this for future research, particularly in the context of broader fiscal-monetary policy interactions and financial sector modeling.

policy responses capable of adapting to economic shifts. Our recommendation is also intended to provide guidance on how the central bank improves its policy stance based on the optimal criteria outlined in our analysis.

Third, there are marked differences between the model-implied simulations of the two alternative economies suggesting that subsidy removal would play a significant role in affecting the business cycle dynamics and economic performances. The effect on private consumption is very different across the different types of households; thus offering an explanation for its potential impact on widening the wealth and income gap, and the different welfare consequences. These effects are more pronounced when the economy is in a high-volatility environment where the severity of the output contraction is amplified, thus emphasizing the importance of proactive policy measures to manage economic volatility and safeguard welfare.

We provide a flexible, novel framework for policy analysis that can be general and geared toward applications in resource-producing emerging economies. There are a number of possible avenues for future research. An issue that certainly deserves further attention is informality, in particular for emerging market economies. The heterogeneity of the model could be enriched by considering a two-sector economy allowing for informality. Gabriel *et al.* (2012) study such a model for India and find empirical evidence of a sizeable informal, low-skilled labor intensive sector. Given the significant presence of informality in developing countries, the adverse impact of subsidy removal could be felt more by the informal sector. Incorporating an informal sector should stylize the nature of productive activity in these economies. Monetary policy actions would impact differently depending on the sector's access to financial wealth.

References

Adebiyi, M. and Mordi, C. (2012). A dynamic stochastic general equilibrium (dsge) model of exchange rate pass-through to domestic inflation in nigeria. ECOMOD Conference 2012.

Akinola, A. O. (2018). *Globalization, Democracy and Oil Sector Reform in Nigeria*. Palgrave Macmillan Cham.

Algozhina, A. (2022). Monetary policy rule, exchange rate regime, and fiscal policy cyclicality in a developing oil economy. *Energy Economics*, **112**, 106126.

Allegret, J. P. and Benkhodja, M. T. (2015). External shocks and monetary policy in an oil exporting economy (Algeria). *Journal of Policy Modeling*, **37**(4), 652–667.

Alstadheim, R., Bjornland, H. C., and Maih, J. (2021). Do central banks respond to exchange rate movements? a markov-switching structural investigation of commodity exporters and importers. *Energy Economics*, **96**, 105138.

Antimiani, A., Costantini, V., and Paglialunga, E. (2023). Fossil fuels subsidy removal and the eu carbon neutrality policy. *Energy Economics*, **119**, 106524.

Asiedu, E. and Lien, D. (2011). Democracy, foreign direct investment and natural resources. *Journal of International Economics*, **84**(1), 99–111.

Barsky, R. B. and Kilian, L. (2004). Oil and the macroeconomy since the 1970s. *Journal of Economic Perspectives*, **18**(4), 115–134.

Bartocci, A., Cantelmo, A., Cova, P., Notarpietro, A., and Pisani, M. (2024). Monetary and fiscal policy responses to fossil fuel price shocks. *Energy Economics*, **136**, 107737.

Bazilian, M. and Onyeji, I. (2012). Fossil fuel subsidy removal and inadequate public power supply: Implications for businesses. *Energy Policy*, **45**, 1–5.

Benmelech, E. and Tzur-Ilan, N. (2020). The determinants of fiscal and monetary policies during the covid-19 crisis. National Bureau of Economic Research Working Paper No w27461.

Bergholt, D., Larsen, V., and Seneca, M. (2019). Business cycles in an oil economy. *Journal of International Money and Finance*, **2019**(96), 283–303.

Best, G. and Hur, J. (2019). Bad luck, bad policy, and learning? a markov-switching approach to understanding postwar u.s. macroeconomic dynamics. *European Economic Review*, **119**, 55–78.

Bianchi, F. (2013). Regime switches, agents' beliefs, and post-world war ii u.s. macroeconomic dynamics. *Review of Economic Studies*, **80**(2), 463–490.

Bianchi, F. and Ilut, C. (2017). Monetary/fiscal policy mix and agents' beliefs. *Review of Economic Dynamics*, **26**, 113–139.

Bianchi, F. and Melosi, L. (2017). Escaping the great recession. *American Economic Review*, **107**(4), 1030–1058.

Bjornland, H. C., Larsen, V. H., and Maih, J. (2018). Oil and macroeconomic (in)stability. *American Economic Journal: Macroeconomics*, **10**(4), 128–151.

Bloom, N. (2009). The impact of uncertainty shocks. *Econometrica*, **77**(3), 623–685.

Brooks, P. and Gelman, A. (1998). General methods for monitoring convergence of iterative simulations. *Journal of Computational and Graphical Statistics*, **7**(4), 434–455.

Caldara, D., Cavallo, M., and Iacoviello, M. (2019). Oil price elasticities and oil price fluctuations. *Journal of Monetary Economics*, **103**, 1–20.

Calvo, G. A. (1998). Capital Flows and Capital-Markets Crises. *Journal of Applied Econometrics*, **1**(1), 35–54.

Chang, Y., Maih, J., and Tan, F. (2021). Origins of monetary policy shifts: A new approach to regime switching in dsge models. *Journal of Economic Dynamics and Control*, **133**, 104235.

Chen, X. and Macdonald, R. (2012). Realized and optimal monetary policy rules in an estimated markov-switching dsge model of the united kingdom. *Journal of Money, Credit and Banking*, **44**(6), 1091–1116.

Clements, B. J., Coady, D., Fabrizio, S., Gupta, S., Alleyne, T. S. C., and Sdralevich, C. A. (2013a). Energy subsidy reform: lessons and implications. International Monetary Fund.

Clements, M. B. J., Coady, D., Fabrizio, M. S., Gupta, M. S., Alleyne, M. T. S. C., and Sdralevich, M. C. A. (2013b). *Energy subsidy reform: lessons and implications*. International Monetary Fund.

Coady, D. (2015). The unequal benefits of fuel subsidies revisited. International Monetary Fund.

Coady, D., Parry, I., Le, N. P., and Shang, B. (2019). Global fossil fuel subsidies remain large: An update based on country-level estimates. *IMF Working Papers*, **19**(89), 39.

Corrado, L. and Silgado-Gomez, E. (2022). Assessing the effects of fiscal policy news under imperfect information. *Oxford Economic Papers*, **75**(2), 574–587.

Couharde, C. and Mouhoud, S. (2020). Fossil fuel subsidies, income inequality, and poverty: Evidence from developing countries. *Journal of Economic Surveys*, **34**(5), 981–1006.

Curdia, V., Ferrero, A., Ng, G. C., and Tambalotti, A. (2015). Has u.s. monetary policy tracked the efficient interest rate? *Journal of Monetary Economics*, **70**, 72–83.

Dartanto, T. (2013). Reducing fuel subsidies and the implication on fiscal balance and poverty in indonesia: A simulation analysis. *Energy Policy*, **58**(C), 117–134.

Davig, T. and Doh, T. (2014). Monetary policy regime shifts and inflation persistence. *Review of Economics and Statistics*, **96**(5), 862–875.

Dennis, A. (2016). Household welfare implications of fossil fuel subsidy reforms in developing countries. *Energy Policy*, **96**, 597–606.

Estache, A. and Leipziger, D. (2009). *Stuck in the middle: is fiscal policy failing the middle class?* Brookings Institution Press.

Fan, W. and Wang, Z. (2022). Whether to abandon or continue the petroleum product price regulation in china? *Energy Policy*, **165**, 112890.

Ferrero, A. and Seneca, M. (2019). Notes on the underground: Monetary policy in resource-rich economies. *Journal of Money, Credit and Banking*, **51**(4), 953–976.

Gabriel, V., Levine, P., Pearlman, J., and Yang, B. (2012). An Estimated Model of the Indian Economy. In C. Ghate, editor, *Handbook of the Indian Economy*. Oxford University Press.

Gabriel, V., Levine, P., and Yang, B. (2016). An Estimated Open-Economy DSGE Model of the Indian Economy with Financial Frictions. Chapter in Monetary Policy in India: A Modern Macroeconomic Perspective, 2016, Springer Verlag .

Gabriel, V. J., Levine, P., and Yang, B. (2023). Partial dollarization and financial frictions in emerging economies. *Review of International Economics*, **31**(2), 609–651.

Gazzani, A., Venditti, F., and Veronese, G. (2024). Oil price shocks in real time. *Journal of Monetary Economics*, **144**, 103547.

Glomm, G. and Jung, J. (2015). A macroeconomic analysis of energy subsidies in a small open economy. *Economic Inquiry*, **53**(4), 1783–1806.

Goldwyn, D. and Clabough, A. (2020). Confronting the resource curse: Advice for investors and partners. Center for Energy Studies Working Paper.

Hamilton, J. D. (2003). What is an oil shock? *Journal of Econometrics*, **113**, 363–398.

Holm-Hadulla, F. and Hubrich, K. (2017). Macroeconomic implications of oil price fluctuations: a regime-switching framework for the euro area. ECB Working Paper Series No 2119.

Hwang, I. and Zhu, X. (2024). State-dependent oil price shocks on inflation and the efficacy of inflation targeting regime. *Journal of International Money and Finance*, **144**, 103077.

Inchauste, G. and Victor, D. G. (2017). *The political economy of energy subsidy reform.* World Bank Publications.

Jin, H. and Xiong, C. (2021). Fiscal stress and monetary policy stance in oil-exporting countries. *Journal of International Money and Finance*, **111**(102302).

Kapetanios, G., Masolo, R. M., Petrova, K., and Waldron, M. (2019). A time-varying parameter structural model of the uk economy. *Journal of Economic Dynamics and Control*, **106**, 103705.

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *American Economic Review*, **99**(3), 1053–1069.

Kim, C.-J. and Nelson, C. R. (2006). Estimation of a forward-looking monetary policy rule: A time-varying parameter model using ex post data. *Journal of Monetary Economics*, **53**(8), 1949–1966.

Kormilitsina, A. (2011). Oil price shocks and the optimality of monetary policy. *Review of Economic Dynamics*, **14**(1), 199–223.

Kumar, A., Mallick, S., and Sinha, A. (2021). Is uncertainty the same everywhere? advanced versus emerging economies. *Economic Modelling*, **101**, 105524.

Kumar, A., Mallick, S., and Sinha, A. (2024). Fiscal spillover in emerging economies: Real versus financial channels. *Journal of International Money and Finance*, **149**, 103168.

Leduc, S. and Sill, K. (2004). A quantitative analysis of oil-price shocks, systematic monetary policy, and economic downturns. *Journal of Monetary Economics*, **51**(4), 781–808.

Leeper, E. M. (1991). Equilibria under active and passive monetary and fiscal policies. *Journal of monetary Economics*, **27**(1), 129–147.

Lin, B. and Jiang, Z. (2011). Estimates of energy subsidies in china and impact of energy subsidy reform. *Energy Economics*, **33**(2), 273–283.

Liu, P. and Mumtaz, H. (2011). Evolving macroeconomic dynamics in a small open economy: An estimated markov switching dsge model for the uk. *Journal of Money, Credit and Banking*, **43**(7), 1443–1474.

Liu, Z., Waggoner, D. F., and Zha, T. (2011). Sources of macroeconomic fluctuations: A regime-switching dsge approach. *Quantitative Economics*, **2**(2), 251–301.

Maih, J. (2015). Efficient perturbation methods for solving regime-switching dsge models. Norges Bank Working papers 01/2015.

Maih, J., Mazelis, F., Motto, R., and Ristiniemi, A. (2021). Asymmetric monetary policy rules for the euro area and the us. *Journal of Macroeconomics*, **70**, 103376.

McCulloch, N., Moerenhout, T., and Yang, J. (2021). Fuel subsidy reform and the social contract in nigeria: A micro-economic analysis. *Energy Policy*, **156**, 112336.

Melina, G., Yang, S.-C. S., and Zanna, L.-F. (2016). Debt sustainability, public investment, and natural resources in developing countries: The dignar model. *Economic Modelling*, **52**, 630–649.

Monacelli, T. (2005). Monetary policy in a low pass-through environment. *Journal of Money, Credit and Banking*, **37**(6), 1047–1066.

Natal, J. (2012). Monetary policy response to oil price shocks. *Journal of Money, Credit and Banking*, **44**(1), 53–101.

Omotosho, B. S. and Yang, B. (2024). Oil price shocks and macroeconomic dynamics in resource-rich emerging economies under regime shifts. *Journal of International Money and Finance*, **144**, 103082.

Oyinlola, M. and Adetunji, M. (2009). A bound testing analysis of exchange rate pass-through to aggregate import prices in nigeria: 1980-2006. *Journal of Economic Development*, **34**(2), 97–109.

Ozili, P. K. and Obiora, K. (2023). Implications of fuel subsidy removal on the nigerian economy. In *Public Policy's Role in Achieving Sustainable Development Goals*.

Pellegrino, G. (2021). Uncertainty and monetary policy in the us: A journey into nonlinear territory. *Economic Inquiry*, **59**(3), 1106–1128.

Poghosyan, T. and Beidas-Strom, S. (2011). An estimated dynamic stochastic general equilibrium model of the jordanian economy. *IMF Working Paper*, **11**(28).

Rahman, S. and Serletis, A. (2010). The asymmetric effects of oil price and monetary policy shocks: A nonlinear var approach. *Energy Economics*, **32**(6), 1460–1466.

Ramey, V. A. and Vine, D. J. (2011). Oil, automobiles, and the us economy: How much have things really changed? *NBER Macroeconomics Annual 2010*, **25**, 333–367.

Rentschler, J., Kornejew, M., and Bazilian, M. (2017). Fossil fuel subsidy reforms and their impacts on firms. *Energy Policy*, **108**, 617–623.

Riggi, M. and Venditti, F. (2015). The time varying effect of oil price shocks on euro-area exports. *Journal of Economic Dynamics and Control*, **59**, 75–94.

Schorfheide, F. (2005). Learning and monetary policy shifts. *Review of Economic Dynamics*, **8**(2), 392–419.

Senbeta, S. (2011). A small open economy new keynesian dsge model for a foreign exchange constrained economy. Technical report, University of Antwerp, Faculty of Applied Economics.

Siddig, K., Aguiar, A., Grethe, H., Minor, P., and Walmsley, T. (2014). Impacts of removing fuel import subsidies in nigeria on poverty. *Energy Policy*, **69**, 165–178.

Taylor, M. (2020). Energy subsidies: Evolution in the global energy transformation to 2050. International Renewable Energy Agency, Abu Dhabi.

Teixeira, A. A., Forte, R., and Assunção, S. (2017). Do countries' endowments of non-renewable energy resources matter for fdi attraction? a panel data analysis of 125 countries over the period 1995–2012. *International Economics*, **150**, 57–71.

Trehan, B. and Wu, T. (2007). Time-varying equilibrium real rates and monetary policy analysis. *Journal of Economic Dynamics and Control*, **31**(5), 1584–1609.

Yau, R. and Chen, G.-H. (2021). Assessing energy subsidy policies in a structural macroeconomic model. *Energy Economics*, **103**, 105509.