Monetary Policy in an Oil-Exporting Emerging Economy with Fuel Subsidies

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This paper develops a DSGE model for an emerging oil-exporting economy with a fuel subsidy regime to analyse the stabilising role of alternative monetary policy rules under different subsidy arrangements. The model is estimated via Bayesian methods using data for Nigeria from 2000Q2 to 2019Q4. This paper (i) estimates a domestic fuel pricing rule for an oil-exporting emerging economy of Nigeria with fuel subsidies, (ii) characterizes monetary policy behaviour under such an estimated fuel pricing rule, and (iii) evaluates the appropriateness of alternative monetary policy rules under different assumptions regarding the fuel subsidy regime. The results show that approximately 45 per cent of changes to the global oil price are transmitted to the retail price of fuel. Also, it was found that the behaviour of monetary policy in Nigeria has been characterised by the headline inflation monetary rule. However, the monetary authority is able to reduce policy loss by approximately 11 per cent if it targets core inflation rather than a measure of inflation that includes energy prices. Under a zero-subsidy regime, the core inflation monetary rule outperforms its competitors in achieving overall macroeconomic stability, provided the share of oil in total consumption is relatively low.

1. Introduction

Over the last three decades, oil has remained an important source of energy for households and firms, accounting for approximately 35 percent of the total energy supply globally (IEA, 2019). This implies that oil price shocks have implications not only for the welfare of households but also for global macroeconomic stability. For instance, oil price shocks have been shown to alter consumption decisions of households (Kilian, 2008), distort the production plans of firms (Backus & Crucini, 2000;

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Mork *et al.*, 1990), disrupt the fiscal and balance of payment positions of countries (Cashin *et al.*, 2000), and generate output losses (Carruth *et al.*, 1998; Mork *et al.*, 1990). Additionally, changes in oil price have been associated with external reserve volatility, exchange rate instability, inflation volatility, and severe macroeconomic imbalances in resource-rich emerging economies (Adeniyi *et al.*, 2011; Akinleye & Ekpo, 2013; Richard & Olofin, 2013).

Several fiscal interventions exist for mitigating the macroeconomic and welfare impacts of oil price shocks, including the use of fuel consumption subsidies.[1] Over time, fuel subsidies have become popular, especially among oil-producing emerging economies. This reflects, among others, the need to make energy more affordable for poor and vulnerable groups of society, enhance energy security, broaden economic and job opportunities in the case of producer subsidies, and achieve domestic price stabilisation (Taylor, 2020). In oil-rich countries, fuel subsidies represent a means of distributing wealth among citizens (Di Bella *et al.*, 2015; Estache & Leipziger, 2009).[2]

Global fossil fuel subsidies have remained quite large despite widespread calls for subsidy reforms. In 2017, approximately 191 countries provided subsidies worth US$5.2 trillion, representing approximately 6.5 percent of global GDP (Coady *et al.*, 2019). An important component of this is the pre-tax subsidy,[3] which arises when the retail price of fuel is administered by the government such that the price paid by the consumer is lower than the supply cost. Thus, pre-tax subsidies impact the government budget and introduce price stickiness that distorts domestic price signals. These consequences have nontrivial implications for the conduct of monetary policy. In 2017, the global pre-tax subsidy was estimated at US$295.93 billion, with low- and middle-income countries accounting for approximately 93.7 percent

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[1]Fuel subsidies arise when the administered fuel prices are lower than the opportunity costs of fuel supply (Coady, Parry, Sears and Shang, 2017), usually in pursuit of social policy goals. For instance, as shown in Figure 3, whereas the world retail price of fuel in 2019 was US$0.94 per litre, the administered pump prices in a number of countries were much lower; ranging from US$0.7 per litre (Pakistan) to US$0.3 per litre (Algeria).

[2]Di Bella *et al.,* (2015) also argues that the oil price increases that began in the mid-2000 led to increased agitation for countries to provide fuel subsidies.

[3]The other components being subsidies relating to global warming, local air pollution, congestion, accidents, road damage, and foregone consumption.

(Coady *et al.*, 2019). Additionally, oil-producing low- and middle-income economies accounted for approximately 48.3 percent of total global pre-tax subsidies in 2017, equivalent to 3.1 percent of their GDP.[4] The cumulative amount of global pre-tax fuel subsidies during 2010-2019 was approximately US$2 trillion, with low- and middle-income countries accounting for approximately 80.0 percent (Coady *et al.*, 2019).[5] This means that pre-tax subsidies are particularly an important issue for oil-producing developing countries. Incidentally, most of these countries are also in dire need of resources to address their developmental challenges and achieve the Sustainable Development Goals (Coady *et al.*, 2019).

Contrary to its original intentions, fuel subsidies have been shown to introduce market distortions, crowd-out priority public spending, cause balance of payment and fiscal imbalance problems, encourage inefficient energy consumption, exacerbate environmental degradation, and increase inequality (Bazilian & Onyeji, 2012; Clements *et al.*, 2013; Coady, 2015; Taylor, 2020). These concerns have led to increased calls for energy subsidy reforms globally (Taylor, 2020), with fears that such reforms could generate greater macroeconomic instabilities that may necessitate significant adjustments to monetary policy (Omotosho, 2019; Rentschler *et al.*, 2017).

Our paper is motivated by the fact that there are few studies investigating the macroeconomic and monetary policy implications of oil price shocks in the presence of fuel subsidies.[6] This is particularly true for oil-producing emerging economies, which are largely responsible for global pre-tax fuel subsidies. To our knowledge, no previous study has investigated the implications of fuel subsidy removal for the conduct of monetary policy in an oil-producing emerging economy. Whereas Allegret and Benkhodja (2015) found support for core inflation monetary rule as a tool for stabilising prices and output under a subsidy regime that allows for 30 percent pass-through of international oil price to domestic fuel price, it is not clear whether such a monetary rule maximises welfare under alternative fuel subsidy arrangements.

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[4]In countries such as Algeria, total subsidy as a share of Gross Domestic Product (GDP) was as high as 7.6 per cent in 2019 (red dots in Figure 3).

[5]The pre-tax fuel subsidy values reported by the IMF and the IEA vary slightly due to slight differences in estimation approaches, especially with regards to tax subsidies (Coady, 2015).

[6]The existing ones include Allegret and Benkhodja (2015), Omotosho (2019) and Oladunni (2020).

The second motivation for our paper relates to the fact that the macroeconomic impacts of oil price shocks are usually more severe in low- and middle-income countries, as they exhibit certain characteristics that exacerbate their vulnerabilities. Such characteristics include high oil dependence (Barrell *et al.*, 2008; Salti, 2008); the presence of hand-to-mouth consumers and financial market inefficiencies (Hallegatte & Przyluski, 2011); inefficient fuel subsidy programs (Coady *et al.*, 2017); fiscal volatility and procyclicality (Abdih *et al.*, 2010; Barnett & Ossowski, 2002); revenue substitution (Tijerina-Guajardo & Pagán, 2003); low policy buffers (Hallegatte & Przyluski, 2011); and high oil import dependence arising from low domestic capacity and weak economic structures (Rodrik, 1999), among others. Thus, as calls for fuel subsidy reforms continue to increase, it is important that more efforts are devoted to the understanding of the macroeconomic consequences and transmission mechanism of oil price shocks in those countries.

This paper studies the dynamic impacts of oil price shocks on a small open oil-producing emerging economy with a fuel subsidy regime and evaluates the stabilising role of alternative monetary rules under different fuel subsidy arrangements. We pose a number of questions. First, given an oil price shock, should the monetary authority of an oil-producing country respond to headline, core, domestic or product price inflation in the presence of fuel subsidies?[7] Second, given that fuel subsidy removal alters the path of domestic inflation and impacts monetary policy transmission, does a fuel subsidy reform require a recalibration of monetary policy strategy? For oil-producing emerging economies contemplating fuel subsidy reforms, these questions are important, as they help in the design of suitable complementary monetary policy for ameliorating the welfare costs associated with such reforms.

To address our research questions, we develop a multi-sector New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model for a small open oil-producing

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[7]This question has been answered for an oil-importing economy of Bangladesh (Amin, Marsiliani and Renstrom, 2018) and an oil-exporting economy of Nigeria (Oladunni, 2020) using calibrated DSGE models. To our knowledge, no study has been conducted for an oil-producing emerging economy using an estimated DSGE model that allows for a computed pass-through coefficient of international price of oil to domestic retail price of fuel. While Allegret and Benkhodja (2015) answered the question using an estimated DSGE model for Algeria, the pass-through coefficient was not estimated.

emerging economy with a fuel subsidy regime. We characterise monetary policy behaviour for a typical resource-rich emerging economy and conduct monetary policy analyses by estimating the model for Nigeria via Bayesian techniques. We find the Nigerian case interesting for a number of reasons. First, the economy typifies a number of features embedded in our model set up, including administered retail fuel price, high share of oil in GDP, oil-driven fiscal policy, low domestic oil refining capacity, and relatively high share of fuel in aggregate imports (Table 11). Second, the few related studies for Nigeria have failed to reach a consensus regarding the macroeconomic implications of fuel subsidy reforms (Ocheni 2015; Siddig *et al.*, 2014).[8] Third, no previous study has characterised monetary policy behaviour in Nigeria using an estimated DSGE model that accounts for the country's fuel subsidy regime.

This paper is organized in five sections. In Section 2, we describe the theoretical model and obtain the characterizing equations. Section 3 discusses the data, model parametrization and estimation procedure. In Section 4, we present the estimation results and discuss them in the context of our research questions. Finally, some concluding remarks are offered in Section 5.

2. The model

The model presented in this section is an extension of the small open economy model of Gali and Monacelli (2005). We incorporate an oil sector as in Ferrero and Seneca (2019). Additionally, we include oil in domestic consumption as in Medina and Soto (2005) to capture the direct impact of oil price shocks on prices and assess the role of core inflation monetary rule in the economy. Further, we allow for the oil intensity

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[8]Whereas Siddig et al. (2014) found that fuel subsidy removal boosts the GDP, Ocheni (2015) showed that such policy reform hurts economic growth and reduce household income. The existing studies on the macroeconomic impacts of fuel subsidy removal in Nigeria applied either the computable general equilibrium model (Adenikinju, 2009; Siddig et al., 2014), ordinary least squares estimation (Nwachukwu, Mba, Jiburum and Okosun, 2013), analysis of survey data (Ocheni, 2015), or the narrative approach (Bazil ian and Onyeji, 2012). These approaches are limited in terms of their usefulness for conducting counterfactual simulations relating to monetary policy. Omotosho (2019) estimated a structural model to study the role of fuel subsidies but did not (i) charac terise monetary rule for Nigeria and (ii) examine the relevance of alternative monetary rules under alternative subsidy regimes.

of domestic production as in Allegret and Benkhodja (2015) to capture the indirect impact of oil price shocks on domestic inflation. To accommodate fuel subsidies, we feature a domestic fuel pricing rule as in Allegret and Benkhodja (2015). We incorporate hand-to-mouth consumers in a fashion akin to a two-agent New-Keynesian (TANK) model described by Galí (2018) and allow for an inefficient financial market, as in Smets and Wouters (2007).

2.1 Households

2.1.1 Demand for consumption goods

Household consumption, C_t, combines both core consumption bundle, $C_{no,t}$, and oil consumption, $C_{o,t}$, based on a constant elasticity of substitution (CES) aggregator as follows:

$$C_t = \left[(1-\gamma_o)^{\frac{1}{\eta_o}} (C_{no,t})^{\frac{\eta_o-1}{\eta_o}} + \gamma_o^{\frac{1}{\eta_o}} (C_{o,t})^{\frac{\eta_o-1}{\eta_o}} \right]^{\frac{\eta_o}{\eta_o-1}} \tag{1}$$

where η_o is the elasticity of substitution between oil and nonoil goods and γ_o is the share of oil in total consumption. The minimization of household expenditures subject to equation (1) yields the demands for core and oil goods as follows:

$$C_{no,t} = (1-\gamma_o) \left[\frac{P_{no,t}}{P_t} \right]^{-\eta_o} C_t, \qquad C_{o,t} = \gamma_o \left[\frac{P_{ro,t}}{P_t} \right]^{-\eta_o} C_t \tag{2}$$

The price of fuel, $P_{ro,t}$, is not simply the world price of fuel expressed in domestic currency but rather a convex combination of the expected open market price (EOMP) and the domestic price of fuel in the previous period.[9] Furthermore, core consumption, $C_{no,t}$, is a CES aggregate of imported bundles, $C_{f,t}$, and domestic goods, $C_{h,t}$:

$$C_{no,t} = \left[(1-\gamma_c)^{\frac{1}{\eta_c}} (C_{h,t})^{\frac{\eta_c-1}{\eta_c}} + \gamma_c^{\frac{1}{\eta_c}} \left(C_{f,t} \right)^{\frac{\eta_c-1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c-1}},$$

where $\eta_c > 0$ is the elasticity of substitution between imported and domestically produced goods. The parameter γ_c is the share of total consumption imported from the

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[9]As in Allegret and Benkhodja (2015), we adopt the fuel pricing rule: $P_{ro,t} = P_{ro,t-1}^{1-v} P^v$
where EOMP, $P_{lo,t}$, is the current world price of fuel expressed in local currency.

rest of the world. The demands for $C_{f,t}$, and $C_{h,t}$ obtained via expenditure minimization are as follows:

$$C_{h,t} = (1-\gamma_c)\left[\frac{P_{h,t}}{P_{no,t}}\right]^{-\eta_c} C_{no,t}, \qquad C_{f,t} = \gamma_c\left[\frac{P_{f,t}}{P_{no,t}}\right]^{-\eta_c} C_{no,t},$$

The aggregate consumer price index, P_t, and core consumption price index, $P_{no,t}$, are expressed as follows:

$$P_t = \left[(1-\gamma_o)P_{no,t}^{1-\eta_o} + \gamma_o P_{ro,t}^{1-\eta_o}\right]^{\frac{1}{1-\eta_o}}, \qquad P_{no,t} = \left[(1-\gamma_c)P_{h,t}^{1-\eta_c} + \gamma_c P_{f,t}^{1-\eta_c}\right]^{\frac{1}{1-\eta_c}}.$$

2.1.2 Ricardian consumers

We consider two types of consumers: Ricardian (R) and non-Ricardian (NR).[10] The Ricardian consumers comprise a fraction, γ_R, who are capable of intertemporal optimization. A representative household under this category is able to smooth consumption over time by buying and selling financial assets without any form of constraints (Gali, 2018). To make intertemporal consumption and savings decisions, the representative optimising household maximises an expected discounted utility function given by

$$U_0^R = E_0 \sum_{s=0}^{\infty} \beta^s \left[\frac{\left(C_{t+s}^R(j) - \emptyset_c C_{t+s-1}\right)^{1-\sigma}}{1-\sigma} - \frac{N_{t+s}^R(j)^{1+\varphi}}{1+\varphi}\right] \tag{3}$$

where E_0 denotes the mathematical expectation operator, the superscript R indicates that the household is Ricardian, C_t^R, is the representative household's current level of consumption, C_t is the economy-wide consumption level, and N_t^R is the number of hours worked. The parameters $\beta \in (0,1)$, σ, and $\varphi > 0$ represent the discount factor, relative risk aversion coefficient, and inverse of the Frisch elasticity of labour supply, respectively. As in Smets and Wouters (2003), we assume external habit formation in consumption, where $\phi_c \in (0,1)$ governs the degree of habit formation. Equation

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[10]According to EFInA (2018), 36.8 per cent of adults in Nigeria were excluded financially in 2018.

(3) is maximised subject to a per period budget constraint:

$$P_t C_t^R + P_{i,t} I_{no,t} + \frac{B_{t+1}}{R_t \mu_t} + \frac{\varepsilon_t B_{t+1}^*}{R_t^*} = W_t N_t^R + R_{h,t} K_{h,t} + B_t + \varepsilon_t B_t^* + D_t - TX_t \quad (4)$$

The Ricardian consumer earns labour income, $W_t N_t^R$, and rental income, $R_{h,t} K_{h,t}$, by supplying N_t^R hours of work and leasing an amount of non-oil capital, $K_{h,t}$, to domestic goods producers. The household also receives an aliquot share, D_t, from the profits of the firms and enters the period with the stock of nominal domestic bonds, B_t, and foreign bonds, B_t^*, which mature in period $t + 1$; TX_t denotes taxes. We incorporate financial market inefficiency by featuring a domestic risk premium, μ_t, over the monetary policy rate. As in Smets and Wouters (2007) and Hollander *et al.* (2018), we allow μ_t to evolve as a first-order autoregressive process with an exogenous shock. On the expenditure side, the household purchases consumption goods, C_t^R, at the cost of P_t per unit, and nonoil investment goods, $I_{no,t}$, at the cost of $P_{i,t}$ per unit. As in Christiano *et al.* (2005) and Schmitt-Grohé and Uribe (2005), we adopt a quadratic investment adjustment cost and assume that the non-oil capital is accumulated as follows:

$$K_{h,t+1} = (1 - \delta_h) K_{h,t} + I_{no,t} \left[1 - \frac{\chi}{2} \left(\frac{I_{no,t}}{I_{no,t-1}} - 1 \right)^2 \right] \quad (5)$$

where δ_h represents the rate at which nonoil capital depreciates and $\chi \geq 0$ is the sensitivity parameter governing the size of the adjustment cost.

2.1.3 Non-Ricardian consumers

Non-Ricardian consumers are assumed to be incapable of intertemporal optimisation. Therefore, the representative consumer in this category completely consumes its after-tax income, and its budget constraint is as follows:

$$P_t C_t^{NR} = W_t N_t^{NR} - TX_t \quad (6)$$

2.1.4 Labour packer and wage setting

The differentiated labour, $N_t(j)$, supplied by each household, j, to intermediate goods producers in a monopolistic market is aggregated by a representative firm as follows:

$$N_t = \left[\int_0^1 N_t(j)^{\frac{\eta_w-1}{\eta_w}} dj \right]^{\frac{\eta_w}{\eta_w-1}} \tag{7}$$

where the elasticity of substitution between differentiated jobs is represented by parameter η_w. The demand for differentiated labour, $N_t(j)$, and the aggregate wage level, W_t, are calculated by minimising the labour-aggregating firm's cost subject to equation (7). Wages are sticky, as a proportion of households, $1 - \theta_w$, selected at random are able to reset their wages in each period, while the other fraction, θ_w, maintains their wages at the level in the previous period. The optimal reset wage (W_t) equation is standard, while the aggregate nominal wage equation is of the form[11]:

$$W_t = \left[\theta_w W_{t-1}^{1-\eta_w} + (1 - \theta_w) W_t^{1-\eta_w} \right]^{\frac{1}{1-\eta_w}} \tag{8}$$

2.2 Firms

2.2.1 Final goods producers

These perfectly competitive firms produce final goods, $Y_{h,t}$, by bundling domestically produced differentiated goods, $Y_{h,t}(z_h)$, using constant returns to scale aggregation technology:

$$Y_{h,t} = \left[\int_0^1 Y_{h,t}(z_h)^{\frac{\epsilon_h-1}{\epsilon_h}} dz_h \right]^{\frac{\epsilon_h}{\epsilon_h-1}} \tag{9}$$

where parameter $\epsilon_h > 1$ is the elasticity of substitution among different intermediate goods. The firm's optimisation problem yields the equation for the demand for intermediate goods, $Y_{h,t}(z_h)$, and the corresponding domestic price aggregator, $P_{h,t}$, as follows:

$$Y_{h,t}(z_h) = \left[\frac{P_{h,t}(z_h)}{P_{h,t}} \right]^{-\epsilon_h} Y_{h,t}, \quad P_{h,t} = \left[\int_0^1 P_{h,t}(z_h)^{1-\epsilon_h} dz_h \right]^{\frac{1}{1-\epsilon_h}} \tag{10}$$

The demand for export-bound intermediate goods, $Y_{h,t}^*(z_h)$, and the corresponding

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[11]Following Erceg et al. (2005) and Medina and Soto (2016), we set the wages for non-Ricardian households equal to the Ricardian households' average wage.

price aggregator, $P_{h,t}^*$, are derived analogously.

2.2.2 Intermediate goods producers

In their production process, the intermediate goods producers combine capital, $K_{h,t}(z_h)$; imported refined oil, $O_{h,t}(z_h)$; and labour, $N_t(z_h)$, as follows:

$$Y_{h,t}(z_h) = A_{h,t} K_{h,t}(z_h)^{\alpha_h^k} O_{h,t}(z_h)^{\alpha_h^o} N_t(z_h)^{\alpha_h^n} \tag{11}$$

The parameters $1 > \alpha_h^k > 0$, $1 > \alpha_h^o > 0$ and $1 > \alpha_h^n > 0$ are factor input elasticities, while the total factor productivity, $A_{h,t}$, is assumed exogenous as follows: $A_{h,t} = (A_{h,t-1})^{\rho_{a_h}} exp\left(\xi_t^{A_h}\right)$. We solve the optimization problem of the intermediate goods producers in two stages. In the first stage, the firm's total cost is:

$$W_t N_t(z_h) + R_{h,t} K_{h,t}(z_h) + P_{ro,t} O_{h,t}(z_h) \tag{12}$$

minimised subject to equation (11) to obtain the optimal input combinations, which are combined with the production function to derive the real marginal cost:

$$mc_t = \frac{1}{A_{h,t} p_{h,t}} \left(\frac{r_{h,t}}{\alpha_h^k}\right)^{\alpha_h^k} \left(\frac{p_{ro,t}}{\alpha_h^o}\right)^{\alpha_h^o} \left(\frac{w_t}{\alpha_h^n}\right)^{\alpha_h^n} \tag{13}$$

where $mc_t = \frac{MC_t}{P_t}$. The input prices are given and expressed in real terms as follows: $r_{h,t} = \frac{R_{h,t}}{P_t}$, $p_{ro,t} = \frac{P_{ro,t}}{P_t}$,[12] $w_t = \frac{W_t}{P_t}$, and $p_{h,t} = \frac{P_{h,t}}{P_t}$. In the second stage, the intermediate goods producer that qualifies for an optimal price reset maximises its expected discounted profit conditional on the new price of its goods (Calvo, 1983). Thus, a fraction θ_h of the intermediate goods producers keep their prices at last fixing as they are unable to re-optimise while the remaining $1 - \theta_h$ are able to reset their prices optimally. A firm that is chosen to optimally set a new price does so by maximising profit subject to the demand for its goods. The optimal reset price is given by:

$$P_{h,t} = \frac{\epsilon_h}{\epsilon_h - 1} \frac{E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s P_{h,t+s} Y_{h,t+s} mc_{t+s}}{E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s Y_{h,t+s}} \tag{14}$$

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[12]The real domestic price of imported fuel is determined via a pricing rule in line with our assumption regarding the presence of fuel consumption subsidies in the economy.

The law of motion equation for the domestic price index is standard:

$$P_{h,t} = \left[\theta_h P_{h,t-1}^{1-\epsilon_h} + (1-\theta_h)(P_{h,t})^{1-\epsilon_h}\right]^{\frac{1}{1-\epsilon_h}} \tag{15}$$

We allow for some firms to also produce intermediate goods for the export market. Thus, in an analogous manner, profit maximisation subject to the demand for intermediate goods meant for the export market, $Y_{h,t}^*(z_h)$, yields an optimal reset price, $P_{h,t}^*$, for such a commodity, while the associated Calvo parameter is denoted as θ_{hf}.

2.2.3 Imported goods retailers

As in Medina and Soto (2007), we ameliorate the expenditure switching effects of exchange rate movements by allowing for incomplete exchange rate pass-through into import prices in the short run. Thus, a group of perfectly competitive assemblers combine a continuum of differentiated imported varieties, $Y_{f,t}(z_f)$, to produce a final foreign good, $Y_{f,t}$, as follows:

$$Y_{f,t} = \left[\int_0^1 Y_{f,t}(z_f)^{\frac{\epsilon_f-1}{\epsilon_f}} dz_f\right]^{\frac{\epsilon_f}{\epsilon_f-1}} \tag{16}$$

where the parameter $\epsilon_f > 1$ is the elasticity of substitution between different imported goods. The firm's optimisation problem yields the demand equation for the imported varieties as well as the corresponding price index, $P_{f,t}$, given as:

$$Y_{f,t}(z_f) = \left[\frac{P_{f,t}(z_f)}{P_{f,t}}\right]^{-\epsilon_f} Y_{f,t}, \qquad P_{f,t} = \left[\int_0^1 P_{f,t}(z_f)^{1-\epsilon_f} dz_f\right]^{\frac{1}{1-\epsilon_f}}.$$

In turn, the imported goods retailer operates in a monopolistic market with the domestic price of imported varieties determined as in Calvo (1983). By law of large numbers, the pricing rule for imported goods is given by

$$P_{f,t} = \left[\theta_f P_{f,t-1}^{\epsilon_f} + \left(1-\theta_f\right)\left(P_{f,t}\right)^{1-\epsilon_f}\right]^{\frac{1}{1-\epsilon_f}} \tag{17}$$

where the Calvo parameter for imported goods is θ_f.

2.2.4 The oil firm

To produce oil output, $Y_{o,t}$, which is sold in the international crude oil market at price $p_{o,t}^*$; the oil firm combines domestic materials M_t and oil-related capital $K_{o,t}$ as follows:

$$Y_{o,t} = A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m} \tag{18}$$

where $A_{o,t}$ represents the oil technology and the parameters α_o^k and α_o^m are factor input elasticities. We assume that $K_{o,t}$ accumulates as follows:

$$K_{o,t} = (1 - \delta_o) K_{o,t-1} + FDI_t^* \tag{19}$$

where FDI_t^* represents foreign direct investment into the oil firm and δ_o is the depreciation rate of oil-related capital. In turn, FDI_t^* responds to the real international price of oil as follows:

$$FDI_t^* = \left(FDI_{t-1}^*\right)^{\rho_{fdi}} \left(p_{o,t}^*\right)^{1-\rho_{fdi}} \tag{20}$$

where parameter ρ_{fdi} captures inertia in the accumulation of foreign direct investment. We assume that the real international price of oil and oil technology evolve exogenously as follows:

$$p_{o,t}^* = \left(p_{o,t-1}^*\right)^{\rho_o} \; exp \left(\xi_t^{p_o^*}\right), \qquad A_{o,t} = (A_{o,t-1})^{\rho_{a_o}} \; exp \left(\xi_t^{A_o}\right) \tag{21}$$

As in Algozhina (2015), the oil firm is assumed to be jointly owned by foreign direct investors and the government. Thus, the oil firm's revenues are computed net of royalties, τ, levied by government as: $\Pi_{o,t} = (1 - \tau) \varepsilon_t p_{o,t}^* Y_{o,t}$.

2.3 Open Economy Features

We assume a law of one price gap such that importing firms have some power in the determination of the prices of their goods (Monacelli, 2005). Thus, the law of one price gap, Ψ_t, is given by:

$$\Psi_t = \frac{\varepsilon_t P_t^*}{P_{f,t}} \tag{22}$$

where P_t^* is the aggregate consumer price index of the foreign economy and ε_t is the nominal exchange rate. As in Gali and Monacelli (2005), the real exchange rate, q_t, is defined as follows:

$$q_t = \frac{\varepsilon_t P_t^*}{P_t} \tag{23}$$

Invoking the definition of the real exchange rate in equation (23), we can rewrite equation (22) as follows:

$$\Psi_t = \frac{q_t}{p_{f,t}} \tag{24}$$

where $p_{f,t} = \frac{P_{f,t}}{P_t}$.[13] Finally, the terms of trade, S_t, are given by:

$$S_t = \frac{P_{f,t}}{P_{h,t}} \tag{25}$$

Finally, we link consumption in the domestic economy to the rest of the world, as in Gali and Monacelli (2005), via the international risk sharing equation:

$$C_t - \phi_c C_{t-1} = \varrho q_t^{\frac{1}{\sigma}} \left(C_t^* - \phi_c C_{t-1}^* \right) \tag{26}$$

where ϱ represents a constant that depends on the relative initial conditions in asset holdings.

2.4 Fiscal Policy

Each period, the government receives oil revenues, OR_t, lump-sum tax, TX_t, and has one period bonds that result in a net-debt position, B_t. These revenues are used to finance government consumption expenditures, $G_{c,t}$; service debt; and make subsidy payments, OS_t. Thus, the government's budget constraint is:

$$TX_t + OR_t + B_t = P_{g,t} G_{c,t} + OS_t + \frac{B_{t+1}}{R_t} \tag{27}$$

As in Medina and Soto (2007), we assume that government consumption comprises

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[13]Except otherwise stated, variables in small letters are in real terms, deflated by the aggregate consumer price index, Pt.

imported and domestically produced goods. The amount of fuel consumption sub-
sidy, OS_t, is derived following Allegret and Benkhodja (2015). Due to low domestic
refining capacity, the government imports refined oil,O_t, produced abroad into the
small open economy at an expected open market price (EOMP), $P_{lo,t}$. The imported
fuel is subsequently sold to domestic consumers at a regulated price, $P_{ro,t}$, based on
the following rule:

$$P_{ro,t} = P_{ro,t-1}^{1-\nu} P_{lo,t}^{\nu} \tag{28}$$

where the EOMP expressed in domestic currency, $P_{lo,t}$, is given by:[14]

$$P_{lo,t} = \varepsilon_t \frac{P_{o,t}^*}{P_t^*} \Psi_t^o \tag{29}$$

where Ψ_t^o captures the inefficiencies associated with domestic fuel pricing in the
emerging economy. The parameter $0 < \nu \leq 1$ governs the level of rigidity in the do-
mestic fuel price and the extent to which the government subsidizes fuel consump-
tion. In equation (28), the value $\nu = 0$ implies zero pass-through effect of international
oil price to retail price of fuel (full subsidy regime) while $\nu = 1$ implies the complete
absence of fuel subsidies (zero subsidy regime). The amount of fuel subsidy pay-
ment made by the government is determined by the gap between the regulated price
of fuel and the EOMP, multiplied by the level of fuel consumption per period, O_t, as
follows[15]:

$$OS_t = (P_{lo,t} - P_{ro,t})O_t \tag{30}$$

where O_t comprises fuel consumption by households and domestic firms. Oil earn-
ings accruing to government are given by:

$$OR_t = \tau \varepsilon_t p_{o,t}^* Y_{o,t} \tag{31}$$

where τ is the royalty rate on oil production quantity. We consider backward looking

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[14]For a similar specification, see Poghosyan and Beidas-Strom (2011).

[15]This definition is consistent with the price gap approach of Coady et al. (2019) for the
estimation of pre-tax fuel subsidies.

fiscal policy rules that allow government consumption and taxes to respond to lagged debt and output (Muscatelli & Tirelli, 2005; Cebi, 2012). In addition, we allow taxes and government consumption to respond to oil revenues and fuel subsidy payments. Thus, our linearised benchmark fiscal policy rules are specified as follows[16]:

$$\tilde{g}_{c,t} = \rho_g \tilde{g}_{c,t-1} + \left(1 - \rho_g\right)\left[\omega_b \tilde{b}_{t-1} + \omega_{gy} \tilde{y}_{t-1} - \omega_{os} \widetilde{os}_t + \omega_{or} \widetilde{or}_t\right] + \xi_t^{G_c} \qquad (32)$$

$$\widetilde{tx}_t = \rho_{tx} \widetilde{tx}_{t-1} + (1 - \rho_{tx})\left[\varphi_b \tilde{b}_{t-1} + \varphi_y \tilde{y}_{t-1} - \varphi_{os} \widetilde{os}_t + \varphi_{or} \widetilde{or}_t\right] + \xi_t^{\tau} \qquad (33)$$

where the parameters ρ_g and ρ_{tx} represent the degree of smoothing in government spending and taxes, respectively. The parameters ω_b, ω_{gy}, ω_{os} and ω_{or} are the feedback coefficients with respect to lagged domestic debt, lagged output, oil subsidy payments and oil revenues, respectively. In equation (33), taxes respond to lagged debt, lagged output, oil subsidy payments and oil revenues with feedback parameters φ_b, φ_y, φ_{os} and φ_{or}, respectively. Tax shock and government spending shock are represented by ξ_t^{tx} and $\xi_t^{G_c}$, respectively.

2.5 Monetary Policy

The central bank follows a simple Taylor rule in setting the short-term nominal interest rate by responding gradually to domestic output, $y_{h,t}$; real exchange rate, q_t, and a measure of inflation. In this paper, we consider four Taylor rule variants according to the measure of inflation that is of interest to the central bank. These monetary rules are shown in Table 1. The parameter ρ_r captures interest rate smoothing, while the weights on domestic output and real exchange rate are represented by ω_y and ω_q, respectively. The parameter $\omega_{\pi,k}$ captures the level of monetary policy reaction to inflation, where $k \in (h, c, d, p)$.[17]

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[16]Variables with tildes represent log-deviations from their steady state values

[17]The letters h, c, d, and p represent headline inflation, core inflation, domestic inflation, and product price, respectively.

Table 1: Monetary policy rules

Model	Rule	Specification
$M1$	HITR	$\tilde{R}_t = \rho_r \tilde{R}_{t-1} + (1-\rho_r)\left[\omega_{\pi,h}\widetilde{\pi}_t + \omega_y \tilde{y}_{h,t} + \omega_q \tilde{q}_t\right]$
$M2$	CITR	$\tilde{R}_t = \rho_r \tilde{R}_{t-1} + (1-\rho_r)\left[\omega_{\pi,c}\widetilde{\pi}_{no,t} + \omega_y \tilde{y}_{h,t} + \omega_q \tilde{q}_t\right]$
$M3$	DITR	$\tilde{R}_t = \rho_r \tilde{R}_{t-1} + (1-\rho_r)\left[\omega_{\pi,d}\widetilde{\pi}_{h,t} + \omega_y \tilde{y}_{h,t} + \omega_q \tilde{q}_t\right]$
$M4$	PPTR	$\tilde{R}_t = \rho_r \tilde{R}_{t-1} + (1-\rho_r)\left[\omega_{\pi,p}\left((1-\Theta_o)\widetilde{\pi}_{h,t} + \Theta_o\widetilde{\pi}_{o,t}\right) + \omega_y \tilde{y}_{h,t} + \omega_q \tilde{q}_t\right]$

The headline inflation monetary rule, HITR, assumed under model $M1$ represents a
flexible Taylor rule where the central bank responds to headline inflation, domestic
output and the real exchange rate. In addition, under model $M2$, we consider the
core inflation monetary rule, CITR, where the monetary authority responds to core
instead of headline inflation. For oil-exporting economies whose headline inflation
measure features oil, it is a natural exercise to evaluate the stabilisation roles of Taylor
rules that are based on headline and core measures of inflation. Under the DITR, the
relevant measure of inflation for the central bank's interest rate decision is domestic
inflation. Finally, model $M4$ considers a variant of the Taylor rule that incorporates
commodity price under the product price targeting rule, PPTR, as in Frankel (2003)
and Frankel and Catao (2011).[18] The weights Θ_o and $1 - \Theta_o$ represent the respective
shares of oil and nonoil goods in the aggregate GDP. To characterise monetary policy
behaviour in the resource-rich emerging economy, we fit the four models to Nigerian
data and select the rule that yields the highest likelihood value.

2.6 Market Clearing and Aggregation

The aggregate *GDP*, Y_t comprises domestically produced goods used up in consump-
tion and production process ($C_{h,t} + M_t$), investment, government consumption, and
net exports, NX_t, as follows:

$$P_t Y_t = P_{h,t} Y_{h,t} + \varepsilon_t P_{o,t}^* Y_{o,t} + IM_t \tag{34a}$$

$$P_{h,t} Y_{h,t} + \varepsilon_t P_{o,t}^* Y_{o,t} + IM_t = P_{h,t} C_{h,t} + P_{h,t} M_t + P_{h,t} I_{h,t} + P_{h,t} G_{h,t} + NX_t \tag{34b}$$

Aggregate exports, EX_t, comprise oil exports ($EX_{o,t}$ measured as $\varepsilon_t P_{o,t}^* Y_{o,t}$) and
nonoil exports $EX_{no,t}$ is measured as $\varepsilon_t P_{h,t}^* C_{h,t}^*$). Similarly, aggregate imports, IM_t,

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[18]A similar rule has been implemented by Algozhina (2015) for the oil-producing econ-
omy of Kazakhstan.

comprise oil imports ($IM_{o,t}$ measured as $P_{lo,t}O_t$) and non-oil imports ($IM_{no,t}$ measured as $P_{f,t}Y_{f,t}$), where the quantity of non-oil goods imported into the economy is given by $Y_{f,t} = C_{f,t} + I_{f,t} + G_{f,t}$. Thus, $NX_t = EX_t - IM_t$. The balance of payments equation is obtained by setting the current and financial accounts equal as follows:

$$\frac{q_t b_t^*}{R_t^*} = q_t b_{t-1}^* + nx_t - (1-\tau)q_t p_{o,t}^* y_{o,t} + q_t fdi_t^* \tag{35}$$

2.7 Rest of the World

The oil-producing economy is insignificant relative to the foreign economy. Thus, activities in the foreign economy are taken as exogenous and modelled as follows:

$$C_t^* = \left(C_{t-1}^*\right)^{\rho \pi^*} exp\left(\xi_t^{c^*}\right) \tag{36}$$

$$\pi_t^* = \left(\pi_{t-1}^*\right)^{\rho \pi^*} exp\left(\xi_t^{\pi^*}\right) \tag{37}$$

$$R_t^* = \left(R_{t-1}^*\right)^{\rho \pi^*} exp\left(\xi_t^{r^*}\right) \tag{38}$$

Overall, the small open economy is driven by twelve stochastic shocks relating to real international oil price ($\xi_t^{p_o^*}$), oil sector productivity ($\xi_t^{a_o}$), law of one price gap for oil ($\xi_t^{\psi^o}$), domestic total factor productivity ($\xi_t^{a_h}$), domestic monetary policy (ξ_t^r), government consumption ($\xi_t^{G_c}$), tax (ξ_t^{tx}), domestic risk premium (ξ_t^{μ}), domestic output ($\xi_t^{\pi_h}$), foreign monetary policy ($\xi_t^{r^*}$), foreign inflation ($\xi_t^{\pi^*}$), and foreign consumption ($\xi_t^{c^*}$).

3. Model Estimation

We estimate the model using Bayesian techniques.[19] This estimation strategy allows us to combine the robust micro foundations in our model that are useful for policy analysis with an intuitive probabilistic distribution of the observable variables (Smets & Wouters, 2007). The model is estimated using Nigerian data for eleven macroeconomic variables spanning the period 2000Q2 - 2019Q4.[20] These comprise seven domestic variables for the small open economy ($y_t, c_t, i_{no,t}, q_t, \pi_t, \pi_{no,t}, r_t$), three foreign variables (y_t^*, π_t^*, r_t^*), and the international price of oil ($p_{o,t}^*$). The choice of

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[19]See An and Schorfheide (2007) for a detailed description of this technique.

[20]The decision regarding the estimation period is based on data availability.

the observable variables is guided by data availability as well as the need to properly identify certain structural and policy parameters that are of specific interest to our empirical investigation. The foreign economy variables are constructed based on data for Nigeria's key trading partners, which are the Euro area, United States, and India.[21] Our sources for the data on domestic observable variables are the Central Bank of Nigeria (CBN) and National Bureau of Statistics (NBS). Datasets on the foreign variables are retrieved from the International Monetary Fund (IMF) and Federal Reserve Bank of St. Louis (FRED) databases.

Table 2: Calibrated parameters

Description	Value	Source
Discount factor, β	0.990	Iklaga (2017)
Depreciation rate, δ_h	0.025	Iklaga (2017)
Imports share in consumption goods, γ_c	0.400	Gali and Monacelli (2005)
Fuel share in household consumption, γ_o	0.085	Omotosho (2019a)
Imports share in investment goods, γ_i	0.200	Omotosho (2019a)
Calvo parameter for wages, θ_w	0.750	Medina and Soto (2007)
Capital input elasticity of domestic output, α_h^k	0.330	Rasaki and Malikane (2015)
Oil input elasticity of domestic output, α_h^o	0.120	Omotosho (2019b)
Labour input elasticity of domestic output, α_h^n	0.550	Ncube and Balma (2017)
Elasticity of capital input in oil production, α_o^k	0.700	Omotosho (2019b)
Elasticity of materials input in oil production, α_o^m	0.300	Omotosho (2019b)
Substitution elasticity in govt. consumption, η_g	0.600	Hollander et al. (2018)
Household share in fuel imports, γ_{co}	0.750	Omotosho (2019b)
Foreign direct investment persistence, ρ_{fdi}	0.300	Algozhina (2015)
Calvo parameter for exports, θ_{hf}	0.750	Medina and Soto (2007)

3.2 Calibration

Table 2 shows the values of the calibrated parameters, which are kept constant in the estimation process. Some of the parameters are based on standard values assumed in the literature for small open economies, as in Gali and Monacelli (2005). Additionally, we take values from studies for resource-rich emerging economies such as Medina and Soto (2007), Iklaga (2017), Algozhina (2015), and Omotosho (2019), while the others are parametrized based on sample data for the Nigerian economy. The parametrization is performed to fit quarterly data.

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[21]Based on trade data for the period 2000 - 2018, 65 per cent of Nigeria's total external
trade is accounted for by these regions.

3.3 Prior Distribution

The priors for the estimated parameters are reported in Table 4. The prior values are chosen based on calibration and the data and partly based on previous studies for Nigeria, such as Iklaga (2017) and Omotosho (2019). Where we have limited information to form credible priors for certain parameters, less informative priors are adopted to allow the data to determine the location of such parameters.

4. Results

4.1 Model Comparison

Table 3 presents the log-likelihood values as well as the computed posterior model odds for the four model variants described in Section 2.5. The results show that of the competing models, the model with the headline inflation-based Taylor rule, $M1$, fits the data best. The log data density obtained based on 500,000 draws from the Metropolis Hastings sampling procedure for the model, $M1$, is 563.34, while the associated posterior model probability is 0.91. This implies that, in terms of policy indexation, the Central Bank of Nigeria responds to an aggregate measure of inflation that combines both core and oil measures of inflation during the sample period. In addition, monetary policy in the resource-rich economy responds to domestic output and the real exchange rate.

Table 3: Log data density and posterior model probability

	$M1$	$M2$	$M3$	$M4$
Log data density	563.34	561.04	543.51	529.82
Posterior model probability	0.9097	0.0903	0.0000	0.0000

Table 4 presents the results of the Bayesian estimation of the selected model, $M1$. The multivariate convergence diagnostic of Brooks and Gelman (1998) shown in Figure 4 indicates that the convergence condition for the estimated model is satisfied. The parameter in the domestic fuel pricing rule, v, is estimated at 0.45, which is higher than the value of 0.43 obtained by Omotosho (2019) and 0.3 applied by Allegret and Benkhodja (2015) for the Algerian economy. This implies that approximately 45 percent of changes in global oil price are transmitted to the retail fuel price. In this paper, we argue that a proper analysis of monetary policy in oil-producing emerging economies with a subsidy regime requires an understanding of the size of

the pass-through effects of international oil prices on the retail price of fuel. This is because the oil price pass-through parameter governs the level of domestic price distortion introduced by the subsidy regime. The fuel pricing rule for the oil-producing economy is as follows:

$$\tilde{p}_{ro,t} = 0.55\, \tilde{p}_{ro,t-1} + 0.45\, \tilde{p}_{lo,t}. \tag{39}$$

Thus, our counterfactual simulations regarding the implications of fuel subsidy reforms for the conduct of monetary policy in the resource-rich economy are based on alternative assumptions with respect to the pass-through coefficient in the fuel pricing rule. The Bayesian estimate for the share of Ricardian consumers, γ_R, is 0.68, which is slightly higher than the 0.62 obtained by Iklaga (2017) for the period 2002:3-2015:4. The relative risk aversion parameter is estimated at $\sigma = 1.37$, lower than 2.0 initially assumed but higher than 1.07 obtained by Iklaga (2017).

The elasticity of substitution between oil and core goods consumed by households (η_o) is estimated at 0.19. This is in line with the estimates reported for South Africa by Hollander *et al.* (2018). The estimated elasticity of substitution between home and foreign goods in the core consumption basket of the household ($\eta_c = 0.61$) is slightly higher than the value of 0.59 obtained by Hollander *et al.* (2018) for the South African economy. Additionally, the household's elasticity of intra-temporal substitution between domestically produced and imported investment goods (η_i) is 0.62.

The estimated Calvo price parameter for domestically produced goods, $\theta_h = 0.71$, is higher than the 0.63 reported by Iklaga (2017),[22] while that of the imported goods, θ_f, is estimated at 0.69. This implies that the prices of domestically produced goods are stickier than those of imported goods, contrary to the findings by Hollander *et al.* (2018) for the South African economy. The estimated Taylor rule suggests that the monetary authority responds actively to headline inflation, as the associated feedback coefficient is estimated at $\omega_\pi = 2.89$, which is higher than the 1.50 obtained by Iklaga (2017) and the 2.86 estimated by Omotosho (2019).

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[22]It is important to state that Iklaga (2017) did not account for domestic fuel price rigidity and the implied subsidy regime in Nigeria.

Table 4: Prior and posterior estimates

Parameter	Prior distribution			Posterior distribution		
	Shape	Mean	St. dev.	Mean	90% HPD Int.	
Ricardian consumers:γ_R	B	0.6	0.1	0.678	0.240	0.636
Labour supply elasticity:φ	G	1.45	0.1	1.445	1.285	1.608
Relative risk aversion:σ	IG	2	0.4	1.369	1.100	1.637
External habit:ϕ_c	B	0.7	0.01	0.695	0.679	0.711
Fuel pricing parameter:	B	0.3	0.1	0.448	0.240	0.636
Oil - core cons. elasticity:η_o	G	0.2	0.1	0.186	0.045	0.324
For. - dom. cons. elasticity:η_c	G	0.6	0.2	0.616	0.280	0.936
For. - dom. inv. elasticity:η_i	G	0.6	0.2	0.621	0.295	0.940
Calvo - domestic prices:θ_h	B	0.7	0.1	0.713	0.622	0.816
Calvo - import prices:θ_f	B	0.7	0.1	0.686	0.521	0.859
Taylor,$\pi : \omega_\pi$	G	1.5	0.2	2.892	2.639	3.141
Taylor,$y : \omega_y$	G	0.125	0.05	0.097	0.034	0.157
Taylor,$q : \omega_q$	G	0.125	0.05	0.102	0.037	0.164
Taylor, smoothing:ρ_r	B	0.5	0.25	0.214	0.043	0.365
Fiscal,$y : \omega_{gy}$	N	0.4	0.5	0.374	-0.440	1.220
Fiscal,$os : \omega_{os}$	N	0.8	1	1.406	-0.420	3.193
Fiscal,$b : \omega_b$	N	0.3	0.5	0.296	-0.455	1.024
Fiscal, or:ω_{or}	N	0.8	1	0.579	-1.000	2.136
Fiscal smoothing,$g_c : \rho_{gc}$	B	0.5	0.25	0.43	0.036	0.808
Tax, y:φ_y	N	0.95	0.5	0.928	0.119	1.757
Tax, os:φ_{os}	N	0.1	0.5	0.091	-0.724	0.917
Tax, b:φ_b	N	0.4	0.5	0.388	-0.437	1.216
Tax, or:φ_{or}	N	0.3	0.5	0.314	-0.526	1.131
Tax smoothing,$tx : \rho_{tx}$	B	0.5	0.25	0.502	0.094	0.900
TFP persistence:ρ_{a_h}	B	0.5	0.25	0.79	0.592	0.984
Oil productivity persistence:ρ_{a_0}	B	0.5	0.25	0.504	0.109	0.915
Risk premium persistence: ρ_μ	B	0.5	0.25	0.745	0.653	0.841
Oil LOP gap persistence:ρ_{ψ^o}	B	0.5	0.25	0.689	0.396	0.996
Oil price shock persistence:$\rho_{p_o^*}$	B	0.5	0.25	0.92	0.862	0.986
TFP shock:$\xi_t^{a_h}$	IG	0.1	4	0.23	0.046	0.376
Oil productivity shock:$\xi_t^{a_o}$	IG	0.1	4	0.073	0.025	0.128
Risk premium shock:ξ_t^{μ}	IG	0.1	4	0.169	0.137	0.198
Fiscal policy shock:$\xi_t^{g_c}$	IG	0.1	4	0.095	0.023	0.189
Tax shock:ξ_t^{tx}	IG	0.1	4	0.103	0.022	0.204
Oil LOP gap shock:$\xi_t^{\psi^o}$	IG	0.1	4	0.823	0.464	1.242
Dom. monetary policy shock:ξ_t^r	IG	0.1	4	0.382	0.304	0.460
Int'l oil price shock:$\xi_t^{p_o^*}$	IG	0.1	4	0.151	0.130	0.172

The prior distributions are abbreviated as follows: B: Beta; G: Gamma; IG: Inverse Gamma; N: Normal. The Bayesian estimates reported are based on 500,000 draws each from two parallel chains of the random walk Metropolis-Hastings after discarding the first 30 per cent of the draws as burn-in.

Furthermore, the estimated reaction coefficient on the exchange rate, ω_q, is 0.1, which is higher than the 0.005 estimated by Iklaga (2017) and the same as the estimate by Omotosho (2019). The estimated interest rate smoothing parameter is $\rho_r = 0.21$, which is quite low but in line with the value reported by Richard and Olofin (2013) for Nigeria over the period 1986-2004 and 0.26 obtained by Medina and Soto (2005) for the resource-rich economy of Chile. Thus, the estimated monetary policy rule is as follows:

$$\tilde{R}_t = 0.214\tilde{R}_{t-1} + 2.273\widetilde{\pi}_t + 0.076\tilde{y}_{h,t} + 0.080\tilde{q}_t \tag{40}$$

Equation (40) indicates that the small open resource-rich economy places a slightly higher weight on the exchange rate than on domestic output, reflecting the desire of the monetary authority to contain undue inflationary pressures emanating from exchange rate instabilities in the face of an oil price shock. The posterior mean of the feedback parameter with respect to output in the government spending rule, ω_{gy}, is estimated at 0.37, suggestive of procyclicality in government spending. Additionally, the parameter for the response of taxes to output is estimated at 0.93, which is slightly lower than the assumed prior of 0.95. Most of the shock processes are more persistent than assumed, with the international oil price shock being most persistent ($\rho_{p_o^*} = 0.92$).

4.3 Impulse Responses to an Oil Price Shock

Figure 1 shows the dynamic responses of selected macroeconomic variables to a negative oil price shock under the four alternative monetary policy rules specified in Table 1. Following a decline in oil prices, oil firms become less profitable, leading to a reduction in oil firms' demand for materials sourced from the domestic economy and a decline in oil output, as implied by equation (18). In view of the size of the oil sector (26% of GDP) as well as the impacts of oil price declines on government consumption, aggregate GDP falls, and the effect is quite persistent. However, private consumption rises as more income becomes available to households following a negative oil price shock - oil constitutes part of the consumption basket of the household in our model, implying that a decline in oil price generates income effects that release more resources to households to spend.

A negative oil price shock causes the non-oil sector to become relatively more attractive as more productive resources are directed from the oil to the non-oil sector. The inflow of productive resources into the non-oil sector as well as the increased private consumption due to the income effect from lower oil prices and reduced marginal costs lead to an increase in non-oil GDP. However, the increase in non-oil output is initially suppressed due to the reduced demand for non-oil goods by the oil sector and the substitution effect that reduces households' demand for home and foreign goods in favour of oil.

Since the price of fuel features the real marginal cost of domestic firms shown in equation (13), a negative oil price shock generates a lower marginal cost and leads to a fall in domestic inflation. However, the instrumentality of exchange rate pass-through causes import prices to rise following a depreciated exchange rate. The combined effects of a negative oil price shock on the prices of domestic and imported goods cause core inflation to increase. Thus, the increases in headline and core measures of inflation are induced by the depreciation in the exchange rate. The monetary authority responds to the initial exchange rate-induced rise in headline inflation by embarking on an interest rate hike, a move that further exacerbates the contractionary effects of the negative oil price shock on the aggregate GDP. In summary, a 1.0 percent negative international oil price shock contract aggregates GDP, reduces domestic inflation, depreciates the real exchange rate, and increases headline as well as core measures of inflation. Consequently, the central bank increases the interest rate in line with its inflation objective.

These observed model dynamics are qualitatively similar under the headline, core and domestic inflation-based policy rules, with only one exception. The exception relates to the response of the interest rate, which requires an interest rate cut under the DITR but a hike under the HITR and CITR. Additionally, with the exception of the outcomes recorded under an export price-based Taylor rule, a negative international oil price shock yields highly persistent contractionary effects on total GDP, lasting over 40 quarters. The core inflation-based Taylor rule performs better than its competitors in taming headline inflation and moderating the level of exchange rate depreciation. Our results suggest that the PPTR, which features the prices of domestic goods and the export price of oil, reverses the contractionary effects of the oil price shock recorded under the other rules.
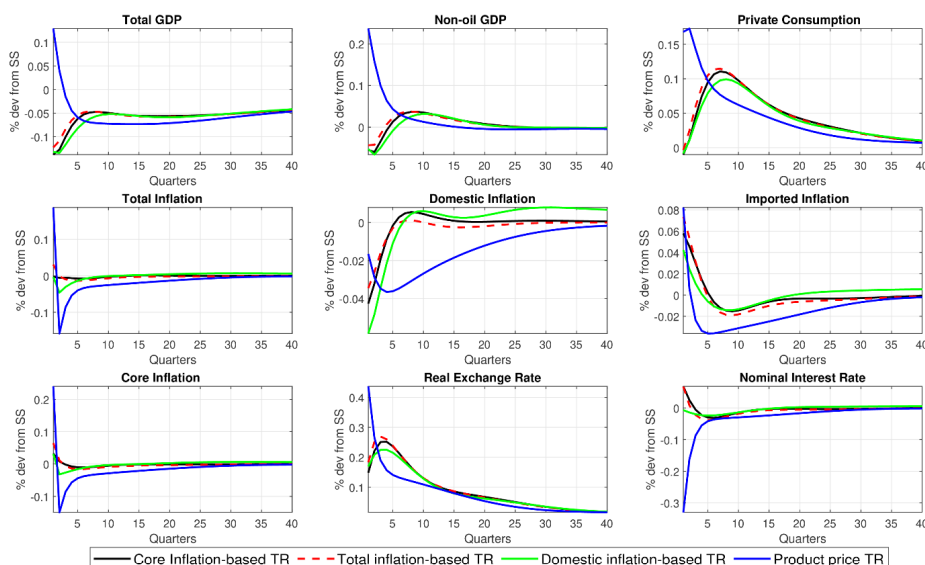
Figure 1: Estimated impulse responses to a negative international oil price shock under
alternative monetary policy rules.

It, however, amplifies the initial increase in headline inflation due to a more depreci-
ated real exchange rate and a higher exchange rate pass-through into inflation (Figure
1). In other words, the exchange rate effectively provides a buffer against adverse
terms of trade shocks under the export-price-based policy rule, thus minimising the
associated negative output effect through expenditure switching effects.

4.4 Ranking of Alternative Monetary Policy Rules

In the previous section, we found that the CBN follows the headline inflation mone-
tary rule in the achievement of its stabilisation objectives. Is such a monetary policy
strategy appropriate for an oil-producing emerging economy with a subsidy regime?
To address this question, the study evaluates the stabilising role of the alternative
monetary policy rules specified in Table 2 and conduct policy ranking based on a
measure of systemic stability represented by an intertemporal loss function of the
central bank.[23] This approach makes it possible for us to adjust the loss function
weights to accommodate diverse monetary policy arrangements often employed by
central banks around the world. Apart from its usefulness for characterising substan-

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[23]Woodford (2002) notes that welfare loss functions that are based on second-order
approximations to household utility yield similar approximations to those defined by a
central bank loss function.

tial macroeconomic fluctuations (Adolfson *et al.*, 2011), such as those often experienced by oil-producing low- and middle-income countries, the loss function appeals to us also because it has been shown to reflect the costs associated with the volatility of inflation (Clarida *et al.*, 1999). Thus, we assume a central bank loss function of the form:

$$Loss_t = \lambda_\pi \widetilde{\pi}_t^2 + \lambda_y \tilde{y}_{h,t}^2 + \lambda_q \tilde{q}_t^2 \tag{41}$$

where $\lambda_\pi \geq 0$, $\lambda_y \geq 0$ and $\lambda_q \geq 0$ are parameters representing the degree of the central bank's dislike for volatility in inflation, output, and real exchange rate, respectively. The first two terms in equation (41) represent the welfare costs associated with nominal and real fluctuations, while the third term stands for the costs associated with volatility in asset prices (Taylor & Williams, 2010). The problem facing the monetary authority involves choosing the monetary policy rule parameters shown in Table 2 to minimize equation (41), subject to the constraints implied by our model.

Table 5 reports macroeconomic fluctuations as well as the policy losses associated with the four alternative monetary policy rules under the model with fuel subsidies.[24] The standard deviations as well as the policy losses are expressed relative to the values for the HITR, which is the rule identified as characterising monetary policy behaviour in the resource-rich economy. Thus, values greater than unity indicate worse outcomes, while values less than unity indicate superior outcomes compared to the case under the HITR. In terms of price stabilisation, the core inflation-based Taylor rule is useful for stabilising both headline and core measures of inflation following a negative oil price shock. The HITR ranks second in stabilising headline inflation, followed by the PPTR and the DITR. However, in terms of domestic output stabilisation, the HITR yields superior outcomes compared to the other competing rules followed by the DITR. Thus, while the CITR represents a useful strategy for stabilising inflation, its headline inflation-based counterpart yields superior outcomes in terms of output stabilisation. While the PPTR is useful for stabilising interest rates, it generates a fairly elevated domestic macroeconomic instability, especially with regard to domestic output and headline inflation. These findings are consistent with the simulation results of Vogel *et al.*, (2015), which showed that pegging the export

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[24]The corresponding optimised simple rule parameters are reported in in panel (A) of   Table 12.

price comes at the cost of losing overall domestic stability.

Table 5: Macroeconomic fluctuations and losses under alternative monetary policy rules

	Standard Deviation (%)					Relative	Rank
	$\tilde{y}_{h,t}$	$\widetilde{\pi}_t$	$\widetilde{\pi}_{no,t}$	$\tilde{q}_t$	$\tilde{R}_t$	Policy Loss	
HITR	1.00	1.00	1.00	1.00	1.00	1.00	2
CITR	1.25	0.15	0.29	0.93	0.79	0.89	1
DITR	1.21	2.85	0.92	0.83	0.41	1.19	4
PPTR	1.38	1.55	0.68	0.87	0.13	1.14	3

In Table 5, we report policy losses associated with the alternative monetary policy rules. Lower values of the loss function correspond to higher welfare (Adolfson *et al.*, 2011). Thus, policies associated with lower policy loss values are ranked better compared to those with higher values. Our simulation results using the model with fuel subsidies indicate that, for the Nigerian economy, a core inflation-based monetary rule ranks best among its competitors. This implies that the optimal monetary policy indexation for the small open oil-producing economy with a subsidy regime is the CITR. By responding to core rather than headline inflation, the monetary authority is able to reduce policy loss by approximately 11% under our model setting. This is in line with the findings reported by Allegret and Benkhodja (2015) for the oil exporting economy of Algeria. The HITR and PPTR ranked second and third, respectively, while the worst performer was the DITR. These results are in contrast to the findings of Ferrero and Seneca (2019), which demonstrated that the domestic inflation-based Taylor rule is more welfare-enhancing in Norway. For an import-dependent oil-exporting emerging economy such as Nigeria, the exchange rate plays a vital role in driving inflation dynamics. Thus, an inflation measure that ignores the effects of the exchange rate may not represent an appropriate anchor for monetary policy design in such an economy.

4.5 Monetary Policy in the Absence of Fuel Subsidies

In this section, we rank the alternative monetary rules under a no-subsidy regime. To achieve this, we simulate an alternative economy under which there is a complete pass-through effect of international oil prices into the retail price of fuel by setting the pass-through coefficient to unity, $v = 1$. In Table 6, we report the macroeconomic fluctuations and policy losses associated with the alternative monetary policy rules. Since the CITR was identified as the optimal monetary rule under the model with

fuel subsidies, we report the values in Table 6 relative to the outcomes under that rule.[25]

Of the competing rules, the core inflation monetary rule yields the least policy loss following the removal of fossil fuel subsidies in the oil-producing economy (Table 6). This result aligns with Allegret and Benkhodja (2015) regarding the stabilising role of core inflation monetary rule in an oil-producing economy with a fuel subsidy regime and presents the first evidence regarding the efficacy of the rule in stabilising the economy even after the removal of fuel subsidies. In addition, our results reveal that the removal of fuel subsidies increases policy loss from 0.0159 to 0.0183 under the CITR (Appendix B), reflecting higher macroeconomic volatility. Given an oil price shock, the monetary authority is able to contain the increased macroeconomic volatility under a model without fuel subsidies by indexing monetary policy to core inflation and increasing the weights of exchange rate and domestic output in the Taylor rule (Appendix B).

Table 6: Macroeconomic fluctuations and losses under alternative monetary policy rules

	Standard Deviation (%)					Relative	Rank
	$\tilde{y}_{h,t}$	$\widetilde{\pi}_t$	$\widetilde{\pi}_{no,t}$	$\tilde{q}_t$	$\tilde{R}_t$	Policy Loss	
HITR	1.00	1.00	1.00	1.00	1.00	1.06	3
CITR	0.74	0.29	5.43	1.08	0.80	1.00	1
DITR	0.93	0.42	3.29	0.97	0.39	1.04	2
PPTR	0.98	0.38	3.36	0.97	0.27	1.07	4

Whereas the headline inflation monetary rule ranked second under the model with fuel subsidies, the DITR came second under the model without fuel subsidies followed by the HITR and lastly, the PPTR. It is important to also note that policy loss increases following fuel subsidy removal under models that feature headline and core inflation monetary rules, the opposite effect is recorded under the monetary rules that do not respond to a measure of inflation that includes energy prices (Appendix B).

The headline inflation monetary rule yields the best outcome in terms of stabilising domestic output, while the domestic inflation monetary rule stabilises the exchange rate with or without fuel subsidies. Additionally, as found under the model with fuel

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[25]The corresponding optimised simple rule parameters are reported in panel (B) of Table 12.

subsidies, the core inflation-based monetary policy rule yields superior outcomes in stabilising core inflation under the no-subsidy regime. While the core inflation monetary rule out-performs its headline inflation counterpart in stabilising aggregate inflation under the model with fuel subsidies, a monetary policy rule that features a broader measure of inflation (i.e., headline inflation monetary rule) yields superior outcomes under a no-subsidy regime. Thus, for a central bank whose sole mandate is price stability, the effectiveness of core inflation-based Taylor calls into question once there is a complete pass-through of global oil prices to retail fuel prices in the resource-rich economy. Our results confirm the policy trade-off confronting the central bank of a resource-rich economy facing an oil price shock, which was highlighted in Ferrero and Seneca (2019). In other words, the CBN faces a trade-off in the achievement of price and output stability following a negative shock to international oil prices. It is important that the CBN is aware of these policy trade-offs, while designing monetary policy strategies for responding to emerging shocks.

Table 7: Policy losses under varying levels of oil share in domestic production

	$\alpha_h^o = 0.1$	$\alpha_h^o = 0.2$	$\alpha_h^o = 0.4$	$\alpha_h^o = 0.5$
HITR	0.0169	0.0307	0.069	0.0891
CITR	0.0163	0.0296	0.0671	0.0869
DITR	0.0195	0.0315	0.0717	0.0929
PPTR	0.0170	0.0319	0.0730	0.1118
Policy choice	CITR	CITR	CITR	CITR

In the resource-rich economy, imported fuel is consumed by households and used up in the production process of nonoil domestic firms. Thus, the relative weight of fuel in household consumption and the degree of oil intensity of domestic production matter for the response of the economy to oil price shocks and may also alter the choice of monetary policy response. Next, we investigate whether these two features matter for the optimality of the core inflation monetary rule following the removal of fuel subsidies.

First, we adjust the parameters in the production function of domestic nonoil firms to allow for varying shares of oil while keeping other model parameters constant. Table 7 reports the policy loss associated with the different levels of oil intensity of domestic production under alternative monetary rules. The results show that (i) higher oil intensity of domestic production, which reflects inefficiency in energy use,

leads to increased policy loss under the four monetary rules considered, and (ii) our findings regarding the optimality of core inflation monetary rule remain valid under different levels of oil intensity of domestic production, as the CITR yields the lowest loss value across the board.

Table 8: Policy losses under varying levels of oil share in household consumption

	$\gamma_o = 0$	$\gamma_o = 0.05$	$\gamma_o = 0.10$	$\gamma_o = 0.15$	$\gamma_o = 0.20$
HITR	0.0217	0.0174	0.0217	0.0357	0.0560
CITR	0.0217	0.0165	0.0207	0.0360	0.0580
DITR	0.0308	0.0204	0.0206	0.0381	0.0574
PPTR	0.0320	0.0211	0.0204	0.0316	0.0564
Policy choice	CITR	CITR	PPTR	PPTR	HITR

Second, we vary the share of oil in household consumption from $\gamma_o = 0$ to $\gamma_o = 20$, allowing for an increment of 0.05 each step. We find that the share of oil in household consumption above 0.10 leads to higher policy loss and requires alternative monetary rules to achieve macroeconomic stability following an oil price shock. However, at values of γ_o lower than 0.1, the core inflation monetary rule retains its efficacy. These results imply that while our results regarding the stabilising roles of core inflation monetary rule are robust to varying levels of oil intensity in domestic production, they are sensitive to alternative assumptions regarding the relative share of oil in household consumption.

With a relatively high share of oil in consumption, the monetary authority achieves greater macroeconomic stability by targeting either product price or headline inflation rather than core inflation. Thus, we caution that while the CBN minimises its loss function by adopting the core inflation-based Taylor rule, no "across-the-board" and "all-times" monetary policy strategy exists for dealing with adverse terms of trade shocks in the resource-rich economy.

4.6 Robustness Analysis
In this section, we study the sensitivity of our results regarding the optimality of CITR for the resource-rich economy under alternative assumptions about the pass-through parameter in the fuel pricing rule as well as the weights in the central bank loss function. First, we simulate our model under different values of the domestic

fuel pricing rule parameter v while keeping the other model parameters constant. This exercise encapsulates different fuel subsidy arrangements, ranging from a no-subsidy regime ($v = 1$) to a high subsidy regime ($v = 0.1$), and the results are reported in Table 9.

Across the different levels of fossil fuel subsidization in the resource-rich economy, the core inflation monetary rule yields the lowest policy loss. Thus, our finding regarding the stabilising role of the core inflation monetary rule is robust to alternative assumptions about domestic fuel price stickiness implied under the different subsidy arrangements.

Next, we examine the sensitivity of the monetary policy analysis conducted under section 4.5 to changes in the loss function parameters specified in equation (41). To this end, we follow Laxton and Pesenti (2003) and assume different values for the loss function weights ranging from 0.5 to 2. We allow for step increments of 0.5 for each weight as in Hove *et al*., (2015). The respective weights on inflation, output and interest rate volatilities are λ_π, λ_y and λ_r. Thus, different configurations of these weights characterise the preferences of the central bank with regard to its monetary stabilization objectives. Table 10 reports the policy loss for the different monetary rules under the model with fuel subsidies ($v = 0.448$) and without fuel subsidies ($v = 1$). The first row reports our benchmark parameter configuration, while the second row reports a situation where the monetary authority places equal weights on domestic output and exchange rate in its loss function. In the next three rows, higher weights are placed on domestic output relative to the weights on exchange rate. In the last three rows, higher weights are placed on exchange rate relative to domestic output.

We document a number of interesting results. First, the core inflation monetary rule yields the least policy loss regardless of the parameter configuration in the central bank loss function. This is true for both the model with and out with fuel subsidies. Second, lower policy losses are recorded under parameter settings that place higher weights on domestic output relative to the exchange rate. In other words, given an oil price shock, the monetary authority of the oil-producing economy achieves higher macroeconomic stability by focusing on inflation stabilisation and giving higher priority to domestic output than the exchange rate in its loss function.

Table 9: Policy loss under different values of the domestic fuel pricing rule parameter

Subsidy stance	HITR	CITR	DITR	PPTR	Policy choice
$v = 0.1$	0.0192	0.0186	0.0244	0.0252	CITR
$v = 0.2$	0.0182	0.0177	0.0228	0.0233	CITR
$v = 0.3$	0.0179	0.0167	0.0213	0.0220	CITR
$v = 0.4$	0.0179	0.0161	0.0271	0.0210	CITR
$v = 0.5$	0.0180	0.0159	0.0197	0.0203	CITR
$v = 0.6$	0.0181	0.0159	0.0189	0.0197	CITR
$v = 0.7$	0.0183	0.0162	0.0189	0.0194	CITR
$v = 0.8$	0.0186	0.0166	0.0188	0.0192	CITR
$v = 0.9$	0.0190	0.0174	0.0188	0.0193	CITR
$v = 1.0$	0.0194	0.0183	0.0191	0.0195	CITR

Table 10: Sensitivity analysis of loss function weights under models with fuel subsidies

Weights			Model with subsidy ($v = 0.448$)				Model without subsidy ($v = 1$)			
λ_π	λ_y	λ_q	HITR	CITR	DITR	PPTR	HITR	CITR	DITR	PPTR
1.0	0.5	0.2	0.0179	0.0159	0.0213	0.0206	0.0194	0.0183	0.0191	0.0195
1.0	0.5	0.5	0.0304	0.0253	0.0296	0.0302	0.0397	0.0318	0.0345	0.0349
1.0	1.0	0.5	0.0377	0.0346	0.0405	0.0415	0.0447	0.0386	0.0424	0.0432
1.0	1.5	0.5	0.0445	0.0434	0.0493	0.0510	0.0493	0.0447	0.0490	0.0502
1.0	2.0	0.5	0.0510	0.0493	0.0566	0.0591	0.0537	0.0517	0.0546	0.0564
1.0	0.5	1.0	0.0436	0.0407	0.0423	0.0427	0.0666	0.0538	0.0542	0.0544
1.0	0.5	1.5	0.0590	0.0510	0.0526	0.0528	0.0942	0.0688	0.0693	0.0693
1.0	0.5	2.0	0.0740	0.0625	0.0615	0.0615	0.0818	0.0858	0.0816	0.0817

5. Summary and Conclusion

We build a small open economy DSGE model suitable for analysing monetary policy response to oil price shocks in oil-producing emerging economies with a fuel subsidy regime. The model accommodates standard Taylor-type monetary rules as well as fiscal rules that account for oil-related flows. The estimated model is employed to characterise monetary policy behaviour in the small open resource-rich economy and conduct simulations regarding the stabilising role of alternative monetary rules under different fuel subsidy arrangements.

We estimate that approximately 45% of changes to international oil prices are transmitted into domestic fuel prices and find that, under such a setting, the monetary authority of the resource-rich economy targets headline inflation. While this rule is useful for stabilising output, it performs poorly in stabilising prices and exchange

rates. Our counterfactual simulations reveal that policy loss can be reduced by approximately 11% if the monetary authority responds to core inflation rather than an aggregate measure of inflation that includes energy prices. This is consistent with the findings reported by Allegret and Benkhodja (2015).

Furthermore, we find that in the aftermath of a subsidy reform, the core inflation monetary rule remains a superior strategy to other rules in reducing policy loss. This finding is robust to varying degrees of oil intensity in domestic production, alternative weights in the central bank loss function, and a continuum of subsidy arrangements that exists between the two extremes of a full subsidy regime and a no-subsidy regime. However, under a model with a relatively high share of oil in total consumption, responding to inflation measures that encompass energy prices become more efficacious than the core inflation monetary rule.

While this paper represents the first attempt at studying monetary rules for an oil-producing emerging economy under different subsidy arrangements, an aspect we have not explored relates to the sensitivity of our results to alternative fiscal rules. Using our model for such an exercise allows for a more comprehensive assessment of the fiscal implications of fuel subsidies as well as the revenue substitution phenomenon highlighted in Tijerina-Guajardo and Pagán (2003) and Salti (2008). Revenue substitution potentially complicates the automatic stabiliser's role of fiscal policy in resource-rich emerging economies and ultimately affects monetary policy. In addition, studies such as Arezki *et al.*, (2012) have argued that when a relatively high share of the population of an emerging economy is credit constrained, the headline inflation monetary rule outperforms its core inflation counterpart. Testing this claim under a resource-rich economy with a fuel subsidy regime would be an interesting exercise for future research.

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Appendix A: Oil and the Nigerian economy, 1980 - 2018

Indicators (%)	1980-1989	1990-1999	2000-2009	2010-2018
Share of oil in GDP	31.23	31.99	24.07	11.21
Share of oil in govt. revenue	70.19	77.11	79.85	64.77
Share of oil in total exports	95.14	97.35	96.97	93.05
Share of fuel in total imports	8.39	20.12	21.3	24.41
Oil refining capacity utilisation	-	40.78	28.68	15.97

Appendix B: Optimized simple rule parameters

| Parameters	ρ_r	ω_π	ω_y	ω_q	Policy loss
(A) Model with fuel consumption subsidy					
HITR	0.2128	2.9056	0.0787	-0.0042	0.0179
CITR	0.2083	2.9012	0.0995	-0.0183	0.0159
DITR	0.9881	3.5268	6.8377	-0.0792	0.0214
PPTR	0.9811	2.7796	0.1786	-0.0542	0.0206
(B) Model without fuel consumption subsidy					
HITR	0.2156	2.9058	0.0854	-0.0251	0.0194
CITR	0.2132	2.8998	0.1029	-0.0254	0.0183
DITR	0.9313	2.8563	-0.0556	-0.0147	0.0191
PPTR	0.9758	2.7974	0.2085	-0.0577	0.0195
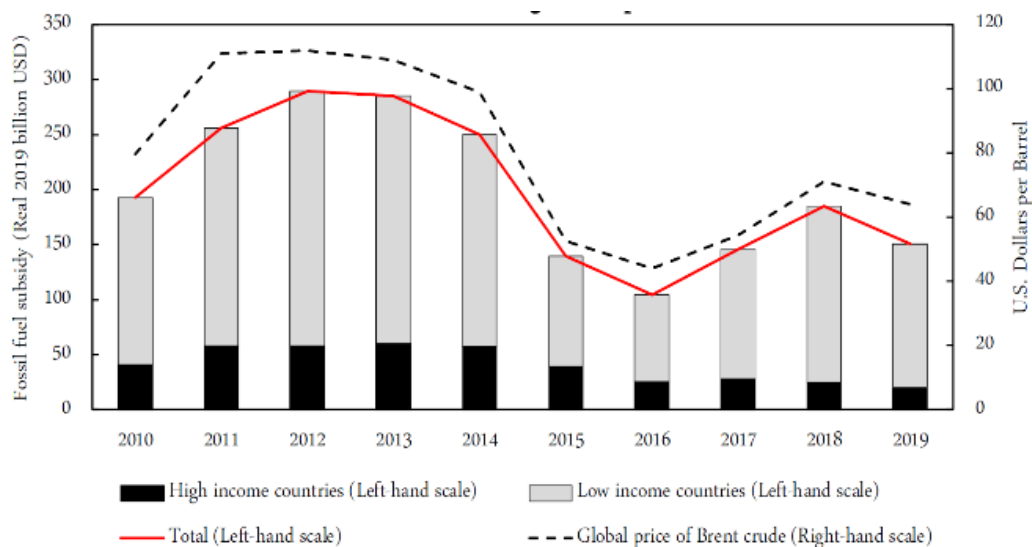
Figure 2: 2019 dollar value of fossil fuel subsidies (total, high-income countries, low-income countries) and global price of Brent crude.
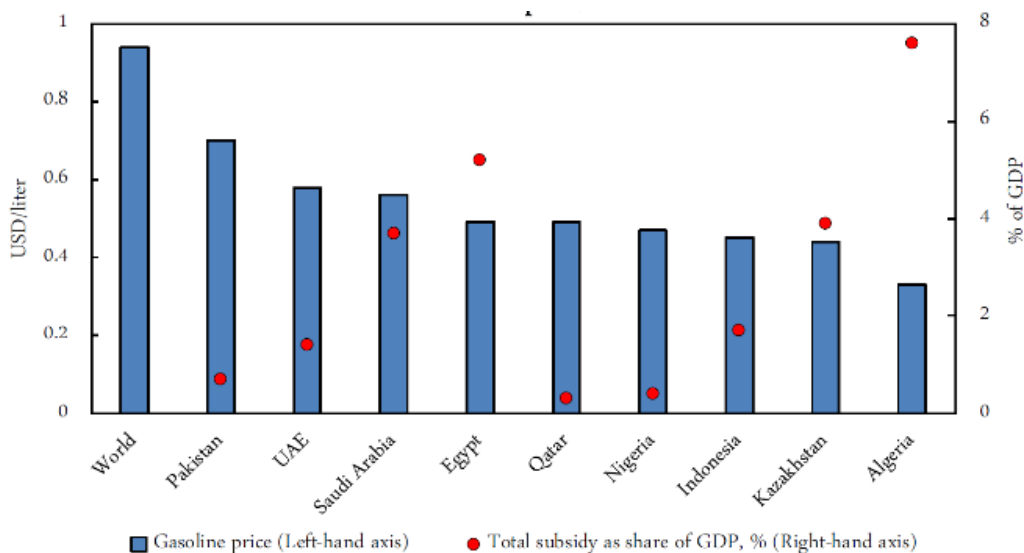

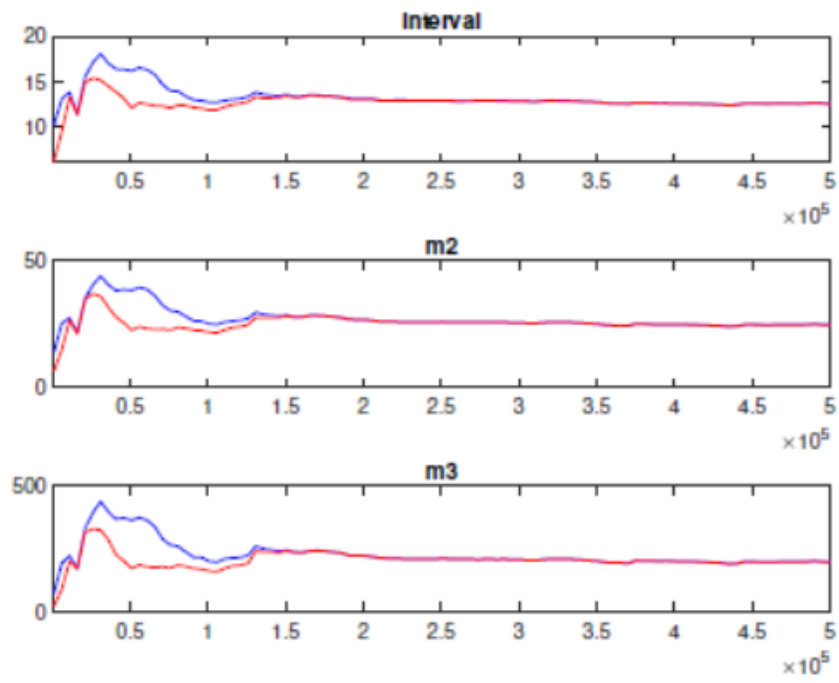
Figure 3: Average retail price of fuel and total subsidy as a percentage share of GDP.

Figure 4: Multivariate convergence diagnostics