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Fuel Subsidy Reform in Nigeria: Macroeconomic Implications and Policy Options

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Abstract

Subsidies are motivated by a desire to reduce inequality, move households out of energy poverty, and mitigate the impact of commodity price volatility on consumers and producers. Global estimated subsidies were approximately 7% of GDP in 2020, with a projected increase to 7.4% of GDP by 2025. However, there is evidence in the literature that subsidy programmes have often failed to achieve their objectives. As a result, there is growing concern about the private and social consequences of subsidies, especially those related to fossil fuels. Attempts at fuel subsidy reforms have provoked protests and strong political responses, especially in oil-producing emerging economies. Recent global shocks, including those arising from the COVID-19 pandemic, have questioned the sustainability of subsidy regimes in these economies, including Nigeria. Thus, there has been an increased call for comprehensive subsidy reform. This study examines the macroeconomic and policy implications of possible fuel subsidy reform in Nigeria. We find subsidy reforms could cause significant macroeconomic fluctuations and severe welfare loss in the short run. However, an optimal combination of monetary and fiscal policies is required to ameliorate the welfare loss. Furthermore, we recommend that necessary safety nets be put in place to protect the poor prior to the implementation of fuel subsidy reforms.

1. Introduction

Subsidies, the gap between user and efficient prices or defined as charging a retail price below the world price, are motivated by the quest to reduce inequality, lift households out of energy poverty, and subsequently leverage upon as a tool to gain political support. Although popular with the citizens, subsidies have often failed to reach the poor as the benefits leak away to the underserving: the rich (Sandefur, 2018). In addition to being a massive drain on fiscal resources, economic theory suggests that subsidies distort market prices, leading to unintended economic, environmental, and social outcomes.

Globally, the estimated subsidies were $5.3 trillion in 2015 and about $6 trillion, equivalent to roughly 7 percent of GDP in 2020. According to IMF estimates, the five biggest subsidisers in 2020 were China ($2.2 trillion), the United States ($0.66 trillion), Russia ($0.52 trillion), India ($0.25 trillion) and Japan ($0.17 trillion). These numbers are expected to surge to 7.4 percent of GDP by 2025, even as the share of fuel consumption in emerging markets, where subsidies are more significant, continues to soar (Coady, Parry, Le, & Shang, 2019).

Worldwide, concerns have been triggered by the private and social costs associated with fossil fuel subsidies. For example, lower prices drive overconsumption of fossil fuels, road crowding and accidents, rise in global warming, and consequently carbon dioxide (CO2) emissions-related deaths, thus prompting a group of G20 countries calling for a phase-out of inefficient subsidies, arguing that eliminating subsidies will shrink CO2 emissions by 36 percent (preventing about one million air population-related deaths), raise revenues by 4 percent of global GDP and increase social welfare by more than 2 percent (Coady et al., 2019).

However, attempts to roll back subsidies often provoke protests and intense political backlash largely won. Neither do the attempts, for instance, in Nigeria, to replace inefficient subsidies with dependable digital transfers (deemed suitable alternatives) that are beyond the reach of local corruption and rent-seeking seem to gain traction or flourish. Nevertheless, Nigeria's experience with subsidy administration is unique, differing significantly from other subsidising countries.

Nigeria churned out roughly 2 million barrels of crude oil daily until the recent production challenges, making it Africa's top producer and the world's thirteenth. However, still, because of its feeble domestic refineries, Nigeria imports about 80 percent of the gasoline it consumes at home, selling it at a government-fixed rate (US$0.43) that is below the international average price (US$0.97) and the landing cost determined by world oil price and cost of freight. The difference is finance in subsidy. For instance, in 2011 alone, the total subsidy amount was over $13 billion—about 3 percent of Nigeria's GDP that year.

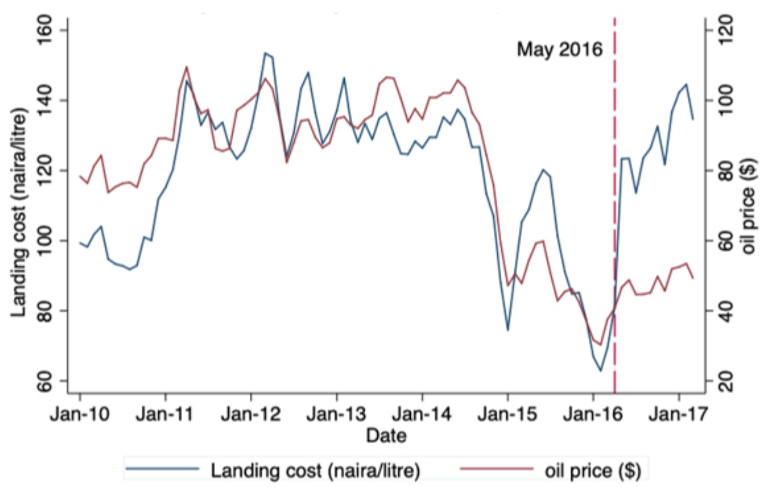
To reduce this substantial fiscal burden, Nigeria's government in January 2012 attempted to free up the gasoline price by ending the subsidy regime and allowing demand and supply to determine the price. The subsidy programme was also considered rife with double-dealing (Dapel, 2019). Although praised by the IMF, the move was met with protests at home, forcing the government to rescind its decision. Within two weeks, the price reverted from N141 to N97 per litre.

However, the price deregulation move was not permanently shelved. The proposal was reconsidered by the government that took office in May 2015. The official price was increased by 67 percent after a year in office, to N145 per litre and then to N165 per litre in December 2021. The oil marketers in Nigeria increased the price to N185 per litre in July 2022. As global crude oil prices head to triple digits, there are concerns that what the government spends on subsidies may rise, potentially pushing up the official price.

As an exporter of crude oil, Nigeria's revenue typically benefits from a positive oil price shock. However, it simultaneously imports gasoline, which also increases in response to positive oil price shocks. As a result, the net import bill combines these two effects. We use a model to separate the two and show that changes in oil prices dominate the bill. These effects are asymmetric, with a more significant impact with oil price decreases than increases. Therefore, world oil prices drive the landing cost per litre of petrol.

There are three possibilities regarding who absorbs the pass-through effect. First, the government could absorb the impact through one hundred percent subsidies. In this case, the pump price stays relatively stable because they are being insulated from shocks in the world oil market by the government's fiscal responsibility. Second, the final consumers of the product. This drives up the pump price by an amount roughly equivalent to the spike in the landing cost – the cost of procurement and freight – such that world prices feed through the landing cost to the pump stations. The third and final possibility is a split in that consumers and government share the burden of a rise in world oil prices, resulting in raising the pump price by some amount but not up to the rate at which the landing cost has risen.

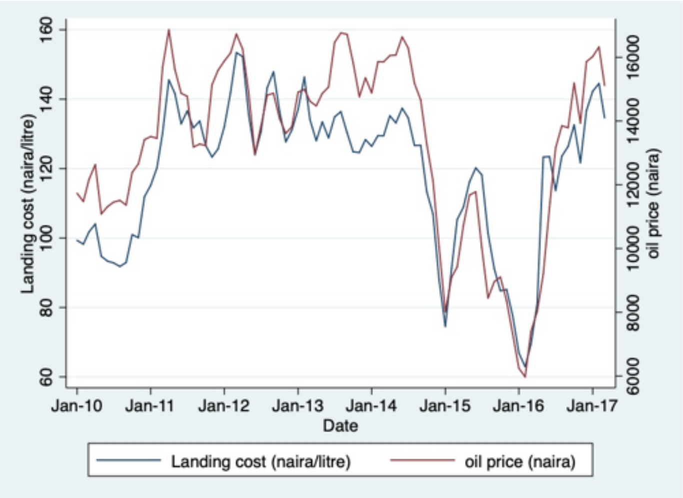
Figure 1: Landing cost and oil price ($)



Source: Authors' using data from the National Bureau of Statistics and the Central Bank of Nigeria

In Figure 1, a divergence in pattern, starting from May/June 2016, between the two lines is observed. This is because, from that period, the official exchange rate rose by more than 55 percent. To account for the effect of the exchange rate, we revalued the oil price from dollars to naira - see Figure 2 - no more divergence, indicating a strange vanishing pattern.

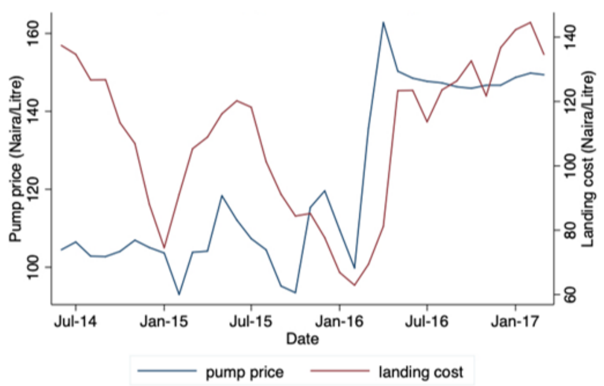
Figure 2: Landing cost and oil price (Naira)



Moreover, in the presence of subsidies, it is expected that the landing cost of petrol – procurement and freight – should be tracked by (rises and falls with) world oil prices and subsidy expenses but not pump prices. For example, in March 2022, the Nigerian National Petroleum Corporation claimed that it incurs a daily subsidy payment of N10 billion ($24 million) to keep the local pump price below the international price.

However, Figure 3 below seems to vindicate the claim by critics of the current subsidy regime in Nigeria: doubting, despite huge amounts being allocated for settling subsidy bills, the existence of fuel subsidies in the country. As depicted, average local pump prices across the country, in recent years, have risen and fallen with international oil prices.

Figure 3: Pump price and landing cost



Source: Authors' using data from the National Bureau of Statistics and the Central Bank of Nigeria

Whereas there have been intermittent calls for removing fuel subsidies in Nigeria, the potential impacts and policy implications of such reforms are poorly understood. In this work, we used an estimated Dynamic Stochastic General Equilibrium (DSGE) model to assess the impact of subsidy reform in Nigeria. We specifically examined the potential macroeconomic implications of discontinuing the subsidy regime and the effect of such a decision on household welfare using a measure of policy loss. In addition to the main objectives of the paper, we also traced the transmission mechanism of an oil price shock on the economy and identified the main drivers of business cycles in the country.

A few results are discerning. For instance, subsidy reform induced significant macroeconomic fluctuations, which could result in considerable welfare loss in the short run. This response calls for optimal macroeconomic policy adjustments and social safety nets to protect the poor.

Section 2 of the paper presents a review of relevant literature. Section 3 outlines the developed DSGE model for Nigeria. It also discusses the estimation procedures and data collection approach. The results are presented in Section 4, while some concluding remarks are provided in Section 5.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2. Brief Literature Review

Subsidies have been used for a variety of purposes around the world, resulting in significant fiscal commitments by governments. The G20 nations, for example, provided about $600 billion in subsidies between 2017 and 2019, the vast bulk of which was used to subsidise oil and gas production rather than any other stage of fossil fuel-related activity (Geddes, Gerasimchuk, Viswanathan, et al., 2020). In developing countries, including Nigeria, fossil-fuel subsidies have primarily been used as a redistributive policy instrument, mainly income redistribution, to mitigate the surge in international crude oil prices and protect the poor. However, this has placed a significant financial burden on developing countries; as a result, various attempts have been undertaken in the last two decades to reform fossil fuel subsidies. There have been several studies on fossil-fuel subsidies, their rationale, effects, consequences, and reforms. However, because the subject is widely debated and documented in the literature, this review concentrates primarily on recent developments, particularly as they relate to Nigeria.

Subsidies and the need for reform have received much attention from policymakers and researchers. According to existing research, subsidies could be directed either at producers to keep production costs low or at consumers to keep fossil-fuel prices low to encourage specific sectors of the economy or alleviate poverty (Sanders & Schneider, 2000; Morgan, 2007). Previous studies have looked at petroleum pricing, its effects on the economy, and its overall welfare effect (see, Gupta et al., 2002; Hossain, 2003; UNEP, 2003; Coady et al., 2006; Adenikiju, 2009; Ellis, 2010; IEA, OPEC, OECD and World Bank 2010; Widodo et al., 2012; Adenikinju & Omenka, 2013; Davis, 2013; Anand et al., 2013; Abraham, 2013; Siddig et al., 2014; Agu et al., 2018; Fasua, 2020). These studies conclude that fuel subsidies distort market outcomes, resulting in inefficiency, inefficient spending and placing pressure on the economy's fiscal position. Other researchers, such as Amegashie (2006), Azel de Granado, Coady, and Gillinghon (2012), and Onwuamaeze and Ekeghe (2020), suggested that fuel subsidies do not always result in waste and inefficiency. However, as Nwachukwu and Chike (2011) demonstrated, fuel subsidies have gained prominence and are no longer regarded as fiction. As a result, governments have had to deal with the consequences even as the financial burden rises.

Removing the fuel subsidy is a challenging policy today, particularly in Nigeria. Arguments against the policy have generally concentrated on the policy's severe negative implications. There are several studies in this area in the literature. In their study, Siddig, Aguiar, Grethe, Minor, and Walmsley (2014) noted that while a reduction in the subsidy often leads to an increase in output, it may have a detrimental impact on household income, especially for low-income families. At the same time, preserving subsidies, particularly fuel, benefits wealthier households more than disadvantaged households (Soile & Mu, 2015). According to the study, the top 20 percent of households benefit from gasoline subsidies twice as much as the bottom 20 percent.

The outcome appears to be predominantly negative for households. However, some studies have indicated the opposite. In this class of studies is Dennis (2016), found that the removal was beneficial in the vast majority of cases but had an uneven impact on individual households in developing countries. Removing the subsidies was encouraged. However, the investigation's findings entail striking a balance between the financial strain on governments and rising poverty among citizens.

Various strategies for achieving the balance have been considered in some developing countries, including Nigeria. For example, there has been a call to implement a policy option to phase out petrol subsidies gradually (Rentschler, 2016). However, considering a gradual phase-out does not guarantee that the measure will not negatively impact disadvantaged households. Indeed, the study predicted that the national poverty rate will rise by 3-4 percent. For its success, subsidy reform should be accompanied by adequate compensation and social protection programmmes.

In their study, Rentschler and Bazilian (2017) emphasised the idea of reform through complementary measures. According to the study, reforming fossil fuel subsidies entails more than just decreasing subsidies; it also involves substantial planning and a set of carefully prepared and sequenced policy actions to ensure public support and social protection for vulnerable populations. The experience of some countries, such as Indonesia and Malaysia, has established that the timing of the sequence of actions is also critical to the success of the reform (Benes, Cheon, Urpelainen, and Yang, 2015).

International oil prices fluctuate, occasionally reaching troughs, resulting in lower subsidy payments. Several governments used the sharp decline in oil prices in 2014 to announce the end of fuel subsidies and the move to market-based pricing with full cost recovery for petrol. For example, Kojima (2016) noted that recent experience in Jordan and Morocco has demonstrated that regular and frequent price modifications help the government and consumers react to global gasoline costs and exchange rate swings. By contrast, freezing prices increases the possibility of a return to price subsidies. The more formally the decision to transition to market-based pricing is disclosed, the more public new price announcements are made. The more frequently prices are changed, the more likely the announced pricing policy reform will be sustained.

In line with the preceding submission, Whitley and Van Der Burg (2015) noticed the government's reluctance to reform, despite the mounting financial implications of fossil fuel subsidies. Some of the reasons for this choice include a lack of information, the pressure of special interests, a lack of more effective policies, and institutional capacity to implement more appropriate policies. This viewpoint was supported by Benes, Cheon, Urpelainen, and Yang (2015), who stated that the major impediments to fuel subsidy reform are political, with vested interests mobilising the public against the government's move to remove subsidies, particularly if the action lacks the necessary institutional capacity.

The government has become increasingly aware that the continued maintenance of subsidies is not viable. Therefore, the necessity for a comprehensive strategy for subsidy elimination becomes apparent. As a result, this study aims to focus more closely on the macroeconomic implications of subsidy reform while also offering solutions for overcoming the observed implementation hurdles to subsidy reforms in Nigeria.

3. Methodology

3.1 The Model

We set up a suitable dynamic stochastic general equilibrium (DSGE) model for replicating the stylised facts about Nigeria's response to structural shocks. At the core of our model is the Gali and Monacelli (2005) small open economy framework. We incorporate features that are important for understanding a typical resource-intensive emerging economy. These include a resource sector that is jointly owned by the government and foreign investors, credit constraints, incomplete exchange rate pass-through, a resource-dominated fiscal sector, an inefficient financial sector, and an implicit fuel subsidy regime that is financed by the government.

To capture both the direct and indirect impacts of the fuel subsidy reform on the economy, we introduce oil into the consumption basket of households and the production function of domestic firms. The model features a government that conducts fiscal policy and a central bank responsible for setting short-term interest rates in line with its price stability objective. The DSGE model is estimated for the Nigerian economy using Bayesian methods. The estimated model will be used to (i) perform structural analysis based on computed impulse responses and variance decompositions, (ii) evaluate the macroeconomic and welfare implications of subsidy reform, and (iii) conduct policy ranking based on a central bank loss function. Model details are provided in Appendix A.

3.2 Model Estimation and Data

The log-linearised version of the model presented in the previous section is estimated via Bayesian methods (Schorfheide, 2000), using data for the period of 2000Q2 - 2019Q1[1]. We consider quarterly data on the following 15 macroeconomic variables: headline consumer price index, core consumer price index, real effective exchange rate, nominal interest rate, tax revenue, government debt, government consumption, oil output, per capita real consumption, per capita real investment, per capita real domestic GDP, international oil price, trade-weighted foreign aggregate CPI, trade-weighted foreign interest rate, and trade-weighted foreign real GDP per capita. Our data sources are the National Bureau of Statistics (NBS) and the Central Bank of Nigeria (CBN) Statistics database for domestic variables as well as the Federal Reserve Bank of St. Louis (FRED) and the International Financial Statistics (IFS) of the International Monetary Fund (IMF) for the foreign variables. Necessary transformations are done on the data to ensure they are model consistent. The calibrated parameters of the model, which are borrowed mainly from Iklaga (2017), Gali and Monacelli (2005), and Omotosho (2019), are presented in Table B.1 of the Appendix. Also, the prior moments assumed for the Bayesian estimation are presented in Table B.2 of the Appendix.

[1] The choice of the estimation sample is largely influenced by data availability for the domestic economy as well as the occurrence of the Covid-19 pandemic.

4. Results and Discussion

In this section, we present the results of our model. As stated, the model includes a resource sector jointly owned by the government and foreign investors. It features credit constraints, incomplete exchange rate pass-through, a resource-dominated fiscal sector, an inefficient financial sector, and a government-financed implicit fuel subsidy regime. To capture both the direct and indirect effects of the fuel subsidy reform on the economy, we introduce oil into the consumption baskets of households and the production function of domestic firms. The subsidy regime is reflected in the domestic fuel pricing rule that accommodates incomplete pass-through of international oil prices to domestic fuel price. In the first section, we analyse the economy's responses to several exogenous shocks, including productivity, fiscal policy, monetary policy, and oil price shock. Next, we present the historical decomposition of selected endogenous variables to understand the main drivers of the economy. Finally, we conduct counterfactual simulations to gain insights into the possible macroeconomic implications of fuel subsidy reforms and the possible outcomes of different monetary and fiscal policy rules.

4.1 Impulse Response Functions

In Figure 4, we show the economy's responses to a productivity shock. Following a positive productivity shock, total GDP (Total_Y) and domestic output (Dom_Y) increase. Government consumption increases while private consumption declines initially upon impact. The efficiency gains arising from the improvement in productivity causes prices to moderate as headline, domestic, and core inflation fall. Consequently, the central bank responds with an interest rate cut that depreciates the real exchange rate.

Figure 5[2] shows the impacts of a positive fiscal policy shock on the economy. As expected, the real endogenous variables increased upon impact, as can be observed from the impulse responses for total GDP (Total_Y), domestic output (Dom_Y), government consumption (G_Cons), and private consumption (P_Cons). However, whereas the increased government expenditure led to higher domestic prices (Dom_Inf), headline (Total_Inf) and core (Core_Inf) measures of inflation declined. The decline in headline inflation is short-lived, causing the central bank to respond with an increase in the monetary policy rate.

[2] Total_Y = Total Output (GDP), Dom_Y = Domestic output, G_Cons = Government consumption, P_Cons = Private consumption, Total_Inf = Headline inflation, Dom_Inf = Domestic inflation, Core_inf= Core inflation, RER= Real exchange rate, and Int_rate = Short term nominal interest rate.

Figure 4: Response of the economy to a positive productivity shock

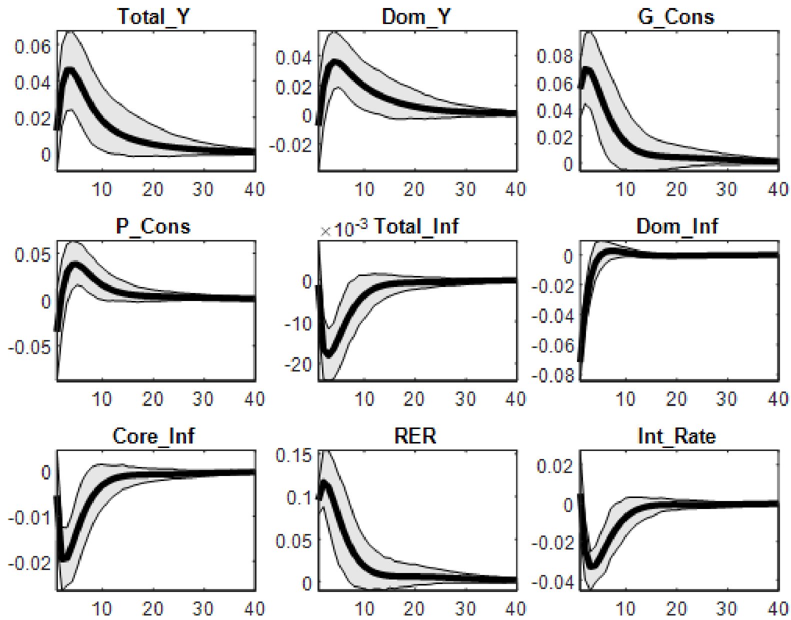
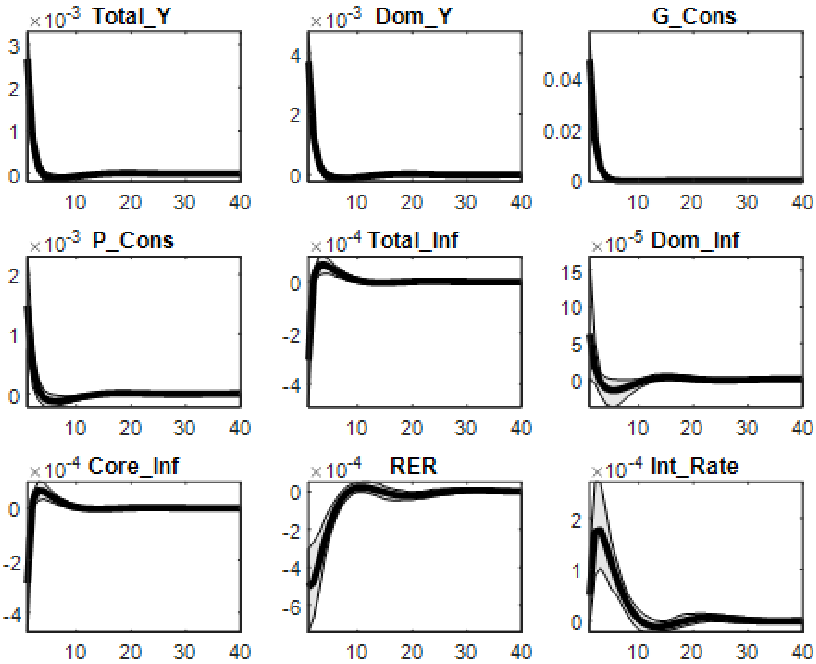
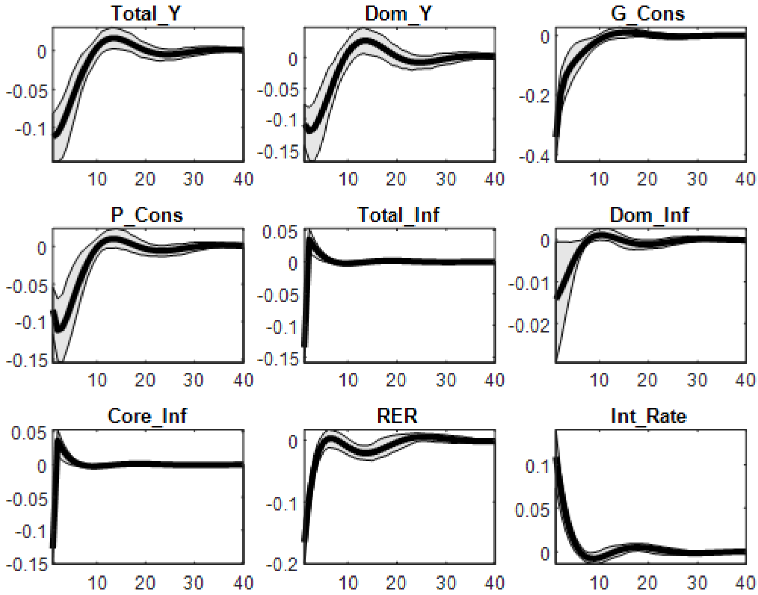


Figure 5: Response of the economy to a positive fiscal policy shock



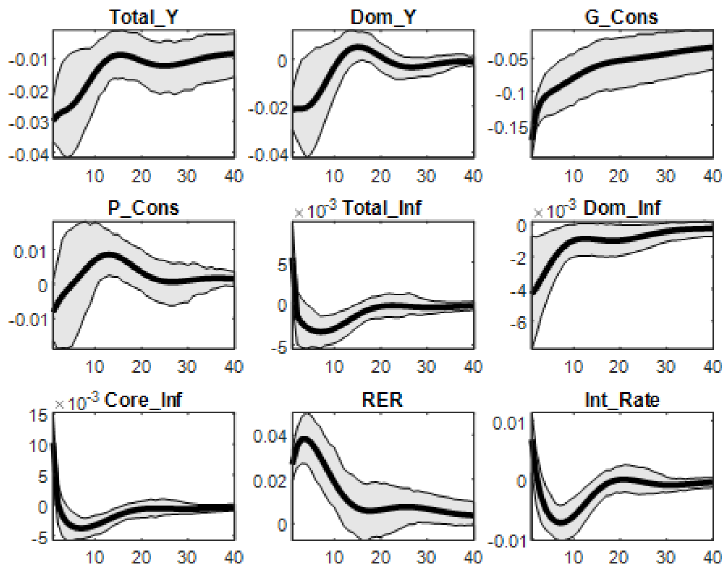
Next, we consider the impacts of a positive monetary policy shock on the domestic economy. As shown in Figure 6, a contractionary monetary policy implemented through an increase in the monetary policy rate causes the three measures of inflation to fall. Also, the real exchange rate appreciated.

Figure 6: Response of the economy to a positive monetary policy shock



Lastly, we computed the impulse responses to a negative oil price shock and the results are shown in Figure 7. Expectedly, the real variables - total output, domestic output, government, and private consumption declined following a negative oil price shock. Domestic inflation fell owing to the lower real marginal costs faced by domestic goods producers.

Figure 7: Response of the economy to a negative oil price shock

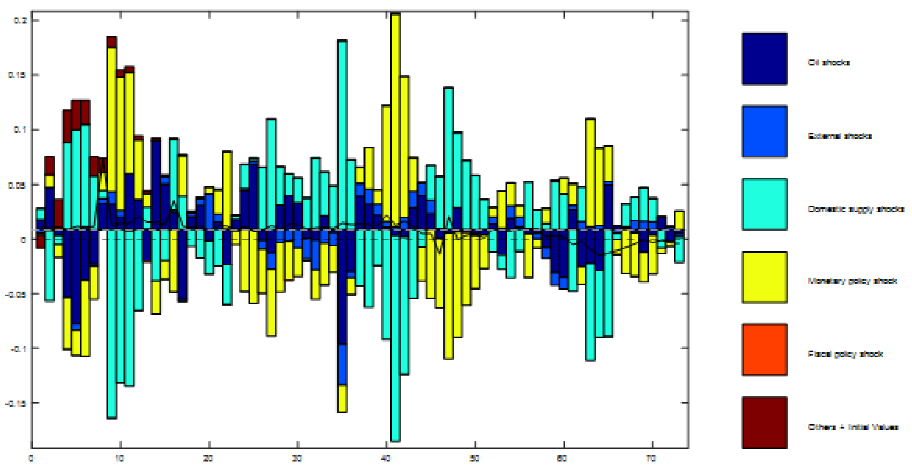


On the other hand, core and headline measures of inflation rose due to the pass-through effect of the exchange rate. Since imported goods are included in the core basket of consumers, the depreciation in the real exchange rate causes the price of imported goods to rise, leading to higher headline inflation. In response to the higher headline inflation, the central bank embarks on a contractionary monetary policy.

4.2 Historical Decomposition

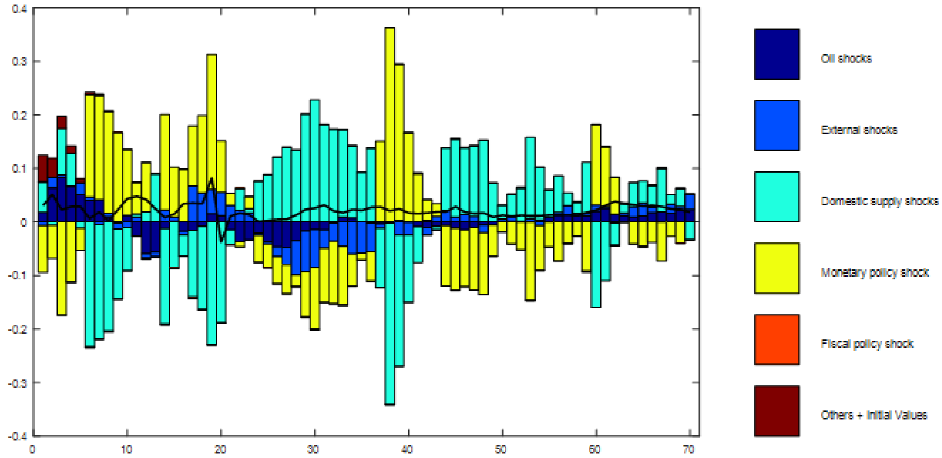
In this section, we discuss the factors driving the evolution of the economy by computing the historical decomposition of selected endogenous variables. As shown in Figure 8, monetary policy shocks, domestic supply shocks, and oil-related shocks were the main drivers of GDP over the study period. Total GDP increased sharply in the second half of 2001 and the second half of 2004. The increase recorded in 2001 was driven by a combination of monetary and oil price shocks, while the 2004 increase was caused by oil price, domestic productivity, and monetary policy shocks. Whereas the five years leading to 2010 recorded relatively stable output growth, negative output growth was observed in the third quarter of 2011. Furthermore, the recession of 2016 was caused by a negative oil price shock that began in 2014. The negative oil price shock led to decreased earnings from oil, lower accretion to external reserves, and scarcity of foreign exchange. A combination of these effects generated negative productivity shocks that exacerbated the recession.

Figure 8: Historical decomposition of GDP



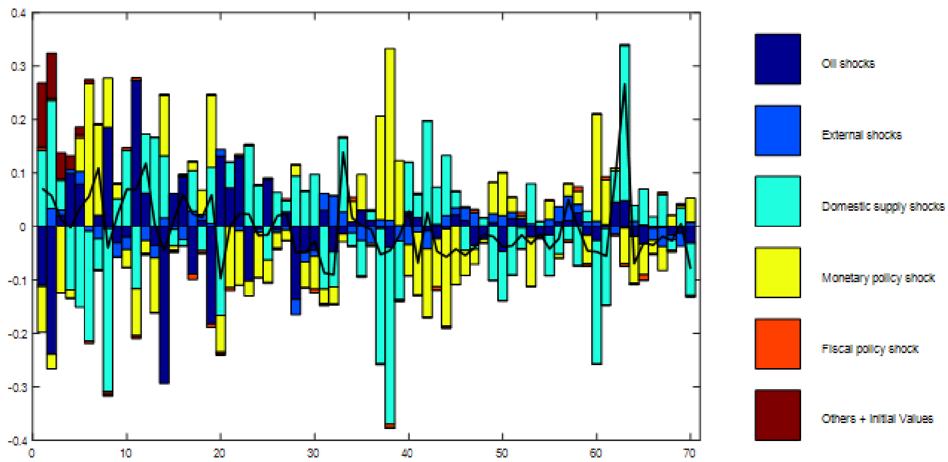
In Figure 9, we show the historical decomposition of headline inflation, an aggregate measure of inflation that combines both core and oil inflation. It is observed that oil, domestic and monetary policy shocks were the main drivers of inflation during the sample period. Whereas the evolution of headline inflation in the early part of the sample was primarily driven by oil-related shocks, domestic supply and monetary policy shocks played non-trivial roles during the 2001-2018 period.

Figure 9: Historical decomposition of headline inflation



The real exchange rate was quite volatile during the sample period, with monetary policy and oil-related shocks accounting for its evolution. In the pre-2008/09 global meltdown period, oil and domestic supply shocks accounted for the volatility in the exchange rate. During the 2015-2017 period, the real exchange rate depreciated sharply due to negative oil price shocks, and domestic supply innovations (Figure 10).

Figure 10: Historical decomposition of Real Exchange Rate

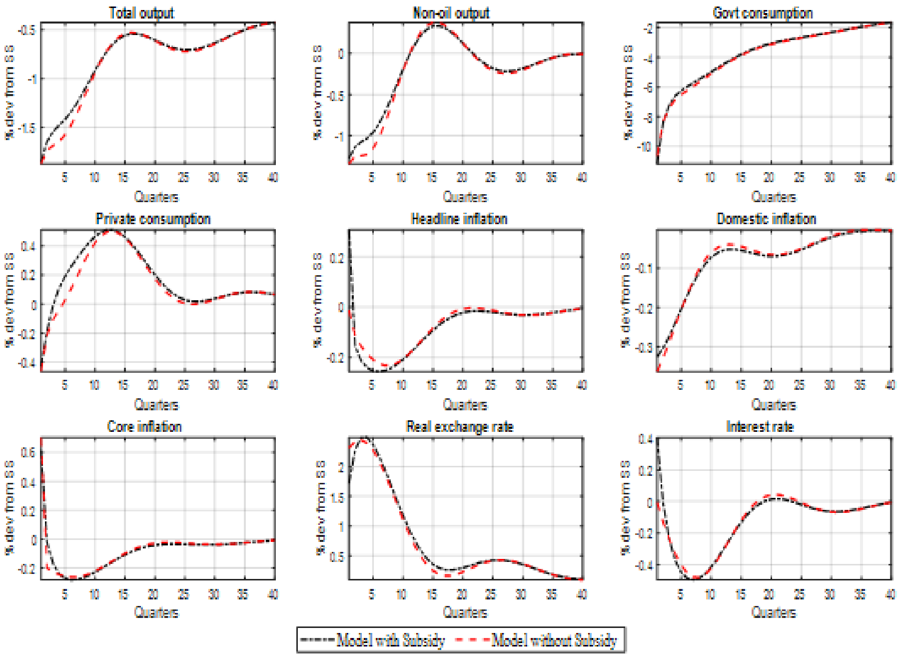


4.3 Macroeconomic implications of subsidy removal

4.3.1 Response of the economy to an oil price shock under alternative subsidy arrangements

Figure 11 presents the impulse response functions of output to a negative oil price shock under two different assumptions regarding fuel subsidies. The black dotted lines indicate the response of the economy under a subsidy regime, while the red dotted lines represent the response of the economy under a no-subsidy regime.

Figure 11: Impulse responses to a negative oil price shock



Following a negative oil price shock, the model without fuel subsidy limits the pass-through effect of the exchange rate to headline inflation. The lower headline inflation recorded under the no-subsidy scenario provides an impetus for the monetary authority to ease – a move that reduces the contractionary impact of a negative oil price shock on output.

4.3.2 Macroeconomic fluctuations under alternative subsidy arrangements

Table 1 presents the variances of selected endogenous variables following a negative oil price shock under subsidy and no-subsidy arrangements. Generally, subsidy reform generates higher macroeconomic fluctuations as most of the macroeconomic variables recorded higher standard deviations under the model without fuel subsidy. However, headline inflation and the real exchange rate recorded lower fluctuations after the subsidy reform. These results provide an empirical basis for the design of appropriate safety nets to protect the poor should there be a reform of the subsidy regime. It also calls for the calibration of macroeconomic policies in a manner that ensures that the short-term instabilities associated with the subsidy removal are contained.

Table 1: Variances of selected macroeconomic variables (with and without subsidy)

Variable	Model with subsidy	Model without Subsidy
Aggregate GDP	5.8680	6.1150
Non-oil GDP	2.9655	3.3800
Government consumption	27.9825	28.2615
Private consumption	1.6805	1.5578
Headline inflation	0.8305	0.6900
Core inflation	1.0206	1.0759
Domestic inflation	0.7135	0.7364
Real exchange rate	6.7588	6.7550
Interest rate	1.4293	1.3388

4.3.3 Welfare implication of subsidy reform[3]

To evaluate the welfare implications of subsidy removal, we employ an inter-temporal loss function of the central bank[4] of the form:

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

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 inflation, output, and interest rate volatility, respectively. A higher policy loss indicates higher welfare loss and vice versa.. A higher policy loss indicates higher welfare loss and vice versa.

Table 2: Policy loss under alternative subsidy arrangements

	Model with subsidy	Model without Subsidy
Policy Loss	5.496	6.547

Table 2 shows that subsidy reform could generate significant welfare implications, given that the model without fuel subsidy yielded higher policy loss. These results are in line with the findings reported under Section 4.3.2. In the next section, we discuss the policy options for containing the macroeconomic fluctuations associated with an oil price shock under different assumptions regarding the subsidy regime.

[3]As described under the model exposition, the fuel pricing parameter defines the extent of subsidies being implemented by the government. Whereas a value of zero implies full regulation of domestic fuel price, a value of one implies complete pass-through from international oil price to domestic fuel price. In between these two lies the spectrum of possible values that define the potential nature of subsidy reforms that could be envisaged. We conducted simulations based on different values within the spectrum and found that the transmission mechanism of oil price shock to the domestic economy is preserved. Also, the impact of oil price shock on the economy under different assumptions of the fuel pricing parameter falls within the two extremes analysed in the paper.

[4]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.

4.4 Policy options

4.4.1 Optimal monetary policy response to an oil price shock following a subsidy reform

In this Section, we compute the welfare implications, approximated by the policy loss, associated with an oil price shock under the model with and without fuel subsidies. We compare the policy losses under nine (9) alternative monetary policy rules to determine the rule that minimises the policy loss. As explained earlier, the rule with the least policy loss is considered optimal.

As shown in Table 3, subsidy reform has welfare implications as the policy losses are generally higher under the model without fuel subsidy, further supporting the case for introducing safety nets. The CPI inflation-based monetary policy rule that also incorporates a measure of output gap represents a superior monetary policy strategy regardless of whether or not a subsidy reform is implemented. Generally, the CPI inflation-based Taylor rules outperformed their core-inflation counterparts. Notably, the CPI inflation-based Taylor rule with output gap yields a lower policy loss under the model without subsidy than under the model with subsidy.

Table 3: Policy loss under alternative subsidy arrangements

Monetary Policy Rule	Model with subsidy	Model without Subsidy
CPI Inflation Targeting Rule (TR)	2.0917	4.2690
Core Inflation TR	7.2534	7.5479
CPI inflation TR with output gap	1.4432	1.4123
Core inflation TR with output gap	2.0364	2.3167
CPI inflation TR with output gap and inertia	1.6055	1.7287
Core inflation TR with output gap and inertia	2.4868	2.6351
CPI inflation TR with output gap and inertia with RER	5.4955	6.5469
Core inflation TR with output gap and inertia with RER	6.9673	7.3984
Domestic inflation TR with output gap and inertia with RER	32.5862	35.5078

4.4.2 Monetary-fiscal policy interaction following a subsidy reform

In this section, we compare the policy losses under different assumptions regarding the subsidy regime, the monetary policy rule, and the cyclicality of fiscal policy. In the aftermath of subsidy reform, lower policy losses are recorded under a counter-cyclical fiscal stance. Also, the CPI inflation-based monetary policy rule remains an optimal strategy, regardless of the stance of fiscal policy. It was also found that monetary policy rules that respond to the real exchange rate yield higher policy losses, implying higher welfare loss. In other words, following the removal of fuel subsidies, the central bank does not improve welfare by responding to the exchange rate in its rate-setting decisions. Overall, the best outcome is obtained under the CPI inflation-based monetary policy rule and a counter-cyclical fiscal policy stance. These results call for effective coordination between monetary and fiscal authorities, especially in the aftermath of the subsidy reform.

Table 4: Policy loss under alternative stance of fiscal policy

Monetary Policy Rule	Model with subsidy	Model without Subsidy
CPI inflation-based Taylor rule (TR)	4.2690	1.2929
Core inflation-based TR	7.5479	2.8320
CPI inflation-based TR with output gap	1.4123	0.8188
Core inflation-based TR with output gap	2.3167	1.5270
CPI inflation-based TR with output gap and inertia	1.7287	0.9103
Core inflation-based TR with output gap and inertia	2.6351	1.5667
CPI inflation-based TR with output gap and inertia with RER	6.5469	2.9423
Core inflation-based TR with output gap and inertia with RER	7.3984	3.5209
Domestic inflation-based TR with output gap and inertia with RER	35.5078	10.8931

Conclusion and Recommendations

Like many developing and emerging market economies, governments intervene to limit the degree to which oil price changes are passed through to domestic fuel prices. We study whether and to what extent this intervention is warranted in an economy characterised by nominal rigidities in the goods and labour markets. We argued that to the extent that monetary policy is capable of stabilising the economy, government intervention in the oil market could be avoided. However, when complete stabilisation is not attainable (for example, due to fiscal dominance, external shocks, and dual mandate), the government can improve social welfare by limiting the degree of pass-through of oil prices.

This study examined the implications of potential fuel subsidy reforms for the macroeconomy and the conduct of monetary policy. It investigated the direct and indirect effects of an oil price shock under different arrangements regarding the fuel subsidy regime. In addition, we evaluated the policy options available to the monetary authority and identified the appropriate monetary policy rule that yields a relatively lower welfare loss. We conducted counterfactual simulations using an estimated DSGE model for Nigeria. The DSGE model includes a resource sector that is owned by the government and foreign investors, credit constraints, incomplete exchange rate pass-through, a resource-dominated fiscal sector, an inefficient financial sector, and a government-financed implicit fuel subsidy regime.

We found that subsidy reform generates both higher macroeconomic fluctuations and significant welfare implications, implying that policy losses are generally higher under the model without fuel subsidy. Hence, there is a need for social safety nets. We also evaluated the policy options available to the monetary authority. We found that a CPI inflation-based monetary policy rule represents a superior monetary policy strategy that yields a relatively lower welfare loss. In terms of monetary-fiscal interactions, our simulations showed that, in the aftermath of the reform, A CPI-based monetary policy rule mixed with counter-cyclical fiscal policy yields the least policy loss. Given the above, we recommend that:

- Rather than a big bang approach, any potential subsidy reforms should be done gradually to allow for the necessary socio-economic adjustments to take place smoothly;
- Appropriate safety nets should be put in place to protect the poor prior to the implementation of possible subsidy reforms;
- In the aftermath of subsidy removal, the optimal monetary policy response to the macroeconomic fluctuations and the attendant welfare loss arising from an oil price shock is the CPI-based monetary policy rule that also incorporates the output gap;
- A combination of CPI-based monetary policy rule and counter-cyclical fiscal policy stance yields the least policy loss and thus constitutes the optimal strategy for responding to an oil price shock in the aftermath of a subsidy reform; and
- The Federal Government should develop an effective communication strategy prior to the commencement of the reform.

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Appendix A

A1.1 Households

We consider two categories of households: Ricardian households (*r*) who are able to save and accumulate physical capital, and non-Ricardian households (*nr*) who neither save nor own assets and completely consume their current labour income within the period. The Ricardian households constitute γ_r of the total number of households in the economy while the non-Ricardian households account for the remaining fraction, $1-\gamma_r$. The amount of capital accumulated by Ricardian households is used up by domestic firms producing non-oil goods.

The representative Ricardian household maximises the following discounted utility function in making its consumption and savings decisions:

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

subject to a per-period budget constraint:

$$P_t C_t^r + P_{i,t} I_{c,t} + \frac{B_{t+1}}{R_t \mu_t} + \frac{\epsilon_t B_{t+1}^*}{R_t^* \mu_t^*} = W_t N_t^r + R_{h,t} K_{h,t} + B_t + \epsilon_t B_t^* + D_t - \tau_t. \tag{2}$$

The current consumption of the Ricardian household, C_t^r depends on the economy-wide consumption, C_t, via an external habit parameter $\emptyset_c \in (0,1)$ while the household's relative risk aversion coefficient is denoted by σ. Furthermore, the household supplies labour hours, N_t^r, with an inverse of the Frisch elasticity of labour supply, $\varphi > 0$. For supplying capital and labour hours, the representative household earns capital income, $R_{h,t}K_{h,t}$, and wages, $W_t N_t^r$, respectively. Finally, a share, D_t, of the domestic non-oil firm's profit goes to the household in addition to its holdings of domestic bonds, B_t, and foreign bonds, B_t^*, maturing in the next period. On the expenditure side of the budget constraint are consumption, $P_t C_t^r$, and investment, $P_{i,t} I_{c,t}$, spendings. The accumulation of non-oil capital is done as follows:

$$K_{h,t+1} = (1-\delta_h)K_{h,t} + I_{c,t}\left[1 - \frac{\chi}{2}\left(\frac{I_{c,t}(j)}{I_{c,t-1}(j)} - 1\right)^2\right], \tag{3}$$

where the rate of depreciation is measured by δ_h and the cost associated with adjustments in investment is measured by $\chi \geq 0$. As in Hollander, Gupta and Wohar (2018), we assume that that the household faces an exogenous risk premium on the return on domestic bonds, μ_t, and a risk premium when acquiring foreign bonds, μ_t^*.

As earlier mentioned, the representative non-Ricardian household does not save; rather, it consumes all of its labour income by maximising a utility function of the form:

$$U_0^{nr} = \frac{(C_{t+s}^{nr} - \Phi_c C_{t+s-1})^{1-\sigma}}{1-\sigma} - \frac{(N_{t+s}^{nr})^{1+\varphi}}{1+\varphi} \tag{4}$$

subject to the budget constraint:

$$P_t C_t^{nr} = W_t N_t^{nr} - \tau_t. \tag{5}$$

A1.2 Demand for consumption and investment goods

The household's aggregate consumption basket, C_t, comprises core (non-oil) goods, $C_{c,t}$, and fuel, $C_{o,t}$, as follows:

$$C_t = \left[(1-\gamma_o)^{\frac{1}{\eta_o}}\left(C_{c,t}\right)^{\frac{\eta_o-1}{\eta_o}} + \gamma_o^{\frac{1}{\eta_o}}\left(C_{o,t}\right)^{\frac{\eta_o-1}{\eta_o}}\right]^{\frac{\eta_o}{\eta_o-1}}, \qquad (6)$$

where γ_o represents the share of fuel in household consumption and $\eta_o > 0$ denotes the degree of substitution between core goods and fuel. Also, the core consumption basket consists of domestically produced goods, $C_{h,t}$, and imported goods, $C_{f,t}$, as follows:

$$C_{c,t} = \left[(1-\gamma_f)^{\frac{1}{\eta_f}}\left(C_{h,t}\right)^{\frac{\eta_f-1}{\eta_f}} + \gamma_f^{\frac{1}{\eta_f}}\left(C_{f,t}\right)^{\frac{\eta_f-1}{\eta_f}}\right]^{\frac{\eta_f}{\eta_c-1}}, \qquad (7)$$

where γ_f represents the share of non-oil goods that is imported from the rest of the world and $\eta_f > 0$ denotes the elasticity of substitution between home and foreign goods. Expenditure minimisation procedures by households yields the optimal demand for core goods and fuel as follows:

$$C_{c,t} = (1-\gamma_o)\left[\frac{P_{c,t}}{P_t}\right]^{-\eta_o} C_t, \quad C_{o,t} = \gamma_o\left[\frac{P_{r,t}}{P_t}\right]^{-\eta_o} C_t,$$

while the demand schedules for domestically produced goods and imported goods are as follows:

$$C_{h,t} = (1-\gamma_f)\left[\frac{P_{h,t}}{P_{c,t}}\right]^{-\eta_f} C_{c,t}, \quad C_{f,t} = \gamma_f\left[\frac{P_{f,t}}{P_{c,t}}\right]^{-\eta_f} C_{c,t},$$

The price index equations for aggregate consumer basket and core goods are given below:

$$P_t = \left[(1-\gamma_o)P_{c,t}^{1-\eta_o} + \gamma_o P_{r,t}^{1-\eta_o}\right]^{\frac{1}{1-\eta_o}}, \quad P_{c,t} = \left[(1-\gamma_f)P_{h,t}^{1-\eta_f} + \gamma_f P_{f,t}^{1-\eta_f}\right]^{\frac{1}{1-\eta_f}}.$$

where P_t is the price index for aggregate consumer goods, $P_{c,t}$ is the price index for non-oil goods, $P_{h,t}$ represents the price of domestically-produced goods, and $P_{f,t}$ denotes the local currency price of imports. The price of fuel, $P_{r,t}$, is determined via a fuel pricing rule that is controlled by the government in such a manner that limits the pass-through effect of global oil price to the domestic pump price of fuel.

Similar to the composition of core consumption goods, the basket of non-oil investment goods, $I_{c,t}$, is a CES aggregate of home-made goods, $I_{h,t}$, and goods imported from the rest of the world, $I_{f,t}$, as follows:

$$I_{c,t} = \left[(1-\gamma_i)^{\frac{1}{\eta_i}}\left(I_{h,t}\right)^{\frac{\eta_i-1}{\eta_i}} + \gamma_i^{\frac{1}{\eta_i}}\left(I_{f,t}\right)^{\frac{\eta_i-1}{\eta_i}}\right]^{\frac{\eta_i}{\eta_I-1}}, \qquad (8)$$

where γ_i denotes the proportion of non-oil investment goods that are imported, and the parameter η_i measures the elasticity of intra-temporal substitution between home-made and imported goods.

Labour and wages

To determine wages in the economy, we assume the existence of a labour aggregating firm that collects differentiated labour, $N_t(j)$, from households to produce a single labour input, N_t, as follows:

$$N_t = \left[\int_0^1 N_t(j)^{\frac{\eta_L - 1}{\eta_L}} dj\right]^{\frac{\eta_L}{\eta_L - 1}}, \tag{9}$$

where the elasticity of substitution among the labour varieties is measured by the parameter η_L. Profit maximisation by the labour aggregating firm yields the standard demand equation for differentiated labour, $N_t(j)$, and the aggregate wage index, W_t, as follows:

$$N_t(j) = \left[\frac{W_t(j)}{W_t}\right]^{-\eta_L} N_t, \quad W_t = \left[\int_0^1 W_t(j)^{1-\eta_L} dj\right]^{\frac{1}{1-\eta_L}}, \tag{10}$$

In our model set up, we allow for sticky wages as in Calvo (1983) by assuming that a proportion of households, $1 - \theta_L$, can reset their nominal wage in each period while the remaining fraction, θ_L, maintain the price fixing in the previous period. For the former category of households, the optimal reset wage, $W_t^{\bullet}(j)$, is determined by maximising the utility function in equation (1) subject to their budget constraint and the demand for differentiated labour (equation 10):

$$W_t^{\bullet}(j) = \left(\frac{\eta_L}{\eta_L - 1}\right) E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\frac{\left(N_{t+s}(j)\right)^{\varphi}}{\lambda_{c,t+s}}\right]. \tag{11}$$

The law of motion for aggregate nominal wage is as follows:

$$W_t = \left[\theta_L W_{t-1}^{1-\eta_L} + (1 - \theta_L) W_t^{\cdot 1-\eta_L}\right]^{\frac{1}{1-\eta_L}}. \tag{12}$$

A1.3 Interaction with the rest of the world

The real exchange rate, q_t, is defined in terms of the nominal exchange rate, ε_t, multiplied by the ratio of prices in the foreign (P_t^*) and domestic (P_t) economies as follows:

$$q_t = \frac{\varepsilon_t P_t^*}{P_t}. \tag{13}$$

In the spirit of Monacelli (2005), we allow for the law of one price gap, Ψ_t, in the economy by assuming that importing firms have some monopoly power in the determination of the prices of imported goods as follows:

$$\Psi_t = \frac{\varepsilon_t P_t^*}{P_{f,t}}. \tag{14}$$

Combining equations (13) and (14) allows us to re-write the law of one price gap equation as follows:

$$\Psi_t = \frac{q_t}{p_{f,t}}, \tag{15}$$

where the price of imports is expressed in real terms. Consumption in the domestic economy is linked with foreign consumption via an international risk sharing equation. To achieve this, we combine the Euler equations for both the domestic and foreign economies, and invoke the definition of the real exchange rate, q_t, as in Gali and Monacelli (2005) as follows:

$$C_t^R - \phi_c C_{t-1} = \zeta S_t^{\frac{1}{\sigma}} (C_t^* - \phi_c C_{t-1}^*), \tag{16}$$

where ζ is a constant representing the relative initial conditions in asset holdings in the domestic and foreign economies, S_t is the terms of trade, and C_t^* denotes aggregate consumption in the foreign economy (Hollander, Gupta and Wohar, 2018). Finally, the terms of trade, S_t, is defined as the ratio of import price, $P_{f,t}$, to the price of domestically produced tradable goods, $P_{h,t}$:

$$S_t = \frac{P_{f,t}}{P_{h,t}}. \tag{17}$$

A1.4 Firms

There are four categories of firms operating in the model economy. These are the final goods producing firms, intermediate goods producing firms, import goods retailers, and the oil firm. The optimisation problems of these firms are presented next.

In aggregating the differentiated goods, $Y_{h,t}(z_h)$ to produce final goods, $Y_{h,t}$, the perfectly competitive final goods firm pursues the following objective:

$$\max_{Y_{h,t}(z_h)} \Pi_{h,t} = P_{h,t}Y_{h,t} - \int_0^1 P_{h,t}(z_h)Y_{h,t}(z_h)dz_h, \qquad (18)$$

subject to a constant return to scale technology of the form:

$$Y_{h,t} = \left[\int_0^1 Y_{h,t}(z_h)^{\frac{\epsilon_h - 1}{\epsilon_h}} dz_h\right]^{\frac{\epsilon_h}{\epsilon_h - 1}}, \qquad (19)$$

where the elasticity of substitution among intermediate varieties is measured by ϵ_h. The first-order condition for the above optimization problem yields the demand intermediate inputs, $Y_{h,t}(z_h)$, as well as the associated domestic price index, $P_{h,t}$, as follows:

$$Y_{h,t}(z_h) = \left[\frac{P_{h,t}(z_h)}{P_{h,t}}\right]^{-\epsilon_h} Y_{h,t}, \qquad P_{h,t} = \left[\int_0^1 P_{h,t}(z_h)^{1-\epsilon_h} dz_h\right]^{\frac{1}{1-\epsilon_h}}. \qquad (20)$$

The analogous demand and price equations for domestically produced goods meant for export are as follows:

$$Y^*_{h,t}(z_h) = \left[\frac{P^*_{h,t}(z_H)}{P^*_{h,t}}\right]^{-\epsilon_h} Y^*_{h,t}, \qquad P^*_{h,t} = \left[\int_0^1 P^*_{h,t}(z_h)^{1-\epsilon_h} dz_h\right]^{\frac{1}{1-\epsilon_h}} \qquad (21)$$

Next, there is a continuum of monopolistically competitive intermediate goods firms producing differentiated goods using a constant return to scale technology[5] that features capital, $K_{h,t}(z_h)$, labour, $N_t(z_h)$, and refined oil, $O_{h,t}(z_h)$ as follows:

$$Y_{h,t}(z_h) = A_{h,t}K_{h,t}(z_h)^{\alpha_h^k}O_{h,t}(z_h)^{\alpha_h^o}N_t(z_h)^{\alpha_h^n}, \qquad (22)$$

where α_h^k, α_h^o and α_h^n are parameters that measure the elasticities of output with respect to capital, labour, and refined oil, respectively. Each intermediate goods firm determines its demand for input factors by minimizing total cost:

$$\min_{N_t(z_h),K^R_{h,t}(z_h),O_{h,t}(z_h)} W_tN_t(z_h) + R_{h,t}K^R_{h,t}(z_h) + P_{ro,t}O_{h,t}(z_h), \qquad (23)$$

subject to equation (22). This yields optimal input combinations given by:

$$\frac{K^R_{h,t}(z_h)}{N_t(z_h)} = \frac{\alpha_h^k w_t}{\alpha_h^n r_{h,t}}, \quad \frac{O_{h,t}(z_h)}{N_t(z_h)} = \frac{\alpha_h^o w_t}{\alpha_h^n p_{ro,t}}.$$

Substituting the input combinations into the production technology enables us to derive the firm's real marginal cost as follows:

$$mc_t = \frac{1}{A_{h,t}p_{h,t}}\left(\frac{r_{h,t}}{\alpha_h^k}\right)^{\alpha_h^k}\left(\frac{p_{r,t}}{\alpha_h^o}\right)^{\alpha_h^o}\left(\frac{w_t}{\alpha_h^n}\right)^{\alpha_h^n}, \qquad (24)$$

[5] We recognise the fact that there are also firms that use diesel, which is already deregulated as an input factor. However, for tractability and parsimony, we abstract from micro founding such category of firms but assumed a rather low parameter for the share of oil in the production function of domestic firms at 0.12. The idea is to ensure that the impact of oil on domestic production is not over-estimated.

where the marginal cost and the input prices are expressed in real terms. As in wages, we allow for stickiness in the retail price of intermediate goods. Thus, following Calvo's (1983) staggered pricing model, a proportion of the intermediate goods producing firms, $(1 - \theta_h)$, can reset their prices optimally in any given period while the other fraction, θ_h maintain the price as at last fixing. The intermediate firms chosen for an optimal price reset follows the rule:

$$P_{h,t}^{\blacksquare} = \frac{\epsilon_h}{\epsilon_h - 1} \frac{E_t \sum_{s=0}^{\infty} (\beta \theta_h)^s P_{h,t+s} Y_{h,t+s} mc_{t+s}}{E_t \sum_{s=0}^{\infty} (\beta \theta_h)^s Y_{h,t+s}}. \tag{25}$$

Given that some of the intermediate goods are produced for exports, the corresponding Calvo parameter for the price of exports, $P_{h,t}^{*\cdot}$, is denoted as θ_{hf}. Consequently, the law of motion for the price of intermediate goods sold to the domestic and export markets are respectively as follows:

$$P_{h,t} = \left[\theta_h P_{h,t-1}^{1-\epsilon_h} + (1 - \theta_h)(P_{h,t}^{\blacksquare})^{1-\epsilon_h}\right]^{\frac{1}{1-\epsilon_h}}. \tag{26}$$

$$P_{h,t}^{*\cdot} = \left[\theta_h P_{h,t-1}^{*1-\epsilon_f} + (1 - \theta_h)(P_{h,t}^{*\blacksquare})^{1-\epsilon_f}\right]^{\frac{1}{1-\epsilon_f}}. \tag{27}$$

The third category of firms are import goods retailers who operate in a perfectly competitive market and aggregates a continuum of differentiated imported varieties, $Y_{f,t}(z_f)$, to produce a final imported good, $Y_{f,t}$, as follows:

$$Y_{f,t} = \left[\int_0^1 Y_{f,t}(z_f)^{\frac{\epsilon_f - 1}{\epsilon_f}} dz_f\right]^{\frac{\epsilon_f}{\epsilon_f - 1}}, \tag{28}$$

where the elasticity of substitution among imported varieties is denoted as $\epsilon_f > 1$. This arrangement allows us to incorporate incomplete exchange rate pass-through into import prices as in Medina and Soto (2007). The importing firm seeks to choose the amount $Y_{f,t}(z_f)$ that maximises its profit subject to the aggregation technology specified in equation (28). This optimisation problem yields a demand function for imported intermediate goods as well as the corresponding pricing rule as follows:

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

Allowing for rigidity in the price of imported varieties based on Calvo (1983), we assume a fraction, θ_f, of the firms keep their price at last fixing while the remaining $1 - \theta_f$ are able to optimally reset their price. The optimal price determined as follows:

$$P_{f,t}^{\blacksquare} = \frac{\epsilon_f}{\epsilon_f - 1} \frac{E_t \sum_{s=0}^{\infty} (\beta \theta_f)^s P_{f,t+s} Y_{f,t+s} \Psi_{t+s}}{E_t \sum_{s=0}^{\infty} (\beta \theta_f)^s Y_{f,t+s}} \tag{29}$$

While the law of motion for the pricing of imported goods is:

$$P_{f,t} = \left[\theta_f P_{f,t-1}^{1-\epsilon_f} + (1 - \theta_f)(P_{f,t}^{\blacksquare})^{1-\epsilon_f}\right]^{\frac{1}{1-\epsilon_f}}. \tag{30}$$

Lastly, the oil firm combines domestically produced materials, M_t, and oil-related capital, $K_{o,t}$, using a constant return to scale Cobb-Douglas production function to produce oil as follows:

$$Y_{o,t} = A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m}, \tag{31}$$

where $A_{o,t}$ denotes an exogenous oil sector technology, and the elasticities of oil production to capital and domestically produced materials are represented by α_o^k and $\alpha_o^m \in (0,1)$, respectively. There is an inflow of foreign direct investment, $FDI_{o,t}^{*}$, into the oil sector, which is used to accumulate oil-related capital as follows:

$$K_{o,t} = (1 - \delta_o)K_{o,t-1} + FDI_{o,t}^{*}, \quad (32)$$

where the depreciation rate of oil-related capital is denoted by δ_o. The inflow of foreign direct investment to the oil sector is a function of its past value and the real international price of oil:

$$FDI_{o,t}^{*} = \left(FDI_{o,t-1}^{*}\right)^{\rho_{fdi}}\left(p_{o,t}^{*}\right)^{1-\rho_{fdi}}. \quad (33)$$

We assume that the real international price of oil and the oil technology are driven by the following exogenous processes:

$$p_{o,t}^{*} = \left(p_{o,t-1}^{*}\right)^{\rho_o} \exp\left(\xi_t^{p_o^*}\right), \quad A_{o,t} = \left(A_{o,t-1}\right)^{\rho_{a_o}} \exp\left(\xi_t^{A_o}\right). \quad (34)$$

The produced oil is sold at an international price, $p_{o,t}^{*}$, to the rest of the world. Thus, oil exports constitute an important source of government revenue and foreign exchange earnings in the economy. The government earns from the oil sector by collecting royalties on production quantity based on a rate, κ.

A1.5 Fiscal policy

The budget constraint of the government is expressed in terms of oil and non-oil revenues and expenditure as follows:

$$\tau_t + OR_t + B_t = P_{g,t}G_t + OS_t + \frac{B_{t+1}}{R_t}. \quad (35)$$

On the revenue side, the government earns from oil, OR_t; collects lump-sum tax, τ_t; and issues one period bonds, B_t. As earlier stated, government's oil revenues, OR_t, are based on royalty rate, κ, levied on the oil firm's production quantity:

$$OR_t = \kappa\varepsilon_t p_{o,t}^{*} Y_{o,t}, \quad (36)$$

On the expenditure side, the government spends on public goods, G_t, makes fuel subsidy payments, OS_t, and services its debt, $\frac{B_{t+1}}{R_t}$. As in Omotosho (2019), we assume that government consumption combines both domestically produced goods, $G_{h,t}$, and goods imported from the rest of the world, $G_{f,t}$. The treatment of fuel subsidy arrangement in our model follows the work of Allegret and Benkodja (2012), where the government pays the difference between the landing price of fuel, $P_{l,t}$, and the administratively determined retail pump price of fuel, $P_{r,t}$. Thus, the amount of fuel subsidy payment is computed as follows:

$$OS_t = \left(P_{l,t} - P_{r,t}\right)O_t, \quad (37)$$

where the imported fuel (O_t) is either consumed by households, $C_{o,t}$, - allowing us to measure the direct impact of an oil price shock on prices, or used up by non-oil goods producers, $O_{h,t}$ – allowing us to measure the indirect impact of an oil price shock on domestic prices. The law of motion for domestic fuel price is:

$$P_{r,t} = P_{r,t-1}^{1-\nu} P_{l,t}^{\nu}, \quad (38)$$

where the parameter ν is the subsidy parameter that determines the pass-through effect of international oil price to pump price of fuel. This parameter ranges from zero to one, where $\nu = 1$ characterises complete pass-through and the absence of subsidies. The fiscal rules are driven by debt, output, and oil-related flows as follows:

$$\tilde{g}_t = \rho_g \tilde{g}_{t-1} + \left(1 - \rho_g\right)\left[\omega_b \tilde{b}_{t-1} + \omega_{gy}\tilde{y}_{t-1} - \omega_{os}\widetilde{os}_t + \omega_{or}\widetilde{or}_t\right] + \xi_t^{g}, \quad (39)$$

$$\tilde{\tau}_t = \rho_\tau \tilde{\tau}_{t-1} + (1-\rho_\tau)\left[\varphi_b \tilde{b}_{t-1} + \varphi_y \tilde{y}_{t-1} - \varphi_{os}\widetilde{os}_t + \varphi_{or}\widetilde{or}_t\right] + \xi_t^\tau, \quad (40)$$

where $\omega_b, \omega_{gy}, \omega_{os}$ and ω_{or} measure the response of government consumption to debt, domestic output, fuel subsidies, and oil revenues respectively. Also, φ_b, φ_y , φ_{os} and φ_{or}, measure the sensitivity of taxes to debt, domestic output, fuel subsidies, and oil revenues, respectively. The parameters ρ_g and ρ_τ capture the degrees of inertia in the fiscal rules. It is important to note that the parameter ω_{gy} captures the notion of fiscal cyclicality while an estimated value for the parameter φ_{or} determines the possible existence of revenue substitution in the economy.

A1.6 Monetary policy

The central bank conducts monetary policy based on a simple Taylor rule that adjusts the short-term nominal interest rate, $\tilde{R}_t$, in line with deviations of aggregate inflation, $\tilde{\pi}_t$, domestic output, $\tilde{y}_{h,t}$, and the real exchange rate, $\tilde{q}_t$, from their steady state levels. Thus, the log-linearised monetary rule is of the form:

$$\tilde{R}_t = \rho_r \tilde{R}_{t-1} + (1-\rho_r)\left[\omega_\pi \tilde{\pi}_t + \omega_y \tilde{y}_{h,t} + \omega_q \tilde{q}_t\right] + \xi_t^r, \quad (41)$$

where the central bank's feedback coefficients on inflation, domestic output and real exchange rate are ω_π, ω_y and ω_q, respectively. The parameter ρ_r captures the degree of monetary policy inertia. The monetary policy shock, ξ_t^r, is assumed independent and identically distributed (iid).

A1.7 Market clearing and aggregation

The aggregate GDP, Y_t, combines both oil ($Y_{o,t}$) and non-oil output ($Y_{h,t}$) as follows:

$$P_t Y_t = P_{h,t} C_{h,t} + P_{h,t} M_t + P_{h,t} I_{h,t} + P_{h,t} G_{h,t} + NX_t. \quad (42)$$

The net exports, NX_t, is measured as the difference between aggregate exports, EX_t, and aggregate imports, IM_t. The aggregate exports consist of oil exports and non-oil exports while aggregate imports also combine oil imports and non-oil imports. Given that imported products are not only consumed and invested by households, but also consumed by the government, the total quantity of non-oil goods import into the economy is given by: $Y_{f,t} = C_{f,t} + I_{f,t} + G_{f,t}$. The Balance of Payments (BOP) equation is derived by equating the current account with the financial account as follows:

$$\frac{q_t b_t^*}{R_t^* \mu_t^*} = q_t b_{t-1}^* + nx_t - (1-\tau) q_t p_{o,t}^* y_{o,t} + q_t fdi_{o,t}^*, \quad (43)$$

A1.8 Rest of the world

Similar to the construct for the domestic economy, the IS curve for the foreign economy is as follows:

$$\frac{1}{R_t^*} = \beta E_t\left[\left(\frac{C_{t+1}^{R*} - \phi_c^* C_t^*}{C_t^{R*} - \phi_c^* C_{t-1}^*}\right)^{-\sigma^*} \frac{1}{\pi_{t+1}^*}\right], \quad (44)$$

where the parameter ϕ_c^* measures habit formation and σ^* is the relative risk aversion coefficient. The foreign economy is large and faces a downward sloping demand schedule for the tradable goods produced in the domestic economy as follows:

$$C_{h,t}^* = \gamma^* \left(\frac{P_{h,t}^*}{P_t^*}\right)^{-\eta^*} C_t^*, \quad (45)$$

where the share of domestic goods in the foreign economy's total consumption is γ^* and the elasticity of demand for the goods produced in the domestic economy is represented by η^*. Finally, the foreign central bank follows a Taylor rule in setting short term nominal interest rate, $\tilde{R}_t^*$ as follows:

$$\tilde{R}_t^* = \rho_{r^*} \tilde{R}_{t-1}^* + (1-\rho_{r^*})\left[\omega_{\pi^*} \tilde{\pi}_t^* + \omega_{y^*} \tilde{y}_{h,t}^*\right] + \xi_t^{r^*}, \quad (46)$$

where ρ_{r^*} measures monetary policy inertia. The response of policy-controlled interest rate to deviations in inflation and output from their respective steady state levels are ω_{π^*} and ω_{y^*}.

Appendix B

Table B.1: Calibrated parameters

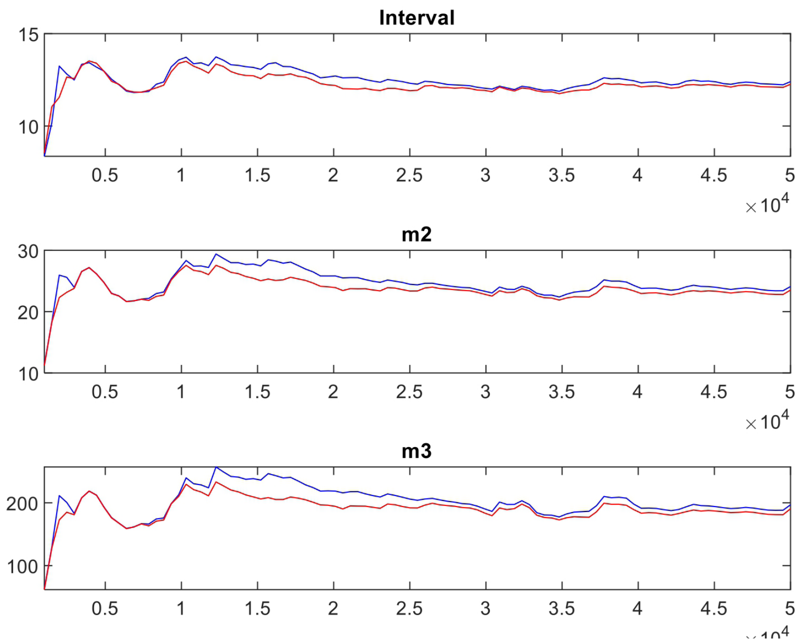
Description	Value	Source
Discount factor, β	0.990	Iklaga (2017)
Capital depreciation rate, $\delta_h = \delta_o$	0.025	Iklaga (2017)
Imports share in consumption goods, γ_c	0.400	Gali and Monacelli (2005)
Fuel share in household consumption, γ_o	0.085	Omotosho (2019)
Imports share in investment goods, γ_i	0.200	Omotosho (2019)
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 (2019)
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 (2019)
Elasticity of materials input in oil production, α_o^m	0.300	Omotosho (2019)
Substitution elasticity in govt. consumption, η_g	0.600	Hollander et al. (2018)
Household share in fuel imports, γ_{co}	0.750	Omotosho (2019)
Foreign direct investment persistence, ρ_{fdi}	0.300	Omotosho (2019)
Calvo parameter for exports, , θ_{hf}	0.750	Medina and Soto (2007)
Foreign relative risk aversion, σ^*	1.000	Hollander et al. (2018)
Foreign habit formation, ϕ_c^*	0.000	Hollander et al. (2018)
Intra-temporal elasticity in foreign demand, $\eta_{c_h^*}$	0.790	Omotosho (2019*b*)
Inflation in Taylor Rule - foreign economy, ω_{π^*}	1.500	Hollander et al. (2018)
Output in Taylor Rule - foreign economy, ω_{y^*}	0.500	Hollander et al. (2018)

Table B.2: Priors and Posterior Estimates

	Prior distribution			Posterior distribution	
Parameter	Density	Mean	Std. Dev.	Mean	90% HPD Int.
Structural parameters					
Ricardian consumers: γ_R	Beta	0.60	0.10	0.610	0.511 – 0.714
Labour supply elasticity: φ	Gamma	1.45	0.10	1.439	1.271 – 1.601
Relative risk aversion: σ	Inv. Gamma	2.00	0.40	1.334	1.077 – 1.584
External habit: ϕ_c	Beta	0.70	0.10	0.477	0.335 – 0.618
Investment adj. cost: χ	Gamma	4.00	3.00	5.611	2.201 – 8.946
Fuel pricing parameter: ν	Beta	0.30	0.10	0.402	0.223 – 0.576
Oil - core cons. elasticity: η_o	Gamma	0.20	0.10	0.224	0.049 – 0.386
For. - dom. cons. elasticity: η_c	Gamma	0.60	0.20	0.618	0.272 – 0.935
For. - dom. inv. elasticity: η_i	Gamma	0.60	0.20	0.641	0.279 – 0.963
Calvo - domestic goods: θ_h	Beta	0.70	0.10	0.896	0.811 – 0.983
Calvo - imported goods: θ_f	Beta	0.70	0.10	0.657	0.456 – 0.843
Policy parameters					
Taylor rule - inflation: ω_π	Gamma	1.500	0.20	2.485	1.991 – 3.078
Taylor rule - output: ω_y	Gamma	0.125	0.05	0.248	0.104 – 0.380
Taylor rule - exch. rate:ω_s	Gamma	0.125	0.05	0.153	0.052 – 0.251
Interest rate smoothing: ρ_r	Beta	0.500	0.25	0.430	0.285 – 0.587
Fiscal policy cyclicality: ω_{yo}	Normal	0.400	0.50	1.090	0.854 – 1.309
Govt. spending persistence: ρ_g	Beta	0.500	0.25	0.023	0.000 – 0.042
Tax response to debt: φ_b	Normal	0.400	1.00	0.103	-0.992 – 1.182
Tax response to debt: φ_g	Normal	0.950	1.00	0.399	-0.269 – 1.029
Tax response to debt: φ_{os}	Normal	0.100	1.00	0.993	0.444 – 1.502
Tax response to debt: φ_{or}	Normal	0.300	1.00	0.513	-0.264 – 1.224
Tax persistence	Beta	0.500	0.25	0.543	0.362 – 0.713
Autoregressive coefficients of shocks					
Dom. productivity: ρ_{a_h}	Beta	0.5	0.25	0.954	0.905 – 0.998
Oil productivity: ρ_{a_0}	Beta	0.5	0.25	0.948	0.905 – 0.994
Dom. risk premium: ρ_μ	Beta	0.5	0.25	0.655	0.584 – 0.718
Law of one price gap-oil: ρ_{ψ^o}	Beta	0.5	0.25	0.558	0.264 – 0.806
Int'l oil price shock: $\rho_{p_o^*}$	Beta	0.5	0.25	0.919	0.867 – 0.974
For. risk premium: ρ_{μ^*}	Beta	0.5	0.25	0.868	0.800 – 0.940
For. inflation: $\rho_t^{\pi^*}$	Beta	0.4	0.25	0.137	0.001 – 0.261
For. monetary policy: ρ_{r^*}	Beta	0.5	0.25	0.445	0.309 – 0.582
Standard deviation of shocks					
Dom. productivity: $\varepsilon_t^{a_h}$	Inv. Gamma	0.1	4	0.051	0.029 – 0.072
Oil productivity:$\varepsilon_t^{a_o}$	Inv. Gamma	0.1	4	0.217	0.187 – 0.247

Dom. risk premium: ε_t^{μ}	Inv. Gamma	0.1	4	0.214	0.171 – 0.254
Govt spending:ε_t^{gc}	Inv. Gamma	0.1	4	0.044	0.033 – 0.055
Law of one price gap-oil: $\varepsilon_t^{\psi^o}$	Inv. Gamma	0.1	4	0.895	0.504 – 0.126
Dom. monetary policy: ε_t^{r}	Inv. Gamma	0.1	4	0.326	0.259 – 0.389
Tax: ε_t^{tx}	Inv. Gamma	0.1	4	0.174	0.149 – 0.200
Dom. Supply: ε_t^{ss}	Inv. Gamma	0.1	4	0.044	0.030 – 0.058
Int'l oil price shock: $\varepsilon_t^{p_o^*}$	Inv. Gamma	0.1	4	0.153	0.133 – 0.173
For. risk premium: $\varepsilon_t^{\mu^*}$	Inv. Gamma	0.1	4	0.041	0.033 – 0.050
For. inflation: $\varepsilon_t^{\pi^*}$	Inv. Gamma	0.01	4	0.005	0.004 – 0.006
For. monetary policy: $\varepsilon_t^{r^*}$	Inv. Gamma	0.1	4	0.102	0.081 – 0.122

Figure B.1: Multivariate convergence diagnostics



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