Oil Price Shocks and Macroeconomic Policy in Resource-Rich Emerging Economies

by

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Abstract

This thesis is a collection of three papers aimed at investigating the macroeconomic effects of oil price shocks on resource-rich economies as well as the appropriate policy responses for ameliorating such effects. The first paper begins by examining the implications of physical capital and oil intensity of domestic production for the response of a small open economy to an oil price shock. Building on the work by Ferrero and Seneca (JMCB 2019), we find that the introduction of physical capital amplifies the responses of output and inflation to oil price shocks whereas the effects are attenuated by the oil intensity in domestic production. Also, our results reveal that the added features are important for the response of monetary policy to an oil price shock. Under our model set up, the optimal monetary policy response requires that the central bank keeps an eye not only on output and inflation, but also the exchange rate. These results highlight the need for cautious interpretation of the quantitative impacts of an oil price shock generated based on New Keynesian models of oil producing economies that abstract from capital. Paper 2 studies the role of oil price shocks in driving business cycle fluctuations of an oil-producing emerging economy with an inefficient fuel subsidy regime. Results from our estimated DSGE model for the Nigerian economy show that output fluctuations are driven mainly by oil and monetary policy shocks in the short run. However, oil shocks play a less prominent role in driving inflation dynamics owing partly to the low pass-through effect of international oil price into domestic prices implied by the fuel subsidy regime. While we find the core inflation-based Taylor rule optimal, we demonstrate that the Central Bank of Nigeria (CBN) faces a dilemma of either stabilising output or inflation in the face of an adverse oil price shock. Simulation results show that an "across-the-board" monetary policy strategy does not exist for dealing with an oil price shock in the resource-rich economy; thus, it is important that the CBN is aware of the observed trade-offs. The last paper investigates monetary-fiscal interactions in a resource-rich emerging economy whose fiscal policy is largely driven by resource-related flows. To achieve this, we analyse Nigeria's experience over the last two decades by developing and estimating a suitable DSGE model. Our results provide convincing evidence of an active monetary and passive fiscal policy over the full sample. Furthermore, we confirm the presence of revenue substitution; a phenomenon that alters the "automatic stabilisers" role of fiscal policy in the resource-rich economy. The 2008/09 global financial crisis did not significantly alter these findings. However, our results are sensitive to (i) the response of fiscal policy to resource-related flows and (ii) the response of monetary policy to exchange rate.

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Author's Declaration

I declare that, except where explicit reference is made to the contribution of others, this thesis is the result of my own work and has not been submitted in any previous application for a higher degree at the University of Glasgow or any other institution. The copyright of this thesis rests with the author. No quotation from it should be published in any format, without the author's prior written consent. Any material used or information derived from this thesis should be acknowledged appropriately.

Babatunde S. Omotosho

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Dissemination

In the course of working on this thesis, I have submitted parts of the chapters for publication. Those that have been published include:

1. Omotosho B. S. (2019). Oil price shocks, fuel subsidy and macroeconomic (in)stability in Nigeria. *CBN Journal of Applied Statistics* 10(2), 1-38.

2. Omotosho B. S. (2019). Business cycle drivers in Nigeria: some insights from an estimated DSGE model. *West African Journal of Monetary and Economic Integration*, 19(1).

List of Abbreviations

AR	Autoregression
CBN	Central Bank of Nigeria
CES	Constant Elasticity of Substitution
CITR	CPI Inflation-based Taylor Rule
CPI	Consumer Price Index
DITR	Domestic Inflation-based Taylor Rule
DSGE	Dynamic Stochastic General Equilibrium
EOMP	Expected Open Market Price
FDI	Foreign Direct Investment
FGN	Federal Government of Nigeria
FRED	Federal Reserve Economic Data
FTPL	Fiscal Theory of Price Level
GDP	Gross Domestic Product
GFC	Global Financial Crisis
HPD	Highest Posterior Density
IMF	International Monetary Fund
IRF	Impulse Response Function
LOP	Law of One Price
MCMC	Monte Carlo Markov Chain
MPC	Monetary Policy Committee
MPR	Monetary Policy Rate
NBS	National Bureau of Statistics
OPEE	Oil-Producing Emerging Economy
OSR	Optimised Simple Rules
PEP	Peg the Export Price
PPPRA	Petroleum Products Pricing Regulatory Agency
RER	Real Exchange Rate
RREE	Resource-Rich Emerging Economy
SWF	Sovereign Wealth Fund
TANK	Two Agents New Keynesian
TR	Taylor Rule
VAR	Vector Autoregression

Chapter 1

Introduction

Over the last three decades, oil has remained an important source of energy for households and firms, accounting for about 35 per cent of total energy supply globally (IEA, 2019)[1]. Also, about 15-20 per cent of the global value added is accounted for by commodity-exporting countries (Bergholt and Larsen, 2016). Thus, oil price shocks have implications not only for the welfare of households, but also global macroeconomic stability. For instance, oil price shocks have been known to be capable of altering consumption decisions of households (Kilian, 2008); distorting the production plans of firms (Backus and Crucini, 2000; Mork, Mysen and Olsen, 1990); disrupting fiscal and balance of payment positions of countries (Cashin, Liang and McDermott, 2000); and generating output and welfare losses (Carruth, Hooker and Oswald, 1998; Mork et al., 1990). Also, changes in oil price have been associated with external reserves volatility, exchange rate instability, inflation volatility, and severe macroeconomic imbalances in resource-rich emerging economies (Adeniyi, Oyinlola and Omisakin, 2011; Akinleye and Ekpo, 2013; Richard and Olofin, 2013). Therefore, developments in the international oil market will continue to attract significant interests from macroeconomists in both oil-importing and oil-exporting countries[2].

The macroeconomic impacts of oil price shocks are not homogeneous across countries for a number of reasons. One of the reasons for the varied outcomes relates to whether the economy in question is a net importer or exporter of oil (Cunado and De Gracia, 2005; Mork et al., 1990). Whereas a number of studies have found empirical support for an inverse

[1]In net oil-exporting countries, it also represents a major source of foreign exchange earnings and fiscal revenues.

[2]Barsky and Kilian (2004) highlights the view that political turmoils in oil producing Middle East countries generate recessions in advanced economies through their effect on oil price.

relationship between oil price increases and output in net oil-importing countries such as the United States (Hamilton, 1983); a positive relationship has been reported for some oil exporting Middle East and North African (MENA) countries, such as Algeria, Iran, Iraq, Kuwait and Libya (Berument, Ceylan and Dogan, 2010). Also, the macroeconomic impacts of oil price shocks are usually more severe in small open Oil-Producing Emerging Economies (OPEEs) as they exhibit certain characteristics that exacerbate their vulnerabilities. Such characteristics include high oil dependence (Barrell, Kirby and Liadze, 2008; Salti, 2008); presence of hand-to-mouth consumers and financial market inefficiencies (Hallegatte and Przyluski, 2011); inefficient fuel subsidy programmes (Coady, Parry, Sears and Shang, 2017); fiscal volatility and pro-cyclicality (Abdih, Lopez-Murphy, Roitman and Sahay, 2010; Barnett and Ossowski, 2002); revenue substitution (Tijerina-Guajardo and Pagán, 2003); low policy buffers (Hallegatte and Przyluski, 2011); and high oil imports dependence arising from low domestic capacity and weak economic structures (Rodrik, 1999); among others. In this thesis, we argue that some of these features have significant implications for the response of OPEEs to oil price shocks.

Several theoretical and empirical studies have extensively examined the macroeconomic effects of oil price shocks in the context of oil-importing advanced economies, especially the United States[3]. For these economies, the consensus among scholars is that oil price increases cause economic recessions, excessive inflation and lower productivity (Barsky and Kilian, 2004). In contrast, little and sometimes mixed evidences have been documented for OPEEs. Consequently, questions regarding the quantitative impacts of oil price shocks, its transmission mechanism and appropriate macroeconomic policy response remain open in those economies. Therefore, the objective of this thesis is to contribute to the literature on the oil-macroeconomy nexus in OPEEs, taking cognisance of some of the idiosyncratic characteristics of those countries. The thesis comprises three papers, each addressing specific questions. The main ideas and findings of the papers are discussed next.

In the first paper, we focus on the implications of abstracting from two key features in DSGE models of OPEEs: These are (1) capital accumulation and (2) oil intensity of output. Most DSGE models commonly used for the analysis oil price shocks and monetary

[3]See for instance Barsky and Kilian (2001); Bodenstein, Erceg and Guerrieri (2011); Hamilton (2009); Kilian (2008); Lorusso and Pieroni (2018). The advanced oil-importing economies possess features (including developed financial markets, high policy buffers, strong domestic production capacity, etc.) that cause them to respond to oil price shocks differently from their less-developed oil-exporting counterparts. These features ameliorate the size and persistence of the impacts of an oil price shock.

policy in OPEEs often abstract from these two key features for the reason of tractability (see e.g. Ferrero and Seneca 2019; Romero 2008). In the paper, we allude to the argument by Vásconez, Giraud, Mc Isaac and Pham (2015) that such a decision to ignore capital is hard to defend on both theoretical and empirical grounds. Apart from the need to reflect the highly capital intensive nature of oil production, abstracting from capital neutralises the investments dynamics of domestic firms in response to real interest rate changes and limits the strength of the interest rate channel of monetary policy transmission (Rupert and Šustek, 2016). Also, failure to allow for oil intensity of output mutes the indirect effects of oil price shocks on domestic prices (Barsky and Kilian, 2004).

To investigate these issues, we build on the DSGE model of Ferrero and Seneca (2019), extending it along two major dimensions. First, we add capital and introduce real rigidity into the model via an investment adjustment cost. Second, oil is incorporated as a factor input in the production technology of domestic firms. We evaluate the implications of these added features for OPEEs facing an oil price shock by comparing simulation results under three different model variants. In addition, we assess the relative performance of alternative monetary policy rules under each model variant based on a central bank policy loss function. In order to generate quantitative results, we calibrate the model to the Norwegian economy with most of the parameter values taken from Ferrero and Seneca (2019).

Our simulation results show that a negative oil price shock contracts domestic output and increases aggregate inflation, consistent with the findings of Ferrero and Seneca (2019). Notably, the addition of capital to Ferrero and Seneca's (2019) model amplifies these responses; implying potential under-estimation of the effects of an oil price shock by DSGE models of small open OPEEs that abstract from capital. Furthermore, we find that the investment dynamics of firms in response to interest rate adjustments cause the economy to rebound faster under the extended model. Second, accounting for oil intensity of domestic production ameliorates the contractionary effects of an oil price shock on output and dampens inflationary pressures arsing from a depreciated real exchange rate. These results highlight the need for caution in the interpretation of the quantitative impacts of oil price shocks generated based on DSGE models of OPEEs that abstract from capital and oil intensity.

Third, monetary policy analyses conducted reveal that domestic inflation-based Taylor rules yield lower losses compared to their headline inflation-based counterparts regardless of whether the model features capital accumulation and oil intensity or not. Contrary to the findings of Ferrero and Seneca (2019), allowing for interest rate inertia in the central bank's reaction function reduces policy loss under the model with capital. The inclusion of exchange rate in the Taylor rule improves performance, regardless of whether the policy rule responds to CPI inflation or domestic inflation. These findings are robust to changes in the parameters of the central bank loss function. Thus, a Taylor rule that features domestic inflation, output, real exchange rate, and interest rate inertia represents an optimal monetary policy response to a negative oil price shock under our extended model. This is contrary to the findings under the model without capital, where simple rules without interest rate inertia and exchange rate yield superior outcomes. In all, our conclusion from the first paper is that the introduction of physical capital and oil intensity to a small open DSGE model of an oil-exporting economy matter for (i) the response of the economy to an oil price shock and (2) the choice of monetary policy response.

Paper 2 examines business cycle dynamics in small open OPEEs with particular attention to the roles of oil price shocks and fuel consumption subsidies. In addition, we study the design of monetary policy under an economic environment characterised by fiscal cyclicality and additional domestic price rigidities arising from a retail fuel pricing rule. Thus, we pose a number of pertinent questions that have been ignored in the literature. First, how important is an oil price shock in driving business cycle fluctuations in small open OPEEs with an inefficient fuel subsidy regime? Second, what is the appropriate monetary policy response to an oil price shock under an economy with incomplete pass-through of international oil prices to domestic fuel price? Third, how relevant is Frankel's (2003) export price-based monetary policy rule for an oil-producing economy with a fuel subsidy regime facing an oil price shock? Fourth, how important is the nature of fiscal cyclicality for the achievement of monetary policy objectives in the oil-producing economy? Fifth, does the presence of hand-to-mouth consumers matter for the economy's response to an oil price shock? Sixth, what are the macroeconomic implications of fuel subsidy reforms for the small open oil-producing economy?

We address these questions by extending the model developed in the first paper, taking cognisance of a number of features that are unique to resource-rich emerging economies. Thus, our model features (i) a fuel pricing rule that introduces additional rigidity to domestic prices and connotes an implicit fuel subsidy regime, (ii) presence of hand-to-mouth consumers, (iii) oil intensity of domestic non-oil production, (iv) oil in household consumption basket, and (v) fiscal policy cyclicality. Closely related to our model are those developed by Algozhina (2015); Allegret and Benkhodja (2015); Gali and Monacelli (2005); Medina and

Soto (2005); Romero (2008) and Ferrero and Seneca (2019). The model developed in the paper is useful not only for the study of business cycle dynamics in resource-rich, resource-dependent emerging economies with a subsidy regime, but also the joint analysis of monetary and fiscal policies in such economies. In all, ten types of structural shocks are incorporated to drive the stochastic dynamics of the model. We employ Bayesian likelihood approach to estimate the model for the Nigerian economy using data on eleven macro-economic variables[4].

We document a number of useful findings. First, the estimated fuel pricing rule indicates that the pass-through effect of international oil prices into domestic fuel price for Nigeria is about 43 per cent. This estimated fuel pricing rule adds additional stickiness to domestic prices which in turn alters the dynamics of aggregate inflation and the response of monetary policy to an oil price shock. To our knowledge, this represents the first attempt at estimating such pass-through coefficient for an oil producing emerging economy with a fuel subsidy regime. Second, results from the forecast error variance decomposition reveal that monetary policy and oil-related shocks are important drivers of output in the short run while domestic supply shocks explain most of the fluctuations in the medium to long term horizons. On the other hand, inflation dynamics are largely driven by monetary policy and domestic supply shocks both in the short and medium term horizons. Oil shocks play a less prominent role in inflation dynamics due to the low pass-through effects implied by the estimated fuel pricing rule.

Third, a negative oil price shock generates a highly persistent negative impact on total GDP and a short-lived positive effect on headline inflation. The contractionary effect of an oil price shock on output is amplified by the fuel subsidy regime and the presence of hand-to-mouth consumers in the short run. Fourth, our results show that the central bank faces a dilemma of either stabilising output or inflation in the aftermath of an oil price shock. While a core inflation-based monetary policy rule outperforms its competitors in stabilising prices and exchange rate, it leads to a significant output loss in the short run. On the other hand, the domestic inflation-based Taylor rule is useful for output stabilisation. Fifth, we fail to find empirical support for the relevance of "Peg the Export Price" (PEP) hypothesis canvassed by Frankel (2003) in stabilising prices and output. While the export price-based Taylor rule reverses the contractionary effect of an oil price shock on total GDP, such an outcome is at the expense of overall domestic macroeconomic stability. Thus, there

[4]The choice of Nigeria is based on the fact that its economy typifies the key features of our model. The sample period covers 2000:Q2 - 2018:Q2.

is no "across-the-board" and "all-seasons" monetary policy strategy for dealing with adverse terms of trade shocks in the resource-rich economy. It is important that the Central Bank of Nigeria (CBN) is aware of the policy trade-offs while designing monetary policy strategies for responding to emerging shocks in Nigeria.

Sixth, the removal of fuel subsidy attenuates the contractionary effects of a negative oil price shock on aggregate GDP in the short run but generates a more depreciated exchange rate. However, the effects of exchange rate depreciation on headline inflation is more than offset by the moderation in domestic inflation; causing the headline inflation to fall. Thus, contrary to the case under the fuel subsidy regime, the central bank responds to a negative oil price shock with an interest rate cut under the no-subsidy regime. Such expansionary monetary policy move ameliorates the contractionary effects of a negative oil price shock on aggregate GDP. Seventh, we find evidence of pro-cyclical fiscal policy and show, based on counterfactual simulations, that macroeconomic stability gains exist under a counter-cyclical fiscal regime. Finally, monetary policy evaluation based on a specified central bank loss function shows that the core inflation-based monetary policy rule that features output and real exchange rate ranks best; thus constituting a useful strategy for stabilising the economy in the face of an oil price shock.

In paper 3, we study monetary and fiscal policy interaction in a resource-rich emerging economy whose fiscal policy is substantially driven by resource-related flows. To this end, we develop a DSGE model that allows for (i) resource earnings in the fiscal rule and (ii) a fuel subsidy regime that places an additional fiscal burden on the government and impacts on the evolution of domestic prices. These features matter for the behaviour of monetary and fiscal authorities as well as the way they interact. The model is estimated for the Nigerian economy using data on fifteen macroeconomic variables for the period 2000Q2 - 2018Q2.

We report a number of useful findings. First, we find empirical evidence in support of active monetary and passive fiscal policy over the sample period. This policy mix generates a stable equilibrium in the sense of Leeper (1991), and is therefore consistent with the implementation of a successful inflation targeting framework. Second, our results show that taxes fall while government consumption declines in response to an increase in debt; implying that government spending plays a critical role in the achievement of government's debt objectives. In rational expectations equilibrium, primary deficit falls in response to increasing debt levels. Third, the estimated tax rule confirms the presence of substitution effects between tax and oil revenues, a phenomenon that alters the role of fiscal policy as automatic stabilisers in the resource-rich economy.

Next, we explore how the monetary-fiscal narrative has evolved over time by splitting the dataset into two sub-samples based on the occurrence of the 2008/09 global financial crisis as follows: (i) pre-GFC sample, 2000Q2-2008Q4 and (ii) post-GFC sample, 2009Q1-2018Q2. We find a stable equilibrium characterised by an active monetary and passive fiscal policy across the two sample periods, implying that the GFC did not alter the nature of policy interaction in the country. However, we find that both monetary and fiscal policy are less persistent in the post-GFC period. Our finding with regards to the fiscal feedback coefficient in the tax rule is sensitive to (i) the response of fiscal policy to oil-related flows and (ii) the response of monetary policy to the real exchange rate.

Chapter 2

Oil Price Shocks and Monetary Policy in Oil-Producing Economies: Does Capital Matter?

2.1 Introduction

Oil price shocks have been recognised as an important source of economic fluctuations in both oil importing and exporting countries, especially since the work of Hamilton (1983). Thus, debates on its macroeconomic implications, transmission mechanisms, and the response of monetary policy have remained of significant interest to policy makers as well as researchers (see for instance Allegret and Benkhodja, 2015; Bacchiocchi and Sarzaeem, 2015; Barsky and Kilian, 2004; Bergholt, 2014; Bergholt and Larsen, 2016; Bernanke, Gertler, Watson, Sims and Friedman, 1997; Berument et al., 2010; Bodenstein, Guerrieri and Kilian, 2012; Cunado and De Gracia, 2005; De Fiore, Lombardo and Stebunovs, 2006; Engemann, Kliesen and Owyang, 2011; Ferrero and Seneca, 2019; Hamilton, 2009; Hamilton and Herrera, 2004; Herrera and Pesavento, 2009; Lorusso and Pieroni, 2018; Medina and Soto, 2005). In oil-exporting economies, shocks to the resource market generate significant impacts on fiscal revenues, foreign exchange supply and overall economic performance (Backus and Crucini, 2000; Barsky and Kilian, 2004; Lorusso and Pieroni, 2018). However, the size and persistence of the macroeconomic impacts of such shocks are determined by the appropriateness of policy response (Berg, Portillo, Yang and Zanna, 2013; Hove, Mama and Tchana, 2015).

A plethora of studies have incorporated oil into standard new-Keynesian Dynamic Stochastic

General Equilibrium (DSGE) models to analyse the channels of oil shocks propagation to the domestic economy (see e.g. Algozhina, 2015; Allegret and Benkhodja, 2015; Benkhodja, 2014; Bergholt, 2014; Bergholt and Larsen, 2016; Bodenstein et al., 2012; Ferrero and Seneca, 2019; Hollander, Gupta and Wohar, 2018; Iklaga, 2017; Romero, 2008). However, a number of these models abstract from two key features: (1) capital accumulation and (2) oil intensity of domestic production[1]. In this paper, we argue that an assessment of the relevance of capital accumulation and oil intensity of domestic output in DSGE models of oil producing economies is important for a number of reasons. First, the process of oil production is highly capital intensive; thus, failure to feature physical capital in models of oil-producing economies is hard to defend on empirical grounds (Vásconez et al., 2015). Second, the exclusion of capital in New Keynesian models prevents an internal dynamic that allows households to smooth out the effects of output fluctuations on consumption. Third, an abstraction from capital neutralises the potential investment dynamics of firms in response to real interest rate changes. For instance, with lower interest rates, households prefer to consume rather than invest. The increased consumption and lower cost of capital cause firms to increase their investments and expand production; leading to an increase in aggregate demand. Fourth, shirking from capital limits the strength of the interest rate channel of monetary policy transmission (Rupert and Šustek, 2016). Also, since oil is an important factor of production, abstracting from oil intensity of output could lead to the under-estimation of the effects of an oil price shock on domestic production and prices (Barsky and Kilian, 2004)[2].

A recent strand of literature has focused on evaluating the role of capital in DSGE models of oil-importing advanced economies. For instance, Vásconez et al. (2015) show that the introduction of capital into a standard DSGE model for the United States, an oil importing country, amplifies the response of the economy to an oil price shock. However, the macroeconomic implications of ignoring capital in DSGE models of small open oil exporting economies remain unexplored in literature. To address this gap, we pose a number of questions. First, what are the macroeconomic implications of abstracting from capital in DSGE models of small open oil-producing economies facing an oil price shock? Second, does the inclusion of oil in the production technology of non-oil producing firms matter for the

[1]Most of the commonly used models for small open economies shirk from these features for the reasons of tractability (see e.g. Ferrero and Seneca (2019); Galí (2015); Romero (2008); Gali and Monacelli (2005), amongst others).

[2]Barrell et al. (2008) highlights the fact that oil intensity of output has been quite substantial and persistent globally.

economy's response to an oil price shock? Third, are these two features important for the choice of monetary policy response to oil price shocks?

This paper addresses these questions by building on the model developed by Ferrero and Seneca (2019) for the Norwegian economy. We develop three distinct models and benchmark our results against those reported in Ferrero and Seneca (2019). The baseline model, $mod3$, simply replicates Ferrero and Seneca (2019) by ignoring capital and assuming that labour is the only relevant input in the production technology of domestic non-oil producing firms. This model is presented in Appendix *A.1.3*. Next, we argue that apart from ignoring a critical part of aggregate demand, small open economy models that abstract from capital accumulation could also be obviating a crucial infrastructure through which monetary policy is transmitted to the real economy (Dennis, 2017). Thus, the second model, $mod2$, extends the baseline model ($mod3$) by introducing capital accumulation and adding capital into the production technology of the domestic firms. This model is presented in Appendix *A.1.2*. Finally, the benchmark model, $mod1$, extends the baseline model ($mod3$) by introducing capital accumulation and adding oil into the production technology of domestic non-oil producing firms. This model is described in detail in Section 2 of this paper and Appendix *A.1.1*. We address the research questions posed by comparing the responses of the economy under the alternative models. The relative performance of alternative monetary policy rules are assessed based on an assumed flexible inflation targeting ad-hoc loss function[3]. The model is calibrated to the Norwegian economy with most of the parameter values taken from Ferrero and Seneca (2019).

We document a number of interesting results. First, simulation results from our benchmark DSGE model show that a negative oil price shock contracts output and increases inflation in the resource rich economy, confirming the oil price shock propagation mechanism observed by Ferrero and Seneca (2019). However, the addition of capital accumulation amplifies these responses. This is consistent with the findings of Vásconez et al. (2015) for the US economy. Also, the economy recovers faster under the model with capital due to the investment response of domestic firms to interest rate changes. Second, including oil as a factor input in domestic production ameliorates the contractionary effects of an oil price shock on output and dampens inflationary pressures. To our knowledge, this effort repres-

[3]We abstract from studying welfare using the second order approximation of the household utility but rather adopt a standard quadratic loss function for the central bank. This is because our focus is on the identification of an appropriate policy response to an international oil price shock. Also, we introduce inertia into the policy rule, which would not be possible under the former.

ents the first attempt at analysing the macroeconomic implications of ignoring capital and oil intensity in DSGE models of small open oil-producing economies. Third, contrary to the findings of Ferrero and Seneca (2019), allowing for interest rate inertia in the central bank's reaction function reduces policy loss under our benchmark model. Fourth, a Taylor rule that features domestic inflation, output, real exchange rate, and interest rate inertia represents an effective monetary policy response to a negative oil price shock. This is contrary to our findings under the model without capital, where a flexible Taylor rule that responds only to domestic inflation and output yields superior outcomes. These findings highlight the need for a cautious interpretation of results emanating from DSGE models of small open oil-producing economies that abstract from capital and oil intensity.

The rest of the paper is laid out as follows. Section 2 presents a review of related literature. Section 3 presents the theoretical model and derives useful optimality conditions guiding the decisions of various agents in the economy. The equations derived in the section characterise the dynamics of the economy. We also calibrate the model in order to generate relevant quantitative results. Section 4 presents the impulse responses to an international oil price shock and explores the usefulness of alternative monetary policy responses. The roles of capital and oil intensity of output in the economy are also discussed in the context of the questions earlier posed. Section 5 concludes. In Appendix A, we present detailed derivations of the equilibrium conditions for the three model variants considered in the paper as well as some useful results.

2.2 Related Literature

This paper is connected to three major strands of literature relating to (i) the design of monetary policy in small open resource-rich economies, (ii) macroeconomic impacts of oil price shocks, and (iii) the use of specific model features to explain the discrepancies in the findings often reported under strands (i) and (ii). There are several theoretical and empirical studies that have addressed the first two strands. However, only a few have focused on the third strand, especially in relation to the roles of capital accumulation and oil intensity of domestic output. Table 2.1 provides a summary of the studies that are closely related to our paper.

The influential work of Gali and Monacelli (2005) provides a useful framework for studying small open economies and evaluating the usefulness of alternative monetary policy rules.

Under Gali and Monacelli's (2005) model set-up, the central bank achieves superior welfare outcomes by following a domestic inflation-based Taylor rule (DITR). This is followed by its CPI inflation-based counterpart and the exchange rate peg. The extent to which this policy ranking holds for small open resource-rich economies have been investigated by studies such as Algozhina (2015); Allegret and Benkhodja (2015) and Ferrero and Seneca (2019).

For instance, Ferrero and Seneca (2019) showed that the DITR is welfare optimal for the oil exporting economy of Norway while a number of other studies have argued that better macroeconomic outcomes are realisable under a monetary policy rule that responds to a core measure of inflation (Allegret and Benkhodja, 2015) or an exchange rate target (Algozhina, 2015). There is, therefore, no consensus among macroeconomists on a cross-cutting monetary policy strategy for dealing with structural shocks confronting small open resource-rich economies.

Also, studies on the macroeconomic impacts of an oil price shock have reported varied findings. The variation in findings are often explained by the nature of monetary policy response to the shock, the degree of oil intensity prevailing in the economy, as well as the circumstance of the economy with respect to its net oil-trading position (Bernanke et al., 1997; Cunado and De Gracia, 2005; Mork et al., 1990; Vásconez et al., 2015). For example, oil price increases are often associated with output contraction, inflationary pressures, and contractionary monetary policy response in net oil-importing countries (Bernanke et al., 1997; Hamilton, 1985; Medina and Soto, 2005,0; Vásconez et al., 2015). For net oil-exporting countries, varied responses to a positive oil price shock have been reported; including: higher output and prices (Allegret and Benkhodja, 2015), higher output and lower prices (Bergholt, 2014; Ferrero and Seneca, 2019), lower output and higher prices (Romero, 2008), as well as lower output and lower prices (Bergholt and Larsen, 2016). Differences in the prevailing exchange rate regime, the extent of the country's dependence on oil, the nature of monetary policy response, and modelling strategy are among the reasons for the mixed findings (Allegret and Benkhodja, 2015; Bergholt, 2014; Bergholt and Larsen, 2016; Ferrero and Seneca, 2019). For instance, macroeconomists differ in terms of how monetary policy should respond to an oil price increase. Whereas Allegret and Benkhodja (2015) prescribes monetary policy tightening, Bergholt and Larsen (2016) advocates monetary policy accommodation while studies such as Fischer (1985) argues for monetary policy restraint under certain circumstances (such as when fiscal policy is capable of addressing both inflation and unemployment concerns).

Table 2.1: Summary of related literature

Author	**Country**	**Modelling strategy**	**Findings**
Algozhina (2015)	Kazakhstan: oil exporter	Model: calibrated DSGE model with oil; capital accumulation: yes; oil in domestic production: yes; TR: CPI, product price, exchange rate	Exchange rate targeting rule with pro-cyclical fiscal policy is welfare optimal. Under this rule, a positive oil price shock increases output, reduces total inflation, depreciates the exchange rate, and leads to contractionary monetary policy.
Allegret and Benkhodja (2015)	Algeria: oil exporter	Model: estimated DSGE model with oil; capital accumulation: yes; oil in domestic production: yes; TR: CPI, core inflation and exchange rate	A positive oil price shock boosts output, increases inflation, and attracts a contractionary monetary policy. Core inflation TR rule emerged welfare optimal while exchange rate rule performs poorly, generating macroeconomic volatility.
Ferrero and Seneca (2019)	Norway: oil exporter	Model: simulated DSGE model with oil, capital accumulation: no; oil in domestic production: no; TR: CPI, domestic inflation and exchange rate	A negative oil price shock contracts total GDP for more than 20 quarters, increases headline inflation, depreciates the exchange rate, causes monetary policy tightening under CITR, and monetary policy easing under DITR. The DITR is welfare optimal.
Bergholt and Larsen (2016)	Norway: oil exporter	Model: estimated DSGE model with oil; capital accumulation: yes; oil in domestic production: no; TR: CPI	A positive oil price shock causes a short-lived contraction in output (only 2 quarters) followed by a boost, fall in headline inflation, appreciation of the real exchange rate and monetary policy easing.
Medina and Soto (2007)	Chile: oil importer	Model: estimated DSGE model with resource sector; capital accumulation: yes; oil in domestic production: yes; oil in domestic consumption: yes; TR: core inflation	A positive oil price shock contracts output, increases inflation, appreciates the real exchange rate and causes monetary policy tightening. The TR that features exchange rate amplifies the responses of output and prices. TR without exchange rate better stabilises inflation.
Romero (2008)	Mexico: oil exporter	Model: estimated DSGE model with oil; capital accumulation: no; oil in domestic production: yes; TR: CPI.	A positive oil price shock leads to a contraction in total output lasting about 30 quarters, rise in inflation, and a contractionary monetary policy.
Vasconez et al. (2015)	United States: oil importer	Model: estimated DSGE model; capital accumulation: yes; oil in domestic consumption: yes; oil in domestic production: yes; TR: core inflation.	A positive oil price shock contracts total GDP for over 40 quarters, increases domestic inflation, and leads to contractionary monetary policy. Reduction in oil dependency attenuates the impacts on domestic inflation and total GDP. Inclusion of capital amplifies the response of the economy to an oil price shock.

The third strand of literature, which is still relatively scanty, is related to studies aimed at explaining some of the varying results obtained in the analysis of the macroeconomic impacts of an oil price shock. Vásconez et al. (2015) represents the first attempt at investigating the implications of capital accumulation and oil dependency for the response of the US economy to an oil price shock within a DSGE framework. Having successfully replicated the stylised facts, the paper showed that capital accumulation amplifies the response of the economy to an oil price shock while a reduction in oil dependency attenuates its inflationary impacts. Till date, Vásconez et al. (2015) represents the only study that have reported the implications of capital accumulation and oil dependency for the response of an oil-importing economy to an oil price shock using a DSGE model. To our knowledge, no similar study exists for a net oil-exporting small open economy, a gap this paper intends to fill.

2.3 The Model

The model economy considered in this paper is a simple cashless New Keynesian small open economy model in the fashion of Gali and Monacelli (2005), extended by Ferrero and Seneca (2019) to include an oil sector. However, the benchmark model described in this section, $mod1$, departs from Ferrero and Seneca (2019) in several ways. First, we introduce capital into the model in order to study the role of savings and investment in an environment in which domestic capital and foreign financial assets act as vehicles of savings to the households. Physical capital is required for the production of both oil and non-oil goods. Second, we introduce real rigidity into the model via an investment adjustment cost to capital accumulation. Third, we permit oil intensity of domestic output by introducing oil into the production technology of non-oil producing firms in addition to capital and labour. This section presents a graphical overview of the model, describes the implied economic environment and derives the associated equilibrium conditions. The log-linearized version of the model as well as the exogenous processes are reported in Appendix *A.1.1*.

2.3.1 Graphical overview of the model

Figure 2.1 presents a bird's-eye view of our benchmark model ($mod1$). The model is populated by six categories of agents: households, final goods-producing firms, intermediate goods-producing firms, oil-producing firms, fiscal authority, and the central bank. The representative utility-maximizing household consumes both domestic and foreign goods as well as leisure. To finance its expenditures, the household supplies labour to non-oil producing firms (earning wages) and accumulates capital, which it leases to both oil and non-oil producing firms at a competitive rental rate. We assume households own the firms and thus receive their profits. Capital, which is accumulated subject to an adjustment cost is perfectly mobile between the oil and non-oil sectors. Finally, the representative household saves by holding a portfolio of domestic and foreign bonds.

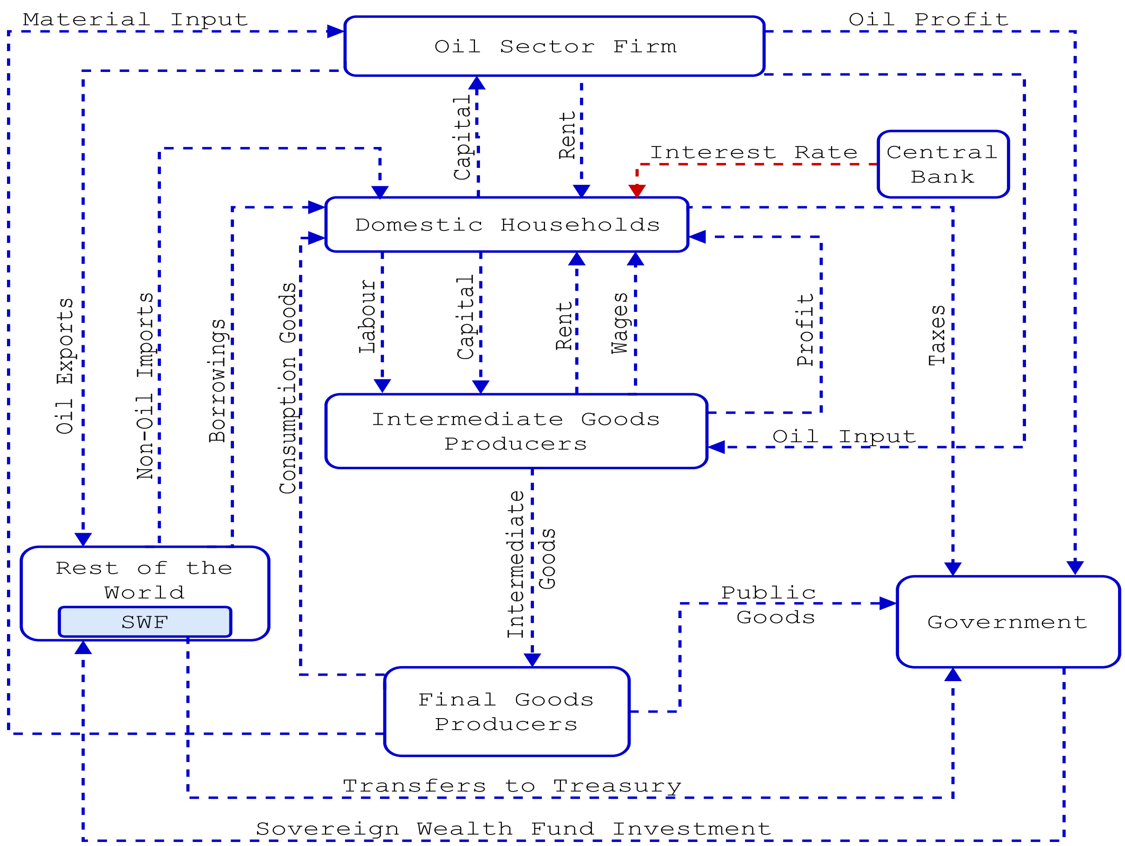

Figure 2.1: Flow chart of the economy

The final-goods producers operate in a perfectly competitive market and use an aggregation technology to bundle varieties of intermediate goods firms. The final goods are not only consumed by households and government, they are also used as input in the extraction technology of oil firms. On the other hand, the intermediate goods firms are monopolistic competitors who combine capital, oil, and labour inputs to produce differentiated goods indexed by $j \in [0, 1]$. The assumption of monopolistic competition in the intermediate goods sector allows for nominal rigidities in our model and a firm j in this sector who is able to set prices in period t is assumed to do so à la Calvo (1983).

The oil firms operate in a competitive market using a diminishing returns production technology that combines domestic materials produced by final-goods firms and capital supplied by households. The produced oil is sold to domestic intermediate goods firms while the residual is exported to the rest of the world at a price determined in the international oil market. The government provides public goods based on revenues received from tax and transfers from a sovereign wealth fund (SWF). Finally, the central bank implements a Taylor-type monetary policy rule by setting short term nominal interest rate in response to inflation and output. In what follows, we describe the economic environment and optimization problem of each of these agents in greater details.

2.3.2 Households

The representative household derives utility from consumption, C_t, and dis-utility from labour, N_t. This implies that the household's utility function is strictly increasing in C_t and decreasing in N_t. Therefore, the representative household optimizes its decisions by maximizing an expected discounted utility function given by

$$U_0 = E_0 \sum_{s=0}^{\infty} \beta^s \left(\ln C_{t+s} - \frac{N_{t+s}^{1+\varphi}}{1+\varphi} \right), \tag{2.1}$$

where E_0 denotes the mathematical expectation operator, $\beta \in (0,1)$ is a discount factor, and $\varphi > 0$ represents the inverse of the Frisch elasticity of labour supply. As in Ferrero and Seneca (2019), we define C_t as a composite consumption index given by a Cobb-Douglas bundle of imported goods, $C_{f,t}$, and domestically produced goods, $C_{h,t}$, such that

$$C_t \equiv \frac{C_{h,t}^{1-\gamma} C_{f,t}^{\gamma}}{\gamma^{\gamma} (1-\gamma)^{1-\gamma}}, \tag{2.2}$$

where γ is a parameter that represents the economy's degree of openness. It measures the share of domestic consumption devoted to imported goods[4]. The budget constraint facing

[4]In the case of a closed economy, $\gamma = 0$ and equation (2.2) collapses to $C_t = C_{H,t}$

the household is given as[5]

$$P_tC_t + P_tI_t + Q_tB_{t+1} + Q_t^*\varepsilon_tB_{t+1}^* = W_tN_t + R_{h,t}K_t + B_t + \varepsilon_tB_t^* + D_t - TX_t. \tag{2.3}$$

On the income side of equation (2.3), four sources are obvious. First, N_t hours of work are supplied at a nominal wage rate, W_t, yielding a labour income, W_tN_t. Second, the household owns an amount of capital, K_t, which it leases to the domestic firms at a rental rate, $R_{h,t}$, to generate a capital income, $R_{h,t}K_t$. Third, the household receives an aliquot share, D_t from the profits of the firms. As in Gali and Monacelli (2005), we assume that households have unfettered access to a complete set of contingent claims traded abroad. Thus, the household enters the period with the stock of nominal domestic bonds, B_t, and foreign bonds, B_t^* maturing in period $t+1$. B_{t+1} and B_{t+1}^* represent household's investments in domestic and foreign bonds at the end of period t, respectively while the nominal exchange rate is denoted by ε_t. As in Galí (2015), each domestic and foreign bond pays one unit of money at maturity and their prices are denoted by Q_t and Q_t^*, respectively. The income received from these various sources are used to finance the purchase of consumption goods, C_t, and investment goods, I_t. The aggregate Consumer Price Index (CPI) in the domestic economy is represented by P_t. The representative household pays lump-sum taxes, represented by TX_t to the government.

The process of capital accumulation is assumed to follow:

$$K_{t+1} = (1-\delta)\,K_t + I_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right], \tag{2.4}$$

where $0 < \delta < 1$ represents the rate at which capital depreciates. The function $S\left(\frac{I_t}{I_{t-1}}\right)$, which defines investment adjustment cost, is a positive function of period-to-period changes in investment. The inclusion of an adjustment cost in equation (2.4) introduces real rigidity into the model as households are unable to vary their investment from one period to another in a costless manner. Following Christiano, Eichenbaum and Evans (2005); Del Negro and Schorfheide (2008); Schmitt-Grohé and Uribe (2005) and Fernández-Villaverde (2010), we

[5] This budget constraint is similar to those in Gali and Monacelli (2005) and Ferrero and Seneca (2019), except that we have introduced capital.

adopt a quadratic investment adjustment cost of the form:

$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\chi}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2, \tag{2.5}$$

where $\chi \geq 0$ is the sensitivity parameter for the adjustment in investment and thus governs the size of the adjustment cost. Putting equation (2.5) into (2.4), we can rewrite the capital accumulation equation as:

$$K_{t+1} = (1-\delta) K_t + I_t \left[1 - \frac{\chi}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right]. \tag{2.6}$$

Thus, the representative household maximises equation (2.1) subject to a per period nominal budget constraint (equation 2.3) and a capital accumulation process (equation 2.6) by choosing $\left\{C_t, N_t, B_{t+1}, B^*_{t+1}, K_{t+1}, I_t\right\}_{s=0}^{\infty}$. Defining the Lagrange multipliers associated with household budget constraint and capital accumulation process as λ_t^c and λ_t^k, respectively, the optimization problem of the household yields the first-order conditions for labour, domestic bonds, capital supply and investment demand as follows

$$\frac{W_t}{P_t} = N_t^{\varphi} C_t, \tag{2.7}$$

$$Q_t = \beta E_t \left(\frac{C_{t+1}}{C_t}\right)^{-1} \frac{1}{\pi_{t+1}}, \tag{2.8}$$

$$\lambda_t^k = \beta E_t \left[\frac{1}{C_{t+1}} r_{h,t+1} + \lambda_{t+1}^k (1-\delta)\right], \tag{2.9}$$

$$\frac{1}{C_t} - \lambda_t^k \left[1 - \frac{\chi}{2} - \frac{3}{2}\chi\left(\frac{I_t}{I_{t-1}}\right)^2 + 2\chi\left(\frac{I_t}{I_{t-1}}\right)\right] = \chi\beta E_t \lambda_{t+1}^k \left[\left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right], \tag{2.10}$$

where $\pi_t = \frac{P_t}{P_{t-1}}$ is CPI inflation - defined as the rate of change in the consumer price index and $r_{h,t} = \frac{R_{h,t}}{P_t}$ denotes the real rental rate on capital.
In addition to the above equilibrium conditions, the representative household seeks to minimize its expenditure on the consumption of foreign and domestically produced goods. Thus, the demands for domestic and foreign goods are obtained by minimizing total expenditure:

$$P_t C_t = P_{h,t} C_{h,t} + P_{f,t} C_{f,t}, \tag{2.11}$$

subject to equation (2.2). $P_{h,t}$ is the price of domestic goods, and $P_{f,t}$ is the price index for imported goods expressed in domestic currency. This optimization problem yields the demand for home and foreign goods as

$$\begin{aligned} C_{h,t} &= (1-\gamma)\left(\frac{P_{h,t}}{P_t}\right)^{-1} C_t, && (2.12) \\ C_{f,t} &= \gamma\left(\frac{P_{f,t}}{P_t}\right)^{-1} C_t, && (2.13) \end{aligned}$$

respectively, while the corresponding aggregate consumer price index is

$$P_t = P_{h,t}^{1-\gamma} P_{f,t}^{\gamma}. \tag{2.14}$$

2.3.3 Firms

The model economy is characterized by two sectors, namely: non-oil producing firms (which consist of final good producers and intermediate goods producers) and oil firms. The optimisation problems of these two categories of firms are discussed next.

Non-oil producing firms

Final good firms supply manufactured goods to domestic households, government and oil firms in a perfectly competitive market by bundling intermediate goods. On the other hand, the intermediate good producers combine capital and labour rented from households with oil to produce goods that are sold in a monopolistically competitive market. The intermediate goods producers set prices as in Calvo (1983) by maximizing profit subject to a downward sloping demand curve for their goods.

Final goods producers: Final goods, $Y_{h,t}$, are produced by perfectly competitive firms who bundle differentiated goods, $Y_{h,t}(j)$, produced by the intermediate firms based on an aggregation technology. Thus, the representative final goods firm's optimization problem involves choosing $Y_{h,t}(j)$ in order to maximize its profit function

$$\Pi_t = P_{h,t}Y_{h,t} - \int_0^1 P_{h,t}(j)\, Y_{h,t}(j)\, dj, \tag{2.15}$$

subject to a constant returns to scale technology

$$Y_{h,t} = \left[\int_0^1 Y_{h,t}(j)^{\frac{\epsilon-1}{\epsilon}} \, dj \right]^{\frac{\epsilon}{\epsilon-1}}, \tag{2.16}$$

where $P_{h,t}(j)$ is the price charged on intermediate goods $Y_{h,t}(j)$ produced by an intermediate goods producing firm and $P_{h,t}$ is the domestic price index. The parameter $\epsilon > 1$ represents the elasticity of substitution among different intermediate goods. The first-order condition for the above optimization problem yields the standard downward sloping demand function for intermediate goods

$$Y_{h,t}(j) = \left(\frac{P_{h,t}(j)}{P_{h,t}} \right)^{-\epsilon} Y_{h,t}, \tag{2.17}$$

which is substituted into equation (2.16) to obtain the final goods pricing rule

$$P_{h,t} = \left[\int_0^1 P_{h,t}(j)^{1-\epsilon} \, dj \right]^{\frac{1}{1-\epsilon}}. \tag{2.18}$$

Intermediate goods producers: There is a continuum of intermediate goods firms, indexed by $j \in [0, 1]$ producing differentiated goods in a monopolistically competitive environment. Departing from a single factor input (labour) assumption of similar works such as Gali and Monacelli (2005), Wills (2014) and Ferrero and Seneca (2019), this paper considers firms producing each intermediate good j using a constant returns to scale technology that combines three inputs: capital, oil and labour as follows:

$$Y_{h,t}(j) = A_{h,t} K_{h,t}(j)^{\alpha_h^k} O_t(j)^{\alpha_h^o} N_t(j)^{\alpha_h^n}, \tag{2.19}$$

where $Y_{h,t}(j)$ is the output of the intermediate firm, $K_{h,t}(j)$ represents capital input, $O_t(j)$ is oil input and $N_t(j)$ denotes labour input employed. The parameters $1 > \alpha_h^k > 0$, $1 > \alpha_h^o > 0$ and $1 > \alpha_h^n > 0$ are elasticities of an intermediate firm's output with respect to capital, oil and labour inputs, respectively. By our assumption of constant returns to scale, $\alpha_h^k + \alpha_h^o + \alpha_h^n = 1$. Featuring capital and oil inputs in equation (2.19) allows us to analyse the implications of physical capital and oil intensity for the response of the oil producing economy to an oil price shock[6]. We assume that the total factor productivity, $A_{h,t}$, evolves as an $AR(1)$ process with an exogenous shock

$$A_{h,t} = (A_{h,t-1})^{\rho_{A_h}} \exp\left(\xi_t^{A_h}\right), \tag{2.20}$$

where $0 < \rho_{A_h} < 1$ and $\xi_t^{A_h}$ is an independent and identically distributed random variable with a mean zero and finite standard deviation, σ_{A_h}. The optimization problem of the intermediate goods producers is solved in two stages. In the first stage, each firm chooses its input factors to minimize total cost

$$\min_{N_t(j), K_{h,t(j)}, O_t(j)} W_t N_t(j) + R_{h,t} K_{h,t}(j) + P_{o,t} O_t(j), \tag{2.21}$$

subject to the production technology specified in equation (2.19). $P_{o,t}$ is the domestic currency price of oil used in the production process. The first-order conditions from this problem with respect to labour, capital and oil are combined to yield the input ratios for the intermediate good producing firm as follows:

$$\frac{K_{h,t}(j)}{N_t(j)} = \frac{\alpha_h^k w_t}{\alpha_h^n r_{h,t}}, \tag{2.22}$$

$$\frac{O_t(j)}{N_t(j)} = \frac{\alpha_h^o w_t}{\alpha_h^n p_{o,t}}, \tag{2.23}$$

where $r_{h,t} = \frac{R_{h,t}}{P_t}$ is the real rental rate on capital, $p_{o,t} = \frac{P_{o,t}}{P_t}$ is the real price of oil in domestic currency, and $w_t = \frac{W_t}{P_t}$ is the real wage. An expansionary monetary policy that decreases the real rental rate on capital leads to an increase in the intermediate goods producing firm's demand for capital (equation 2.22). Also, equation (2.23) indicates that a fall in the real price of oil increases intermediate goods firm's demand for oil and decreases its demand for labour. Substituting the input demands into the production technology and invoking the relation between terms of trade and relative prices shown in equation (2.38), we obtain the expression for the real marginal cost

$$mc_t = \frac{1}{A_{h,t} s_t^{-\gamma}} \left(\frac{r_{h,t}}{\alpha_h^k}\right)^{\alpha_h^k} \left(\frac{p_{o,t}}{\alpha_h^o}\right)^{\alpha_h^o} \left(\frac{w_t}{\alpha_h^n}\right)^{\alpha_h^n}, \tag{2.24}$$

[6]Barrell et al. (2008) argues that oil continues to remain an important source of energy for domestic production globally.

where $mc_t = \frac{MC_t}{P_t}$ is the real marginal cost. In contrast to the set up under Ferrero and Seneca (2019), equation (2.24) features input prices relating to capital and oil in addition to wages[7]. This implies that changes in capital rental rate and domestic oil price are important for inflation dynamics under our model set up.

In the second stage, the intermediate goods producers choose price to maximize their expected discounted profit. Following Calvo (1983) staggered pricing model, we allow a proportion of the intermediate goods producing firms, $(1-\theta)$, to reset their prices optimally in any give period while the other fraction, θ, who are unable to re-optimise their prices maintain the price as at last fixing. It then follows that the evolution of domestic price level is given by a law of motion

$$P_{h,t} = \left[(1-\theta)\left(P^{\bullet}_{h,t}\right)^{1-\epsilon} + \theta P^{1-\epsilon}_{h,t-1}\right]^{\frac{1}{1-\epsilon}}, \tag{2.25}$$

where $\theta \in [0,1]$ is an index of price stickiness (Calvo, 1983) and $P^{\bullet}_{h,t}$ represents the optimal reset price. For firms who qualify to re-optimise their prices, the optimal reset price, $P^{\bullet}_{h,t}$, is determined by solving a profit maximization problem

$$\max_{P^{\bullet}_{h,t}(j)} E_t \sum_{s=0}^{\infty} (\beta\theta)^s Y_{h,t}(j)\left[(1+\zeta)P^{\bullet}_{h,t}(j) - P_{h,t+s}mc_{t+s}\right], \tag{2.26}$$

subject to the downward sloping demand curve for their goods

$$Y_{h,t+s}(j) = \left(\frac{P_{h,t}(j)}{P_{h,t}}\right)^{-\epsilon} Y_{h,t+s}, \tag{2.27}$$

where ζ is the subsidy introduced to offset distortions arising from monopolistic competition. The optimal price resulting from the above problem is

$$P^{\bullet}_{h,t} = \frac{1}{1+\zeta}\frac{\epsilon}{\epsilon-1}\frac{E_t \sum\limits_{s=0}^{\infty}(\beta\theta)^s P_{h,t+s}Y_{h,t+s}mc_{t+s}}{E_t \sum\limits_{s=0}^{\infty}(\beta\theta)^s Y_{h,t+s}}, \tag{2.28}$$

where $\frac{\epsilon}{\epsilon-1}$ represents a frictionless markup. Equation (2.28) indicates that the optimal price is set as a constant mark-up over the ratio of an expression relating the expected discounted

[7]The real marginal cost in Ferrero and Seneca (2019) is given as $mc_t = \frac{w_t}{A_{h,t}s_t^{-\gamma}}$.

nominal total cost to the expected discounted real output.

Oil sector firms

The representative oil firm combines capital and materials inputs under perfect competition to extract oil which is sold in the world market, taking price as determined at the international oil market. Thus, in addition to materials input featured in the oil firm's extraction technology of Ferrero and Seneca (2019), we include capital[8]. Unlike Ferrero and Seneca (2019), but consistent with Romero (2008), we assume that a fraction of oil produced by these firms is used as inputs in the production technology of domestic non-oil sector firms while the residual is exported to the rest of the world, taking price as given.

The oil firm's decision problem involves choosing capital, $K_{o,t}$, and materials, M_t, inputs to maximize a profit function

$$\mathit{\Pi}_{o,t} = P_{o,t}Y_{o,t} - R_{h,t}K_{o,t} - P_{h,t}M_t, \tag{2.29}$$

subject to a decreasing return to scale extraction technology

$$Y_{o,t} = A_{o,t}K_{o,t}^{\alpha_o^k}M_t^{\alpha_o^m}, \tag{2.30}$$

where $Y_{o,t}$ represents oil output and $P_{o,t}$ is the price of oil in domestic currency. The parameters α_o^k and α_o^m represent the elasticities of oil output with respect to capital and material inputs, respectively. The input demand for M_t by the oil firm captures the demand channel for spillover of oil price shocks to the domestic economy. In line with Romero (2008) and Ferrero and Seneca (2019), we assume diminishing marginal returns, such that $\alpha_o^k + \alpha_o^m < 1$. Oil sector productivity, $A_{o,t}$, follows an $AR\,(1)$ process with an exogenous shock

$$A_{o,t} = (A_{o,t-1})^{\rho_{A_o}} \exp\left(\xi_t^{A_o}\right), \tag{2.31}$$

where $0 < \rho_{A_o} < 1$ and $\xi_t^{A_o}$ is an independent and identically distributed random variable with a mean zero and finite standard deviation, σ_{A_o}. Our assumption of a small open economy implies that the oil producer can not affect the world price, $P_{o,t}^*$. Thus, the dollar price of oil is assumed exogenous. Following Ferrero and Seneca (2019), we define the real price of

[8] This extension is reasonable due to the capital intensive nature of oil investments.

oil, $p_{o,t}$, in domestic currency as

$$p_{o,t} = \frac{P_{o,t}}{P_t} = \frac{P^*_{o,t}}{P^*_t}\frac{\varepsilon_t P^*_t}{p_t} = \frac{P^*_{o,t}}{P^*_t}{s_t}^{1-\gamma} = q_t p^*_{o,t}. \tag{2.32}$$

where $p^*_{o,t} = \frac{P^*_{o,t}}{P_t}$ is the international price of oil in real terms, ε_t is the nominal exchange rate, q_t is the real exchange rate, and s_t is the terms of trade. The definition of the real exchange rate shown in equation (2.43) has been invoked in equation (2.32). The world price of oil, $P^*_{o,t}$, follows a first order autoregressive process with an exogenous shock

$$P^*_{o,t} = \left(P^*_{o,t-1}\right)^{\rho_o} \exp\left(\xi_t^{p^*_o}\right), \tag{2.33}$$

where $0 < \rho_o < 1$ and $\xi_t^{p^*_o}$ is an independent and identically distributed random variable with a mean zero and finite standard deviation, $\sigma_{p^*_o}$. The first-order conditions from the profit maximization problem of the oil firm yield the optimal demands for capital, $K_{o,t}$, and materials, M_t, as

$$K_{o,t} = \frac{\alpha_o^k p^*_{o,t} s_t^{1-\gamma} Y_{o,t}}{r_{h,t}}, \tag{2.34}$$

$$M_t = \frac{\alpha_o^m p^*_{o,t} s_t^{1-\gamma} Y_{o,t}}{p_{h,t}}, \tag{2.35}$$

where $r_{h,t} = \frac{R_{h,t}}{P_t}$ is the real rental rate on capital, $p_{h,t} = \frac{P_{h,t}}{P_t}$ is the real price of domestic goods, and $p^*_{o,t} = \frac{P^*_{o,t}}{P_t}$ represents the international price of oil in real terms. The definition of the real oil price in domestic currency as well as the expression for real exchange rate shown in equations (2.32) and (2.43) have been invoked in equations (2.34) and (2.35). Consequently, the demands for factor inputs by the firm are functions of input prices, terms of trade, the real dollar price of oil and the aggregate oil output. Substituting equations (2.34) and (2.35) into (2.29) yields the real profit function of the firm as:

$$\pi_{o,t} = p_{o,t} Y_{o,t} \left[1 - s_t^{1-\gamma}\left(\alpha_o^k - \alpha_o^m\right)\right]. \tag{2.36}$$

where $\pi_{o,t} = \frac{\Pi_{o,t}}{P_t}$. The oil firm's profits are fully taxed and thus transferred to government for onward investment in a sovereign wealth fund located outside the domestic economy. From equations (2.34) and (2.35), it is clear that a positive shock to real dollar price of oil leads to increased demand for capital and materials inputs.

2.3.4 Open economy features

We consider a small open economy in which the home economy is insignificant relative to the foreign economy. Thus, activities in the foreign economy are taken as exogenous since they are not impacted by developments in the domestic economy. In this section, we examine how the domestic economy relates with the rest of the world.

Relative prices, real exchange rate and terms of trade

The terms of trade is a crucial relative price in the model as it distributes home and foreign goods amongst households in both the domestic and foreign economies. Following Gali and Monacelli (2005), we define the terms of trade facing the domestic economy as the price of imports in terms of the home goods

$$s_t = \frac{P_{f,t}}{P_{h,t}}, \tag{2.37}$$

where s_t denotes the terms of trade at time t. A decline in the price of domestically produced goods, $P_{h,t}$, increases s_t and depreciates the real exchange rate as shown in equation (2.43). The equation for the aggregate CPI, equation (2.14) can be combined with equation (2.37) to derive relations between terms of trade and relative domestic prices as follows:

$$s_t^{-\gamma} = \frac{P_{h,t}}{P_t}. \tag{2.38}$$

Log-linearising equation (2.38) yields $\widetilde{P}_t = \widetilde{P}_{h,t} + \gamma \widetilde{s}_t$. Applying time difference yields $\widetilde{\pi}_t = \widetilde{\pi}_{h,t} + \gamma \Delta \widetilde{s}_t$, which expresses CPI inflation as a function of domestic inflation, the home economy's degree of trade openness as well as the change in terms of trade. The tildes represent log-deviations of the variables from their steady state levels. Similarly, equations (2.14) and (2.37) can be combined to express the terms of trade in terms of foreign prices

$$s_t^{1-\gamma} = \frac{P_{f,t}}{P_t}, \tag{2.39}$$

which can then be used to pin down imported inflation, $\pi_{f,t}$, as follows

$$\pi_{f,t} = (\Delta s_t)^{1-\gamma} \pi_t, \tag{2.40}$$

where $\pi_{f,t} = \frac{P_{f,t}}{P_{f,t-1}}$ represents imported inflation and $\Delta s_t = \frac{s_t}{s_{t-1}}$ is the change in terms of trade. Based on equations (2.38) and (2.39), the demand for home goods (equation 2.12) and foreign goods (equation 2.13) can be rewritten respectively as

$$C_{h,t} = (1-\gamma) s_t^{\gamma} C_t, \tag{2.41}$$

$$C_{f,t} = \gamma s_t^{\gamma-1} C_t. \tag{2.42}$$

Equations (2.41) and (2.42) imply that an increase in the terms of trade increases demand for domestically produced goods but decreases the demand for foreign goods.

The real exchange rate, q_t, is defined as the nominal exchange rate, ε_t, multiplied by the ratio of CPI in the foreign economy, P_t^* (in foreign currency) to CPI in the domestic economy, P_t. Thus, $q_t = \varepsilon_t \times \frac{P_t^*}{P_t}$. In order to derive a relation between the real exchange rate and the terms of trade for the domestic economy, we make two assumptions. First, we assume that the domestic economy does not export consumption goods to the foreign economy, implying that $\gamma^* = 0$. Since the analogous equation for aggregate consumer price index in the foreign economy (equation 2.14) can be written as $P_t^* = P_{f,t}^{*1-\gamma} P_{h,t}^{*\gamma}$, it then follows by our assumption that $P_t^* = P_{f,t}^*$. Second, we assume law of one price holds, which implies that $P_{f,t} = \varepsilon_t P_{f,t}^*$. Combining the results from these two assumptions with the expression for domestic terms of trade in equation (2.39) yields a relation between real exchange rate and the terms of trade as

$$q_t = s_t^{1-\gamma}, \tag{2.43}$$

such that the real exchange rate prevailing in the domestic economy evolves as a function of the terms of trade, s_t, and the trade openness parameter, γ.

Uncovered interest parity

Under the assumption of complete markets for international financial assets, the Euler equations for the domestic and foreign economies can be combined to obtain the standard uncovered interest parity condition. We assume that households trade in a portfolio of both domestic bonds, B_t, and foreign bonds, B_t^*, as in Gali and Monacelli (2005) and Ferrero and Seneca (2019). Maximising equation (2.1) subject to the budget constraint (equation 2.3) and taking the partial derivatives with respect to B_{t+1} and B_{t+1}^* yield the following conditions, respectively:

$$
\begin{aligned}
1 &= \beta E_t\left[Q_t^{-1}\left(\frac{C_{t+1}}{C_t}\right)^{-1}\frac{P_t}{P_{t+1}}\right], && (2.44)\\
1 &= \beta E_t\left[Q_t^{*-1}\left(\frac{C_{t+1}}{C_t}\right)^{-1}\frac{P_t}{P_{t+1}}\frac{\varepsilon_{t+1}}{\varepsilon_t}\right]. && (2.45)
\end{aligned}
$$

Combining equations (2.44) and (2.45) yields the uncovered interest parity condition which expresses the domestic interest rate as a function of the world interest rate and the expected rate of depreciation of the domestic currency:

$$
\frac{1+R_t}{1+R_t^*} = E_t\left(\frac{\varepsilon_{t+1}}{\varepsilon_t}\right), \tag{2.46}
$$

given that $Q_t^{-1} = 1 + R_t$. Where R_t is the nominal net return on a one-period risk-free bond in the domestic economy and its foreign economy equivalent is R_t^*.

International risk sharing

As demonstrated in Gali and Monacelli (2005), the relationship between consumption in the small open economy and the rest of the world is defined by the international risk sharing condition. Assuming perfect market for bonds, a condition similar to equation (2.44) holds for a representative household in a foreign country such that

$$
1 = \beta E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-1}\frac{P_t}{P_{t+1}}\right] = \beta E_t\left[\left(\frac{C_{t+1}^*}{C_t^*}\right)^{-1}\frac{\varepsilon_t}{\varepsilon_{t+1}}\frac{P_t^*}{P_{t+1}^*}\right]. \tag{2.47}
$$

We can simplify equation (2.47) as follows:

$$
\begin{aligned}
1 =& E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-1}\frac{P_t}{P_{t+1}}\left(\frac{C_{t+1}^*}{C_t^*}\right)\frac{\varepsilon_{t+1}}{\varepsilon_t}\frac{P_{t+1}^*}{P_t^*}\right],\\
C_t^{-1} =& E_t\left[\left(\frac{C_{t+1}^*}{C_{t+1}}\right)(C_t^*)^{-1}\frac{q_{t+1}}{q_t}\right],\\
C_t =& E_t\left[\left(\frac{C_{t+1}}{C_{t+1}^*}\right)C_t^*\frac{q_t}{q_{t+1}}\right].
\end{aligned}
$$

This enables us to obtain the international risk sharing condition as:

$$C_t = \varrho C_t^* s_t^{1-\gamma}, \tag{2.48}$$

where $\varrho = \frac{C_{t+1}}{C_{t+1}^* q_{t+1}}$ is the relative net asset position, which is assumed symmetric (i.e. $\varrho = 1$) as in Gali and Monacelli (2005) and Ferrero and Seneca (2019). In equation (2.48), we have invoked the definition of real exchange rate, q_t, given in equation (2.43) in line with Ferrero and Seneca (2019). Foreign consumption, C_t^*, is assumed to follow an $AR(1)$ process with exogenous shock. In summary, equation (2.48) expresses aggregate domestic consumption, C_t, as a function of consumption in the rest of the world, C_t^*; the terms of trade, s_t; as well as the trade openness parameter, γ.

2.3.5 Government

The government receives revenues from taxes and annual transfers from the sovereign wealth fund. These receipts are used to finance a given government expenditure on goods, $G_{c,t}$, bought at a domestic price, $P_{h,t}$, from the final goods firms. Thus, in line with Ferrero and Seneca (2019), we assume the government respects a budget constraint

$$P_{h,t} G_{c,t} = TR_t + TX_t, \tag{2.49}$$

where TX_t denotes lump-sum tax paid to government and TR_t is the transfer to government from the sovereign wealth fund (SWF). We assume $G_{c,t}$ follows an $AR\,(1)$ process, whereas the evolution of TR_t is governed by a fiscal rule

$$TR_t = \rho \left(1 + R_{t-1}^*\right) \varepsilon_t F_{t-1}^*, \tag{2.50}$$

where $0 < \rho < 1$ is a fixed proportion of the initial dollar value of the sovereign wealth fund, F_{t-1}^*, allocated for government spending each period and R_{t-1}^* represents foreign interest rate in the previous period. The SWF evolves based on its initial residual value (i.e. after deductions have been made to the fiscal authority), interest earnings on the fund and finally, the oil sector profits. This dynamic is depicted as

$$\varepsilon_t F_t^* = (1-\rho)\left(1 + R_{t-1}^*\right) \varepsilon_t F_{t-1}^* + \mathit{\Pi}_{o,t}. \tag{2.51}$$

Following Ferrero and Seneca (2019), ρ is restricted as $(1-\rho)\left(1+R_{t-1}^{*}\right) < 1$ in order to ensure that the SWF is stationary. This implies that government spending is roughly equal to the average yield on the SWF per period.

2.3.6 Central bank

We consider a monetary authority that sets interest rate and faces a dual mandate of achieving stability in both prices and output. Therefore, following Canova (2009); Clarida, Gali and Gertler (1999); Fernández-Villaverde (2010) and Ferrero and Seneca (2019), we assume that monetary policy is conducted based on a simple three-parameter Taylor type rule that features interest rate inertia, domestic inflation and domestic output as follows

$$\frac{R_t}{\overline{R}} = \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_r} \left[\left(\frac{\pi_t}{\overline{\pi}}\right)^{\omega_\pi} \left(\frac{Y_{h,t}}{\overline{Y_h}}\right)^{\omega_y}\right]^{(1-\rho_r)} \exp\left(\xi_t^r\right), \tag{2.52}$$

where R_t is the nominal interest rate set by the central bank, ρ_r is the interest rate smoothing parameter capturing monetary policy inertia, ω_π and ω_y are the feedback coefficients on inflation and output, respectively and ξ_t^r represents an independent and identically distributed monetary policy shock. The incorporation of interest rate inertia measured by ρ_r in equation (2.52) implies that monetary policy seeks to correct deviations of current domestic inflation, $\pi_{h,t} = \frac{P_{h,t}}{P_{h,t-1}}$, and output, $Y_{h,t}$, from their steady state values by gradually adjusting the short term nominal interest rate. According to Sack and Wieland (2000), such gradual adjustments are often done in sequences of small steps in the same direction while a reversal of direction is effected only infrequently. The benefits of including a smoothing parameter in central bank policy reaction function are discussed in Clarida, Gali and Gertler (2000) and Woodford (2003)[9].

Our choice of the modified Taylor rule in equation (2.52) hinges on the argument that interest rate rules that react to both inflation and output work better than rules that focus on either of them. In particular, Romero (2008) noted that Taylor rules that include inflation and output better characterize the behaviour of most central banks in oil producing

[9]It has been argued that policy reaction functions that exclude interest rate inertia are restrictive, not representative of the behaviour of the Funds rate and limits the performance of forward looking models. According to Sack and Wieland (2000), the uncertainties regarding data and relevant model parameters are also important reasons for incorporating interest rate smoothing. This is because aggressive monetary policy reactions to such uncertainties yield unnecessary fluctuations in the interest rate and generate unintended effects on output and inflation.

economies. However, in section 2.3.8, we modify equation (2.52) to accommodate a case where the central bank has a third objective of responding to the exchange rate[10].

2.3.7 Market clearing and aggregation

The aggregate demand equation derives from the model set up, whereby goods produced domestically are consumed by households, intermediate goods firms, oil-producing firms, and the fiscal authority. Thus, the resource constraint is as follows:

$$Y_{h,t} = C_{h,t} + M_t + I_t + G_t. \tag{2.53}$$

Also, total capital supplied by the household clears the demands by the oil and non-oil sectors

$$K_t = K_{h,t} + K_{o,t}, \tag{2.54}$$

where $K_{h,t} \equiv \int_0^1 K_{h,t}(j)\, dj$. Lastly, consumption goods produced in the foreign economy, C_t^* are consumed abroad, $C_{f,t}^*$, and imported to the domestic economy, $C_{f,t}$, as follows:

$$C_t^* = C_{f,t}^* + C_{f,t}. \tag{2.55}$$

2.3.8 Policy regimes

In this section, we specify alternative monetary policy rules with a view to evaluating their relative performance in stabilising the small open oil-producing economy following an international oil price shock. We define a central bank loss function with three arguments, namely: inflation volatility, output volatility and changes in interest rate for the purpose of conducting policy ranking and exploring optimal monetary policy.

Simple policy rules

In order to study optimal monetary policy, we specify eleven Taylor-type interest rate rules. The specifications considered enable us to answer questions regarding the relevance of interest

[10] Whereas Williams (2003) argue that increases in rule complexity yield only trivial reductions in aggregate variability, the extent to which this holds under our model set up is of interest to this paper.

rate inertia and the exchange rate in the central bank's reaction function as well as the appropriate measure of inflation to include in the policy rule[11].

Table 2.2 presents the log-linearized form of the eleven Taylor-type interest rate rules considered in this paper. The parameter ρ_r defines policy inertia while the feedback coefficients for inflation, output and exchange rate are denoted as ω_π, ω_y and ω_q, respectively. In the first two rules, we consider cases in which the central bank responds solely to either CPI inflation (*CITR*) or domestic inflation (*DITR*). In the next two rows, we specify flexible cases of the Taylor rule that focus on domestic output movements in addition to the inflation variants considered in the first two rows. Thus, we define a CPI inflation-based Taylor rule that also features output level (*FCITRy*) as well as its domestic inflation counterpart (*FDITRy*).

Table 2.2: Alternative Taylor rule specifications

Taylor Rule	Specification
CITR	$\widetilde{R}_t = \omega_\pi \widetilde{\pi}_t$
DITR	$\widetilde{R}_t = \omega_\pi \widetilde{\pi}_{h,t}$
FCITRy	$\widetilde{R}_t = \omega_\pi \widetilde{\pi}_t + \omega_y \widetilde{y}_{h,t}$
FDITRy	$\widetilde{R}_t = \omega_\pi \widetilde{\pi}_{h,t} + \omega_y \widetilde{y}_{h,t}$
IFCITRy	$\widetilde{R}_t = \rho_r \widetilde{R}_{t-1} + (1-\rho_r)\left[\omega_\pi \widetilde{\pi}_t + \omega_y \widetilde{y}_{h,t}\right]$
IFCITRyq	$\widetilde{R}_t = \rho_r \widetilde{R}_{t-1} + (1-\rho_r)\left[\omega_\pi \widetilde{\pi}_t + \omega_y \widetilde{y}_{h,t} + \omega_q \widetilde{q}_t\right]$
IFDITRy	$\widetilde{R}_t = \rho_r \widetilde{R}_{t-1} + (1-\rho_r)\left[\omega_\pi \widetilde{\pi}_{h,t} + \omega_y \widetilde{y}_{h,t}\right]$
IFDITRyq	$\widetilde{R}_t = \rho_r \widetilde{R}_{t-1} + (1-\rho_r)\left[\omega_\pi \widetilde{\pi}_{h,t} + \omega_y \widetilde{y}_{h,t} + \omega_q \widetilde{q}_t\right]$
SCITR	$\widetilde{\pi}_t = 0$
SDITR	$\widetilde{\pi}_{h,t} = 0$
SNGDPGT	$\widetilde{\pi}_{h,t} + \Delta \widetilde{y}_{h,t} = 0$

In the next four set of rules, we extend the flexible Taylor rules by incorporating interest rate inertia as well as exchange rate. The inclusion of interest rate inertia in the policy reaction function has been justified on a number of grounds. For instance, Clarida et al. (2000) argue that policy reaction functions that abstract from interest rate inertia do not characterize the behaviour of the Funds rate and are too restrictive. Sack and Wieland (2000) also note that uncertainties regarding data and relevant model parameters are major reasons why central banks imbibe interest rate smoothing. According to him, aggressive

[11]Taylor and Williams (2010) noted that a key issue for simple rule is the appropriate measure of inflation to include in such rules.

monetary policy reactions to such uncertainties yield unnecessary fluctuations in the interest rate and generate unintended effects on output and inflation. Also, Taylor and Williams (2010) opine that accommodating significant degree of inertia in the Taylor rule can help improve performance in forward looking models. Therefore, we consider flexible Taylor rules which feature interest rate inertia: the CPI inflation based type ($IFCITRy$) and its domestic inflation-based variant ($IFDITRy$).

Another issue that has attracted a great deal of attention in the literature relates to the implications of including asset prices, such as the exchange rate or equity prices, in the monetary policy reaction function (Clarida, 2001; Lubik and Schorfheide, 2007; Taylor and Williams, 2010). To explore this argument for resource-rich economies, we consider a central bank that also responds to the exchange rate (Garcia and Gonzalez, 2010,1; Laxton and Pesenti, 2003). Thus, we specify two additional variants of flexible Taylor rules that feature the real exchange rate: the CPI inflation based type ($IFCITRyq$) and its domestic inflation-based variant ($IFDITRyq$).

In the last three rules, the central bank pursues simple policy rules that strictly target zero CPI inflation ($SCIT$R), zero domestic inflation ($SDIT$R) and completely stabilises nominal gross domestic output ($SNGDPGT$). The relative performance of these alternative monetary policy rules are evaluated based on the macroeconomic fluctuations implied by them as well as the associated policy loss (equation 2.56).

Loss function and optimal policy

In policy evaluation literature, a measure of welfare is often adopted as a basis for drawing conclusions regarding the relative performance of alternative policies. While some studies estimate welfare based on the utility function of the representative household (Ferrero and Seneca, 2019), others assume an inter-temporal loss function for the central bank and maps the loss function to an aggregate measure of household welfare (Hove et al., 2015). As shown by Woodford (2002) and noted by Dennis (2004), welfare loss functions that are derived from second-order approximations to household utility yield similar approximations to the type defined by a central bank loss function.

For simplicity, we consider a standard ad-hoc quadratic loss function in deviation from steady state (Benchimol and Fourçans, 2019; Dennis, 2004; Garcia and Gonzalez, 2014; Hove et al., 2015; Hunt, 2006; Ilbas, Røisland and Sveen, 2012; Laxton and Pesenti, 2003; Nisticò, 2012). This approach appeals to us due to the fact that the primary intention of this paper is not to derive optimal monetary policy based on representative household's utility function but rather to evaluate the relative performance of the alternative policy rules specified in Table 2.2 in generating stabilizing effects following an oil price shock. As alluded to by Nisticò (2012), the possibility of adjusting the loss function weights under this approach allows us to accommodate diverse monetary policy arrangements often employed by central banks around the world. Thus, we assume that the central bank's inter-temporal loss can be defined as a discounted weighted sum of the unconditional variances of inflation, output and interest rate changes:

$$Loss_0 = E_o \sum_{t=0}^{\infty} \beta^t \left[\lambda_\pi \widetilde{\pi}_t^2 + \lambda_y \widetilde{y}_{h,t}^2 + \lambda_r \Delta \widetilde{R}_t^2 \right], \tag{2.56}$$

where $\lambda_y \geq 0$ and $\lambda_r \geq 0$ are parameters representing the degree of central bank's dislike for output volatility, $\widetilde{y}_{h,t}^2$, and interest rate variability, $\Delta \widetilde{R}_t^2$, respectively. The first two terms in equation (2.56) represent the costs associated with nominal and real fluctuations while the third term stands for the costs associated with swings in interest rates (Taylor and Williams, 2010). Since the model developed in this section is calibrated to the Norwegian economy, we adopt a loss function in equation (2.56) that reflects the Norges bank's monetary policy objective of stabilising inflation, output and interest rate as in Ilbas et al. (2012).

We interpret the loss value implied by equation (2.56) as the central bank's perception regarding overall macroeconomic instability in the system. Therefore, the central bank's problem is to choose the parameters of a policy rule to minimize the central bank's expected loss subject to the constraints imposed by the model[12]. In general, policies associated with lower values of the loss function are ranked better than those with higher values while optimal monetary policy is the one which minimizes the value of the loss function (Adolfson, Laséen, Lindé and Svensson, 2011). In this paper, we use equation (2.56) to gauge the relative performance of the different monetary policy rules specified in Table 2.2. Following Wolden-Bache, Brubakk and Maih (2008) and Garcia and Gonzalez (2010), we assume that $\lambda_\pi = 1$, $\lambda_y = 0.5$ and $\lambda_r = 0.2$ under our benchmark parametrization.

[12]The quadratic terms, especially those involving inflation and output, represent the policy maker's view that business cycle fluctuations and high or variable inflation and interest rates are undesirable (Taylor and Williams (2010)).

2.3.9 Parametrization

In order to generate quantitative results and facilitate meaningful comparison with the results presented in Ferrero and Seneca (2019), the model developed in this chapter is calibrated to the Norwegian economy. The parametrization of the model is done following relevant extant literature, including Gali and Monacelli (2005) for a typical small open economy as well as Romero (2008), Wolden-Bache et al. (2008), Hove et al. (2015) and Ferrero and Seneca (2019) for emerging markets and resource-rich economies. As much as possible, our parametrization is aligned with Ferrero and Seneca (2019). The parametrization presented in Table 2.3 is done to fit quarterly data. The discount factor, β, is set equal to 0.9963, consistent with a real interest rate of about 1.5% in the steady state as in Ferrero and Seneca (2019). Following Brubakk, Husebø, Maih, Olsen and Østnor (2006) and Wolden-Bache et al. (2008), we assume capital depreciates at a rate $\delta = 0.018$ on quarterly basis.

Table 2.3: Parameter calibration for the representative economy

Parameter Definition	Symbol	Value
Degree of openness	γ	0.4000
Inverse of labour supply elasticity	φ	3.0000
Price stickiness	θ	0.7500
Elasticity of domestic output with respect to capital	α_h^k	0.3000
Elasticity of domestic output with respect to oil	α_h^o	0.2000
Elasticity of domestic output with respect to labour	α_h^n	0.5000
Proportion of SWF transfer to government	ρ	0.0100
Elasticity of substitution between intermediate goods	ϵ	6.0000
Depreciation rate	δ	0.0180
Degree of interest rate smoothing in Taylor Rule	ρ_r	0.7500
Coefficient of inflation in Taylor Rule	ω_π	1.5000
Coefficient of output in Taylor Rule	ω_y	0.1250
Coefficient of exchange rate in Taylor Rule	ω_q	0.1250
Elasticity of oil output with respect to capital	α_o^k	0.3000
Elasticity of oil output with respect to materials	α_o^m	0.2800
Discount factor	β	0.9963

The inverse of the Frisch elasticity of labour supply, φ, is set to 3.0 in agreement with

Brubakk et al. (2006), Unalmis, Unalmis and Unsal (2009) and Ferrero and Seneca (2019). The Frisch elasticity measures the household's degree of disutility for supplying an additional unit of labour. Following Gali and Monacelli (2005) and Ferrero and Seneca (2019), we set the share of foreign imported goods in the total consumption basket of domestic households (a measure of degree of trade openness) to $\gamma = 0.40$, a value that has been found to be fairly consistent with a typical resource rich economy like Norway. We assume the investment adjustment cost parameter, $\chi = 4.85$ (Bergholt and Larsen, 2016). Following Gali and Monacelli (2005), Hove et al. (2015) and Ferrero and Seneca (2019), the Calvo parameter, θ, is set to 0.75, consistent with a situation in which firms can reset prices only once in every four quarters on average[13]. We assume that the elasticity of substitution between intermediate goods $\epsilon = 6.0$, implying a steady state monopolistic markup value of 20 per cent[14], which is in agreement with existing literature for oil producing economies, such as Brubakk et al. (2006), Romero (2008) and Ferrero and Seneca (2019).

Following the work of Wolden-Bache et al. (2008) for the Norwegian economy, we assume the elasticity of domestic output with respect to capital, α_h^k, is 0.30. This is close to the value of 0.33 assumed in an earlier work by Brubakk et al. (2006). The share of oil in non-oil domestic production is set to 0.20 in agreement with Bergholt and Larsen (2016). The share of capital in oil production, α_o^k, is assumed to be 0.3 (Bergholt and Larsen, 2016) while the share of materials input is $\alpha_o^m = 0.28$ as in Ferrero and Seneca (2019). In the Taylor rule, we assume an interest rate smoothing parameter, ρ_r, of 0.75 while the policy feedback coefficients with respect to inflation and output are respectively $\omega_\pi = \omega_{\pi_h} = 1.5$ and $\omega_y = 0.125$ (Galí, 2015)[15]. Finally, $\rho = 0.01$ proportion of the sovereign wealth fund is transferred to the treasury for the purpose of financing government consumption (Ferrero and Seneca, 2019).

[13] Expected duration between price changes is computed as $\frac{1}{1-\theta}$ (Walsh, 2010)

[14] ϵ is a measure of the degree of competition in the market for intermediate goods. Higher values of the elasticity are associated with higher level of competition amongst the firms in the market and lower price markup above marginal cost in steady state (Brubakk et al. (2006)).

[15] This is also as in Gali and Gertler (2007), Romero (2008), Unalmis et al. (2009) and Ferrero and Seneca (2019). It implies that the central bank raises nominal interest rate 150 basis points for every 100 basis point rise in inflation.

2.4 Results

In this section, we present the results from our benchmark model ($mod1$). As earlier explained, the benchmark model allows for capital accumulation and oil intensity of domestic output. In the first part, we show the impulse response functions of the economy to an oil price shock under different monetary policy rules. The roles of capital and oil intensity in the model dynamics are discussed in the second part. We conduct some monetary policy exercises in the third part and report some sensitivity analyses in the last part.

2.4.1 Impacts of an oil price shock

The dynamic responses of some selected macroeconomic variables to a negative international oil price shock under alternative monetary policy rules are discussed here. The responses are shown under three monetary policy rules: domestic inflation-based targeting rule ($DITR$), CPI inflation-based targeting rule ($CITR$) and an optimized simple rule (OSR)[16].

Oil price shock under simple rules

The impulse responses of selected macroeconomic variables to a one standard deviation negative shock to international oil price shock are presented in Figures 2.2 and 2.3.

Qualitatively, the economy's response are broadly similar under the three monetary policy rules considered. Following a negative international oil price shock, the oil firm's profit declines, leading to a reduction in its demands for capital and material inputs (Figure 2.3). However, upon impact, the magnitude of the decline in the demand for materials input is slightly higher than the decline in the demand for capital. The lower input demands, especially with regards to materials input produced by domestic non-oil producing firms generates contractionary effects on domestic output. The contractionary effect is more pronounced under a monetary policy rule that targets CPI inflation as the interest rate cut required under such a rule is relatively smaller (Figure 2.2). This is in line with the findings by Ferrero and Seneca (2019). Domestic output remains below steady state for only about 3-4 quarters compared to over 20 quarters reported in Ferrero and Seneca (2019). This implies that, under our model set up, the contractionary effect of an oil price shock on domestic

[16] In this case, an optimal simple rule algorithm is used to numerically search for parameters of the policy rule that mimimize the weighted sum of the variances in relevant macroeconomic variables as depicted in equation (2.56).

output is rather shorter-lived. The faster rebound under our model set up is driven by the investment dynamics of the non-oil firms in response to lower factor prices as well as the relatively higher lax in monetary policy. Non-oil firm's demand for capital rose whereas the demands for labour and oil fell.

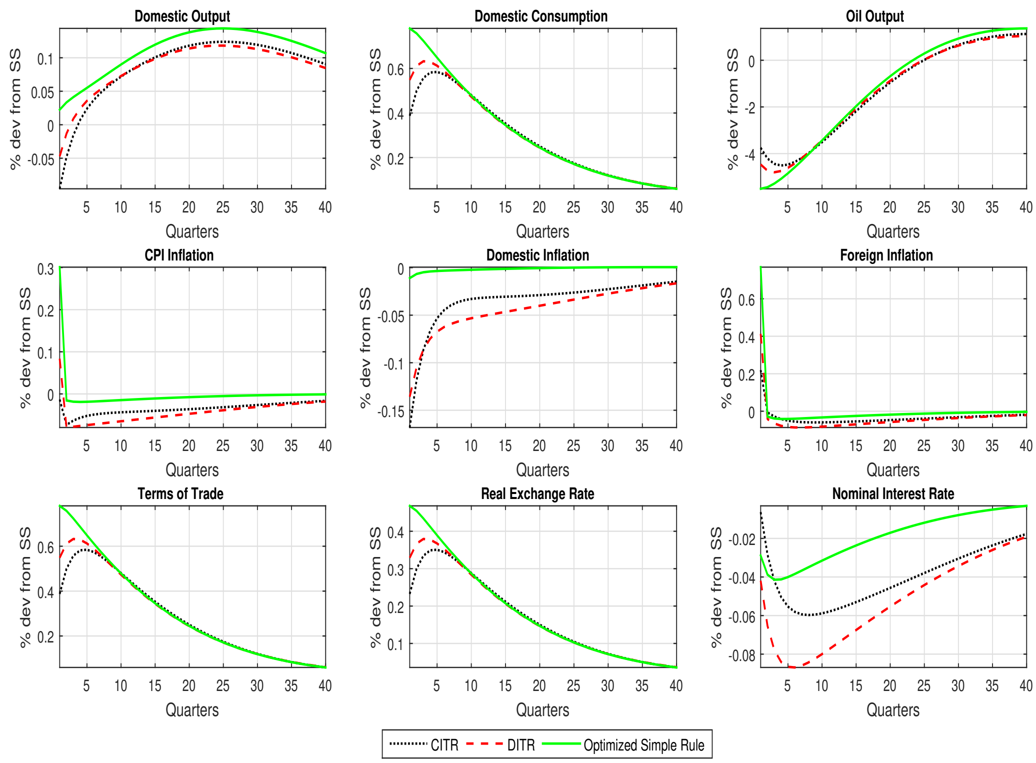

Figure 2.2: Responses to a negative international oil price shock under the benchmark model ($mod1$). The values of the optimized parameters under the optimised simple rule are: $\rho_r = 0.7250$, $\omega_\pi = 9.3813$, $\omega_y = -0.0676$.

Consumption of domestically produced goods rises following the decline in oil price due to the increased terms of trade and the expansionary monetary policy implemented to boost aggregate demand (Figure 2.2). As implied by equation equation 2.37, an increase in the terms of trade implies that domestic goods are relatively cheaper than foreign goods thereby causing an increase in the consumption of the former. Indeed, following a negative oil price shock, real marginal cost falls, leading to a decline in domestic inflation. On the other hand, the depreciated real exchange rate causes a rise in imported goods inflation.

On the non-oil production side, the decline in domestic output leads to a reduction in the equilibrium level of labour in the economy as well as real wages (Figure 2.3). Contrary to the situation in the oil sector, the demand for capital by the non-oil sector increases due to the increased demand for consumption goods and the interest rate cut implemented by the monetary authority. The net effect of the demand for capital in both the oil and non-oil sector generates a decline in the rental rate. Also, the demand for oil inputs for domestic production increases steadily for about 20 quarters following a decline in the domestic price of oil. The decline in input prices (i.e. wages, rental rate and domestic price of oil) causes marginal cost to fall.

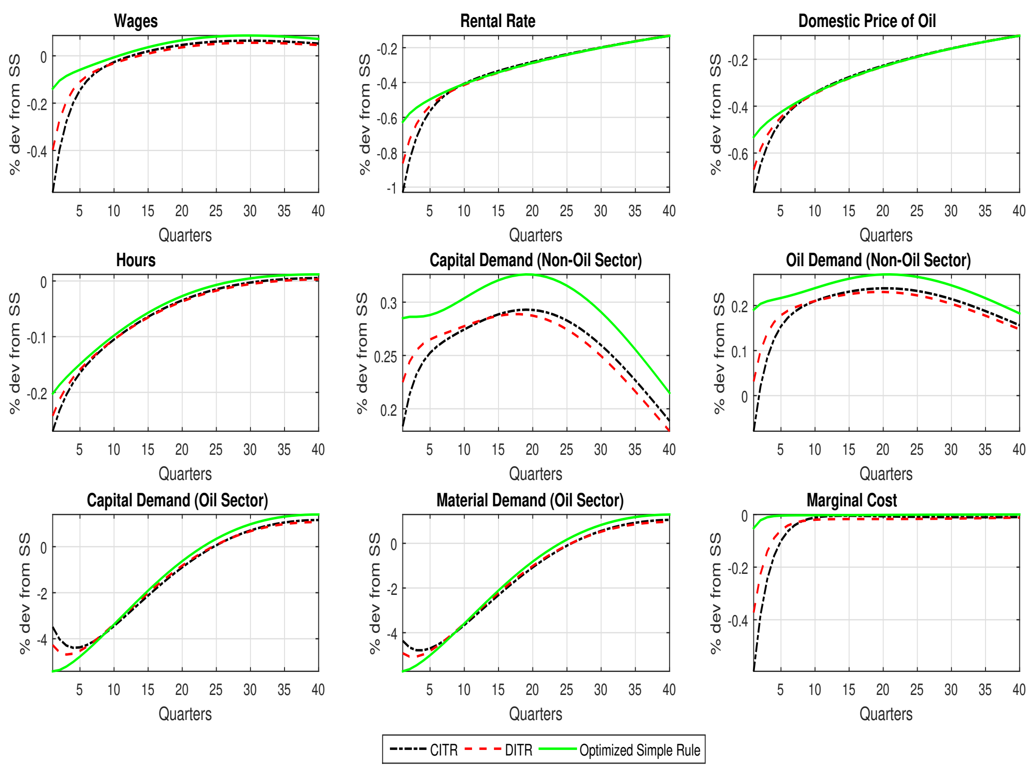

Figure 2.3: Responses to a negative international oil price shock under alternative monetary policy rules, with a model that includes capital as well as oil in the production technology of domestic firms ($mod1$). Under the optimised simple rule, equation (2.52) is optimised. The values of the optimized parameters are: $\rho_r = 0.7250$, $\omega_\pi = 9.3813$, $\omega_y = -0.0676$.

The decline in marginal cost provides incentives for domestic firms to adjust prices downwards, providing impetus for the central bank to cut the nominal interest rate (Figure 2.2). The increased terms of trade as well as the expansionary monetary policy leads to a depreciation of the real exchange rate, which in turn causes the domestic price of foreign goods to increase (imported inflation), relative to the price of domestically produced goods. The effect of the increase in imported inflation outweighs the slight decline in domestic inflation, causing the headline inflation in the small open economy to rise in response to a negative oil price shock. The lower real exchange rate depreciation under the *CITR* is due to the less expansionary monetary policy stance occasioned by the central bank's response to a broader measure of inflation that encompasses the price of imported goods.

In terms of monetary policy response under alternative Taylor rules, Figures 2.2 and 2.3 show outcomes that are similar qualitatively, but slightly different in quantitative terms. Under the domestic inflation-based Taylor rule (*DITR*), the central bank responds to a declining domestic inflation rate with a larger cut in the nominal interest rate relative to the case under the alternative rules. The exchange rate depreciates more, leading to higher headline inflation and an elevated response of domestic consumption to terms of trade effects. Also, the larger interest rate cut implemented under the DITR generates higher domestic consumption and less contraction in domestic output, especially in the first 5 quarters following the oil price shock. On the other hand, CPI inflation-based Taylor rule (*CITR*) leans against the slightly lower CPI inflation, causing the central bank to cut nominal interest rate. However, the size of the downward adjustment to interest rate is smaller under the *CITR* compared to the case under the *DITR*. Consequently, compared to the case under the *DITR*, the contractionary effect of a negative oil price shock on domestic output and consumption is more severe under the former.

The *CITR* yields short run benefits in terms of lower domestic inflation (in the first 2-3 quarters), lower imported inflation, lower CPI inflation, and lower real exchange rate depreciation (which further dampens the effect of international oil price changes on the domestic price of oil). However, the downside risks associated with a *CITR* monetary rule are in terms of lower domestic consumption and output. It is clear from Figure 2.2 that the optimised simple rule (OSR) leads to some gains in terms of domestic output, domestic consumption and domestic inflation compared to the other rules. However, this rule is associated with greater depreciation of the real exchange rate and by implication, higher imported inflation. As expected, the exchange rate acts as a buffer against external shocks under our model set up. These findings tend to suggest that the stance of monetary policy plays an important role in shaping the response of the small open economy to an oil price shock (Bernanke et al., 1997).

Overall, we conclude that a negative shock to the international price of oil yields contractionary effects on the domestic output of an oil-producing economy while domestic inflation falls. Second, depending on the measure of inflation included in the Taylor rule, the monetary authority responds by embarking on expansionary monetary policy to boost the domestic economy and push inflation to its steady state. The real exchange rate depreciates, causing headline inflation to rise. A central bank reaction function that responds to domestic inflation (DITR) generates less contractionary effects on output, but leads to higher CPI inflation and greater depreciation of the real exchange rate. On the other hand, the CITR, which encompasses imported inflation is useful for containing headline inflation and lowering the extent of real exchange rate depreciation. It however generates a more contractionary effects on output. These findings confirm the trade-off faced by the central bank of commodity exporting economies highlighted by Ferrero and Seneca (2019). Therefore, a good policy choice for an oil-producing economy whose objective is to ameliorate the recessionary effects of negative oil price shock is a *DITR*. However, if the overriding objective of the central bank is to stabilise prices and exchange rate, the *CITR* provides a better anchor for monetary policy.

Optimal policy under commitment and discretion

In this section, we make assumptions regarding the ability of the monetary authority to either or not commit to a given plan in the conduct of monetary policy. Under commitment, it is assumed that the central bank is able to commit to a state-contingent policy plan and thus conducts monetary policy in terms of the ex ante optimal policy (Galí, 2015). Woodford (2003) argues that optimal policy under commitment enhances monetary policy effectiveness and avoids policy sub-optimality. However, in the absence of an ability to commit, the central bank is assumed to conduct monetary policy in a time-consistent manner without any obligation to uphold past commitments. In this case, the central bank exercises discretion in setting monetary policy instruments based on its understanding of the economy and the need to act in the public interest (Woodford, 2003)[17].

Figure 2.4 presents the economy's responses to a negative international oil price shocks under three policy scenarios: optimal policy under commitment, optimal policy under discretion and an optimized simple rule. Generally, under both discretionary and commitment

[17] Woodford (2003) argues that discretionary optimization causes bias in average levels of inflation and results in sub-optimal responses to shocks

policies, a negative international oil price shock leads to similar qualitative effects on real variables, such as domestic output and consumption. Also, the responses of the real exchange rate and the terms of trade are quite similar. However, the earlier observed contractionary effects on domestic output is reversed.

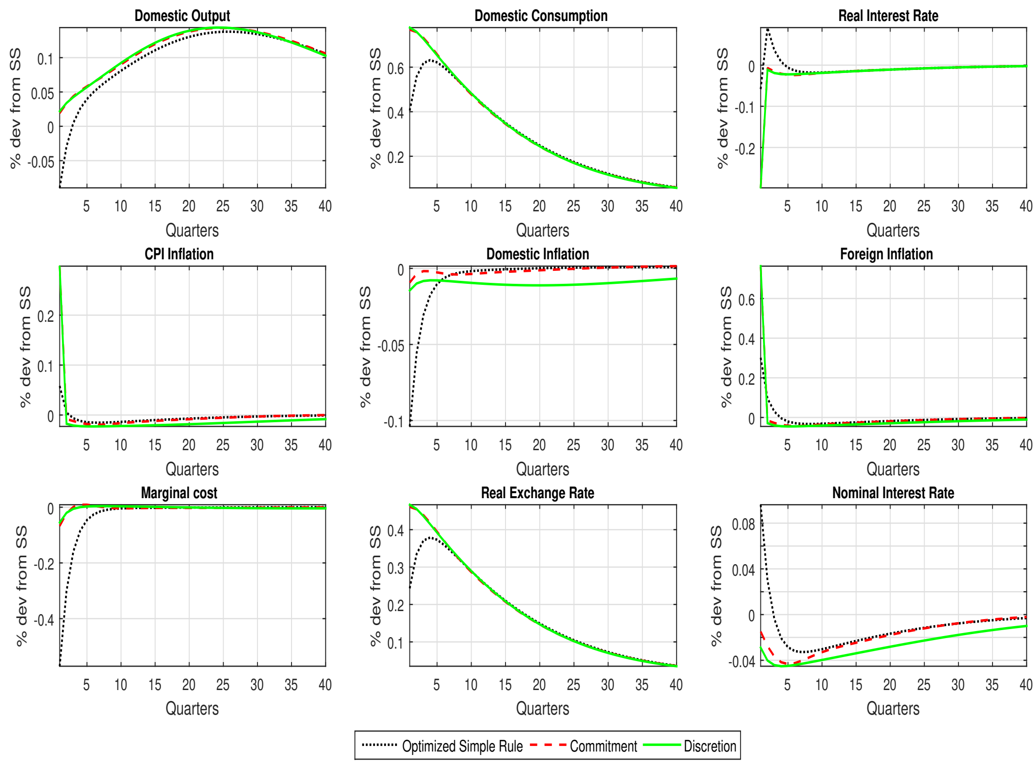

Figure 2.4: Responses to a negative international oil price shock under optimal commitment and discretion, with a model that includes capital as well as oil in the production technology of domestic firms ($mod1$). Under the optimised simple rule, equation (2.52) is optimised. The values of the optimized parameters are: $\rho_r = 0.7250$, $\omega_\pi = 9.3813$, $\omega_y = -0.0676$.

Under both policy regimes (i.e. commitment and discretion), a negative international oil price shock causes a decline in oil output, a reduction in input demand by oil firms, a decline in input prices, a fall in marginal cost, and lower domestic inflation. In response to lower domestic prices, the central bank cuts the interest rate to boost aggregate demand. However, the size of the interest rate cut under discretionary policy is larger than under commitment. Compared to the optimised simple rule, commitment and discretionary policies generate higher real exchange rate depreciation, higher CPI inflation, higher terms of trade and consequently higher domestic consumption in the short-run.

The OSR requires a sharp but short-lived contractionary monetary policy in response to increased inflationary pressure, which in turn causes output to remain below its steady state level in the first 3 quarters and above the steady state subsequently[18]. The contractionary effects cause lower input demand, which lead to lower input prices and a significant decline in marginal cost. Consequently, domestic inflation is substantially lower under the OSR. CPI inflation rises due to exchange rate pass-through effect on prices, though less significantly compared to the case under commitment policy. The macroeconomic fluctuations associated with these policy regimes are discussed in section 2.4.4.

2.4.2 Role of capital

In this section, we investigate the macroeconomic implications of introducing capital into the Ferrero and Seneca (2019) model. We do this by comparing the impulse responses to a negative international oil price shock under two model variants: a baseline model ($mod3$) and an intermediate model ($mod2$). The baseline model, $mod3$, replicates Ferrero and Seneca (2019) and differs from the benchmark model presented in section 2 by: (i) completely abstracting from capital, and (ii) excluding oil input from the production technology of non-oil producing firms. On the other hand, the intermediate model, $mod2$, features capital, but excludes oil input from non-oil production. In Table 2.4, we show the key differences between $mod2$ and $mod3$ in terms of the relevant log-linearized equations. As can be seen, the equations relating to the demand for capital, investment assets, rental rate on capital, demand for capital by the oil firm, and the capital accumulation process are absent in $mod3$ while the marginal cost equation under the intermediate model ($mod2$) features the real rental rate of capital.

The comparison between the two models is done under two alternative monetary policy regimes: Domestic inflation-based Taylor rule ($DITR$) and the CPI inflation-based Taylor rule ($CITR$). Figure 2.5 presents the impulse responses under a domestic inflation-based Taylor rule. The economy's responses to a negative international oil price shock under the intermediate model, $mod2$, are represented by the dashed red lines while the dotted black

[18]It is important to note that the during the few quarters of domestic output contraction, the real interest rate remained negative serving to boost output. In this regards, the optimal policy is to initially pursue an expansionary policy to boost output and immediately revert to a regime of gradual monetary tighening to contain inflation (see the impulse response of real interest rate).

lines replicate the economy's responses under the Ferrero and Seneca (2019) model, *mod*3.

Table 2.4: Differences between *mod*2 and *mod*3

Intermediate Model (mod2)	*Ferrero and Seneca (2019) - (mod3)*
$\widetilde{\lambda}_t^k = \chi\left[\left(\widetilde{i}_t - \widetilde{i}_{t-1}\right) - \beta E_t\left(\widetilde{i}_{t+1} - \widetilde{i}_t\right)\right] - \widetilde{c}_t$	-
$\widetilde{\lambda}_t^k = \beta E_t\left[\overline{r}_h\left(\widetilde{r}_{h,t+1} - \widetilde{c}_{t+1}\right) + (1-\delta)\,\widetilde{\lambda}_{t+1}^k\right]$	-
$\widetilde{k}_{t+1} = (1-\delta)\,\widetilde{k}_t + \delta\widetilde{i}_t$	-
$\widetilde{y}_{h,t} = \widetilde{A}_{h,t} + \alpha_h^k\widetilde{k}_{h,t} + \alpha_h^n\widetilde{n}_t$	$\widetilde{y}_{h,t} = \widetilde{A}_{h,t} + \alpha_h^n\widetilde{n}_t,$
$\widetilde{k}_{h,t} = \widetilde{w}_t + \widetilde{n}_t - \widetilde{r}_{h,t}$	-
$\widetilde{w}_t = \widetilde{A}_{h,t} + \alpha_h^k\widetilde{r}_{h,t} + \left(\alpha_h^n - 1\right)\widetilde{n}_t - \gamma\widetilde{s}_t + \widetilde{mc}_t$	$\widetilde{w}_t = \widetilde{A}_{h,t} - \gamma\widetilde{s}_t + \widetilde{mc}_t$
$\widetilde{mc}_t = \alpha_h^k\widetilde{r}_{h,t} + \alpha_h^n\widetilde{w}_t - \widetilde{A}_{h,t} + \gamma\widetilde{s}_t$	$\widetilde{mc}_t = \widetilde{w}_t - \widetilde{A}_{h,t} + \gamma\widetilde{s}_t$
$\widetilde{y}_{o,t} = \widetilde{A}_{o,t} + \alpha_o^k\widetilde{k}_{o,t} + \alpha_o^m\widetilde{m}_t$	$\widetilde{y}_{o,t} = \widetilde{A}_{o,t} + \alpha_o^m\widetilde{m}_t,$
$\widetilde{k}_{o,t} = \widetilde{p}_{o,t}^* + (1-\gamma)\,\widetilde{s}_t + \widetilde{y}_{o,t} - \widetilde{r}_{h,t}$	-

As can be seen from Figure 2.5, the economy's responses to a negative international oil price shock are qualitatively similar under the two models. Thus, our results confirm the transmission mechanism enunciated in Ferrero and Seneca (2019) where the effects of a negative international oil price shock are transmitted into the domestic economy through a reduction in the oil sector's demand for material input. However, an interesting result is that, following a negative international oil price shock, the reduction in demand for materials input by the oil firms is substantially larger in the model with capital (*mod*2), leading to a more severe contractionary effects on domestic output when compared to the case under the model without capital, *mod*3. Also, the contractionary effect of of a negative oil price shock on output is shorter-lived under the model with capital, *mod*2*,* as the economy rebounds faster compared to the case under *mod*3*.* Under the model with capital, there is a larger terms of trade effect that amplifies the expenditure-switching mechanism arising from lower domestic prices in the small open economy. Thus, while the duration of output contraction lingers longer under *mod*3 (spanning over 40 quarters), domestic output remains below its steady state level for only about 10 quarters under *mod*2*.* This quicker recovery is driven by higher domestic consumption driven by the larger terms of trade effect and the consequent higher demand for capital inputs by non-oil producing firms. More so, the lower prices recorded under the model with capital give ample headroom for larger interest rate cut by the central bank.

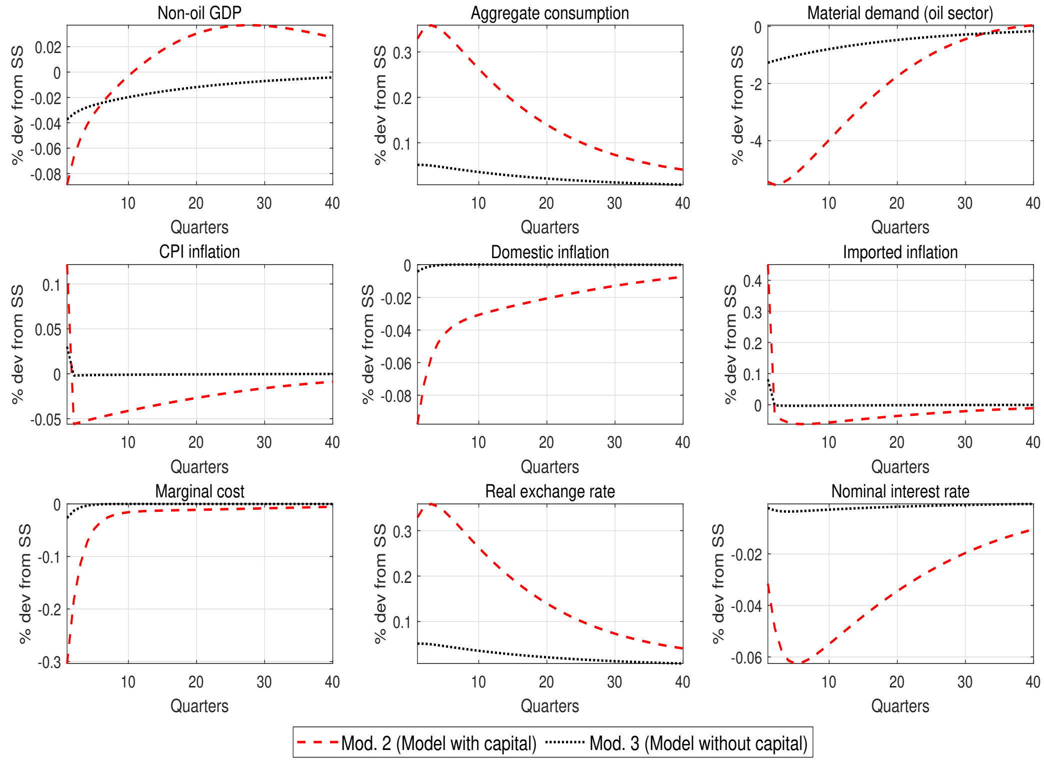

Figure 2.5: Responses to a negative international oil price shock under domestic inflation-based Taylor rule for the intermediate model (*mod*2, which features capital) and the baseline model (*mod*3, which abstracts from capital)

Furthermore, the reduction in demand for input factors causes a decline in marginal cost. This causes non-oil producing firms to adjust their prices downwards, leading to lower domestic inflation. However, the declines in the marginal cost and the domestic inflation are relatively larger under *mod*2. Consequently, while the central bank embarks on a lax monetary policy under the two models, the response is more dovish under the model with capital, *mod*2. Expectedly, the economy recovers faster under the model with capital, *mod*2, while the real exchange rate depreciated more. In other words, the greater interest rate cut under *mod*2 leads to a relatively higher level of depreciation in the real exchange rate which in turn translates into higher CPI inflation in the short-run. Overall, we show that adding capital to Ferrero and Seneca's (2019) model amplifies the economy's responses to a negative international oil price shock with the amplification cutting across both real and nominal variables.

Figure 2.6 presents the impulse response functions of the two models under a CPI inflation-based Taylor rule (*CITR*). The analysis and findings presented under the *DITR* also holds for *CITR*. However, a number of variations are discernable. First, the extent of the decline in domestic inflation is greater under the *CITR,* driven by the lower marginal cost faced by domestic producers compared to the case under the *DITR*. Second, in contrast to an expansionary policy implemented under under the *DITR*, the central bank pursues a contractionary monetary policy under the *CITR* in response to the increased CPI inflation caused by the depreciation in the real exchange rate. Third, the contractionary monetary policy pursued under the *CITR* generates a deeper recession in the aftermath of a negative international oil price shock. We conclude that a monetary policy rule that responds to a broader measure of inflation, such as the CITR, is more successful at stabilising real exchange rate and achieving lower CPI inflation compared to a policy that responds to a more restrictive measure of inflation, such as the DITR.

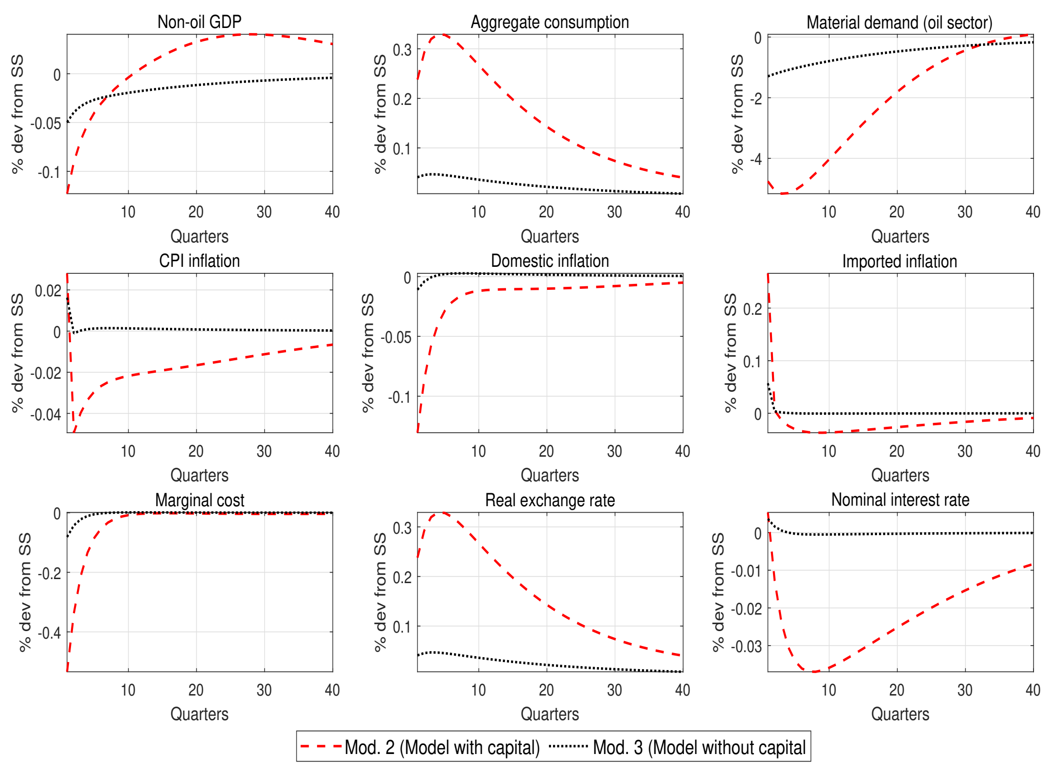

Figure 2.6: Responses to a negative international oil price shock under a CPI inflation-based Taylor rule for the intermediate model ($mod2$, which features capital) and the baseline model ($mod3$, which abstracts from capital)

Based on the analyses conducted in this section, some useful results are documented. We find that adding capital to the DSGE model of the small open oil-producing economy amplifies the response of the economy to an international oil price shock, regardless of whether monetary policy responds to domestic or headline inflation (Figures 2.5 and 2.6). This conclusion is consistent with the findings of Vásconez et al. (2015) for the US economy. Second, the presence of capital causes the economy to recover faster from the economic recession induced by a negative international oil price shock. While the demands for most factor inputs by both oil and non-oil producing firms fall following a negative oil price shock, the non-oil sector's demand for capital increases in order to be able to satisfy the increased consumption demand for domestic goods. Thus, capital plays a critical role in the recovery process of the economy (Figure 2.3). Third, the central bank is generally more active in its interest rate adjustments under the model that features capital owing to a higher pass-through effect of exchange rate to prices and the higher policy headroom created by the lower marginal cost (Figures 2.5 and 2.6).

2.4.3 Oil intensity of domestic production

In this section, we investigate the implications of incorporating oil intensity of domestic production for the response of the economy to an oil price shock. To this end, we show the impulse responses to a negative oil price shock under the benchmark model (*mod*1, which features both capital and oil intensity) and the intermediate model (*mod*2, which features capital, but ignores oil intensity). In Table 2.5, we show the key differences between the benchmark and intermediate models in terms of three relevant log-linearized equations. In Figure 2.7, we present the economy's responses under a domestic inflation-based Taylor rule (*DITR*) while the dynamic responses under *CITR* are presented in Figure 2.8. The impulse responses for the benchmark model, *mod*1, are represented by the dashed lines while the impulse responses for the intermediate model, *mod*2, are represented by the dotted lines.

Table 2.5: Differences between the benchmark and intermediate models

Benchmark Model (*mod*1)	*Intermediate Model* (*mod*2)
$\widetilde{y}_{h,t} = \widetilde{A}_{h,t} + \alpha_h^k \widetilde{k}_{h,t} + \alpha_h^o \widetilde{o}_t + \alpha_h^n \widetilde{n}_t,$	$\widetilde{y}_{h,t} = \widetilde{A}_{h,t} + \alpha_h^k \widetilde{k}_{h,t} + \alpha_h^n \widetilde{n}_t,$
$\widetilde{mc}_t = \alpha_h^k \widetilde{r}_{h,t} + \alpha_h^o \widetilde{p}_{o,t} + \alpha_h^n \widetilde{w}_t - \widetilde{A}_{h,t} + \gamma \widetilde{s}_t,$	$\widetilde{mc}_t = \alpha_h^k \widetilde{r}_{h,t} + \alpha_h^n \widetilde{w}_t - \widetilde{A}_{h,t} + \gamma \widetilde{s}_t,$
$\widetilde{o}_t = \widetilde{w}_t + \widetilde{n}_t - \widetilde{p}_{o,t},$	-

Notably, the impulse responses for the two models are qualitatively similar and the oil price shock transmission channel is preserved. In other words, a negative shock to international price of oil causes oil firms to cut down on their demand for factor inputs. This lowers input prices, reduces marginal cost, causes domestic inflation to moderate and leads to an interest rate cut.

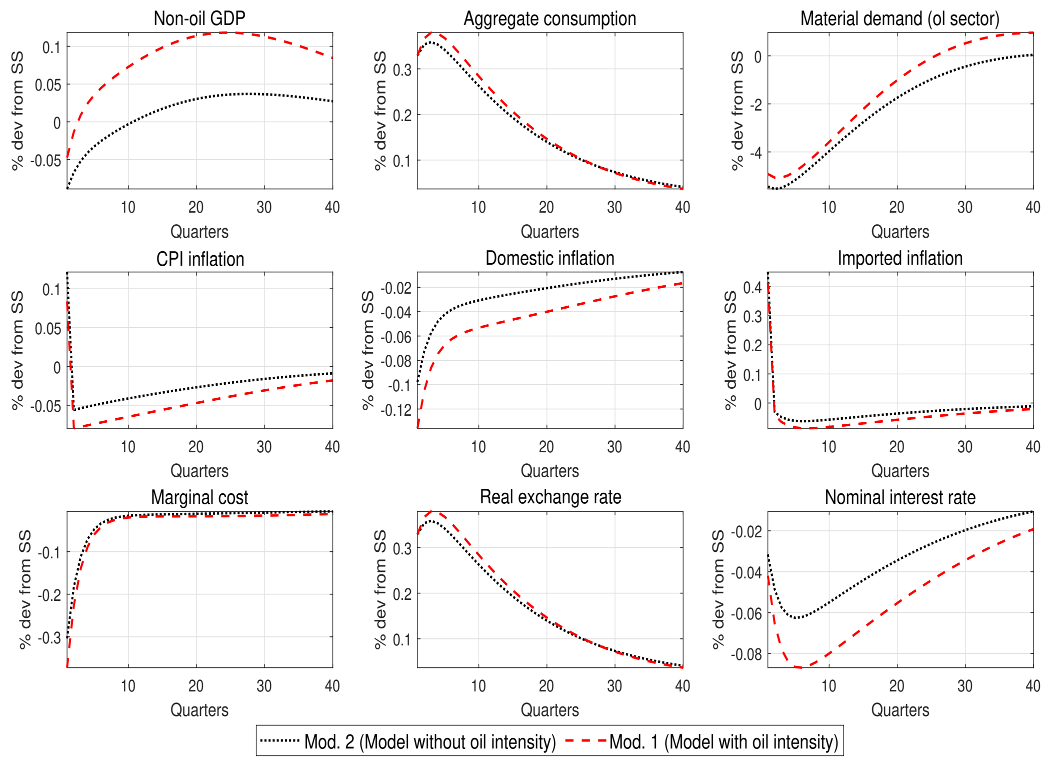

Figure 2.7: Responses to a negative oil price shock under domestic inflation-based Taylor rule for a model with oil oil intensity ($mod1$) and without oil intensity ($mod2$)

While these behaviours are in line with our findings in Section 2.4.1, we note that the extent of the decline in domestic inflation is more pronounced under the benchmark model, $mod1$ (which features oil in the production technology of domestic firms). This outcome is in line with the dictates of the log-linearized equation for the real marginal cost shown in Table 2.5. In contrast to the case under the intermediate model (which ignores oil intensity), the real marginal cost facing non-oil producing firms under our benchmark model includes an additional term relating to the real price of oil. Thus, any shock hitting the system that causes the real price of oil to fall subsequently leads to a larger decline in marginal cost, and hence domestic inflation under the benchmark model, $mod1$, falls more substantially.

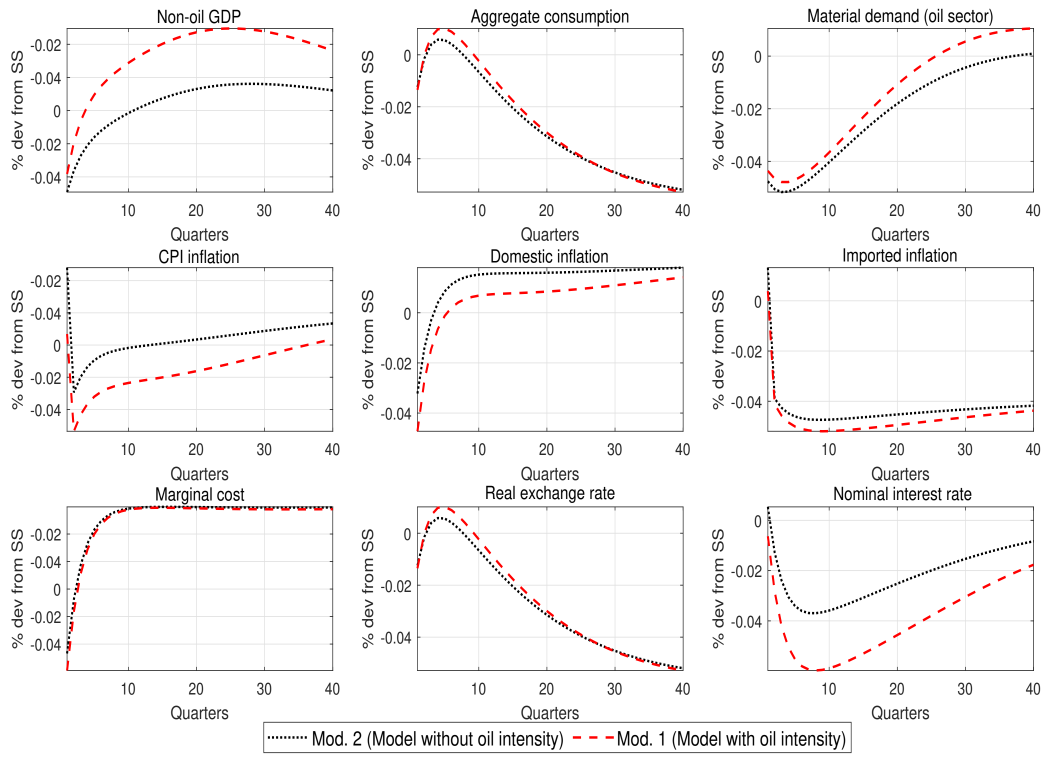

Figure 2.8: Responses to a negative oil price shock under CPI inflation-based Taylor rule for a model with oil intensity ($mod1$) and without oil intensity ($mod2$)

Responding to the lower domestic inflation as well as the contraction in output, the central bank, under *DITR*, immediately cuts interest rate in order to re-inflate the economy and boost aggregate demand. However, the extent of the interest rate cut is deeper under the benchmark model, $mod1$. Consequently, the contractionary impact of a negative oil price shock on domestic output is less pronounced and shorter-lived under $mod1$ compared to the case under $mod2$. These findings imply that accounting for oil intensity of domestic production ameliorates the contractionary effect of a negative international oil price shock on domestic output. Under the *DITR,* the amelioration is more pronounced.

In conclusion, the impulse response functions presented in Figures 2.7 and 2.8 show that DSGE models of oil-producing economies that ignore oil intensity of domestic production may generate results that overstate the contractionary effect of a negative international oil price shock on domestic output. However, including oil in the production technology of domestic firms generates lower domestic inflation and limits the the pass-through effects of exchange rate into CPI inflation via lower domestic inflation. Furthermore, irrespective of the measure of inflation included in the monetary policy reaction function, the central bank's interest rate adjustments in response to a negative international oil price shock are more aggressive under the benchmark model, *mod*1, compared to the case under the intermediate model, *mod*2. This seems to suggest that oil producing economies with high oil intensity of domestic output are susceptible to higher interest rate volatilities as the lower domestic inflation provides greater headroom for monetary policy to boost domestic output.

2.4.4 Monetary policy analysis

In this section, we compare the macroeconomic fluctuations and losses associated with the alternative monetary policy rules specified in Table 2.2 for our benchmark model, *mod*1. The results for the other two model variants (i.e. the intermediate model, *mod*2, and the baseline model, *mod*3) are presented in Appendix A.2.2. The policy loss corresponding to each policy rule is calculated based on the central bank's loss function specified in equation (2.56). Table 2.6. shows the policy outcomes under eleven simple rules as well as the outcomes for optimal policy under commitment and discretion. The optimised Taylor rule parameters for the respective policy rules presented in Table 2.6 below are shown in Table A.3 of Appendix A.2.2.

The first question we ask is: are there gains from the central bank of an oil-producing economy committing to a monetary policy plan? As shown in Table 2.6, the best performance in terms of policy loss is achieved under an optimal commitment policy (with a policy loss of 0.3252), thus highlighting gains from monetary policy credibility. Under this policy regime, the volatilities of domestic inflation and interest rate are relatively low. When compared to the outcomes under discretionary policy, optimal commitment policy yields superior outcomes in terms of stabilising domestic consumption, CPI inflation, domestic inflation, exchange rate as well as the nominal interest rate. However, discretionary policy performed slightly better in stabilising domestic output. Overall, the best outcomes in term of systemic stability is recorded when the central bank of the oil-producing economy is able to commit to a policy plan.

In the first two rows of Table 2.2, we compare the performance of simple inflation-based Taylor rules that either feature CPI inflation (*CITR*) or domestic inflation (*DITR*) in terms of the policy loss value. Of the duo, *DITR* performs better in terms of generating lower policy loss and also yielding lower volatilities of domestic inflation and interest rate. However, the

CITR, is more successful in stabilizing domestic output, domestic consumption, CPI inflation as well as exchange rate, following an international oil price shock.

Table 2.6: Macroeconomic fluctuations and losses under $mod1$

Taylor rule	Standard Deviations (%)						Policy loss
	$\widetilde{y}_{h,t}$	$\widetilde{c}_{h,t}$	$\widetilde{\pi}_t$	$\widetilde{\pi}_{h,t}$	$\widetilde{q}_t$	$\widetilde{R}_t$	
$CITR$	0.7723	2.1906	0.0828	0.1183	1.3144	0.1759	0.5977
$DITR$	0.8030	2.4043	0.3299	0.0123	1.4426	0.1549	0.3322
$FCITRy$	0.7711	2.1902	0.0820	0.1181	1.3141	0.1729	0.5963
$FDITRy$	0.8008	2.4010	0.3282	0.0138	1.4406	0.1542	0.3315
$IFCITRy$	0.7701	2.1810	0.0785	0.1240	1.3086	0.1528	0.5910
$IFCITRyq$	0.8246	2.3301	0.2511	0.0555	1.3980	0.1110	0.3894
$IFDITRy$	0.7998	2.3843	0.3077	0.0167	1.4306	0.1441	0.3275
$IFDITRyq$	0.7979	2.3876	0.3076	0.0178	1.4326	0.1446	0.3258
$SCITR$	0.7928	2.1256	0.0000	0.1524	1.2753	0.1294	0.7306
$SDITR$	0.8104	2.4081	0.3319	0.0000	1.4448	0.1435	0.3347
$SNGDPGT$	0.7823	2.3739	0.2990	0.0392	1.4243	0.1563	0.3340
$Commitment$	0.7978	2.3891	0.3050	0.0179	1.4334	0.1441	0.3252
$Discretion$	0.7901	2.3935	0.3169	0.0646	1.4361	0.1897	0.3821

Next, we consider the case of a central bank that reacts to output in addition to prices by specifying flexible variants of the two simple rules discussed above. These are flexible CPI inflation-based Taylor rule with output (*FCITRy*) and flexible domestic inflation-based Taylor rule with output (*FDITRy*). Our results show that the *FDITRy* outperforms its CPI inflation-based counterpart (*FCITRy*) in terms of policy loss as well as the its ability to stabilise domestic inflation and interest rate. However, in terms of stabilising real variables such as domestic output and consumption, the *FCITRy* performs better. In addition, the *FCITRy* is superior to the *FDITRy* in stabilising the exchange rate. Thus, while responding to a negative international oil price shock, the central bank of an oil-producing, oil-dependent economy is able to reduce policy loss by keeping an eye not only on inflation, but also output.

Should the central bank of a resource-rich economy bother about interest rate smoothing? To answer this question, we compute the policy losses associated with flexible Taylor rules that also include interest rate inertia. These are CPI inflation-based flexible Taylor rule with inertia (*IFCITRy*) and its domestic inflation-based counterpart (*IFDITRy*). The results shown in Table 2.6 indicate that adding interest rate inertia to our previous specifications (i.e. *FCITRy* and *FDITRy*) further lowers policy losses. Also, we find that a central bank reaction function that features domestic inflation, domestic output and interest rate inertia (*IFDITRy*) outperforms its CPI inflation counterpart, *IFCITRy*, in terms of generating lower losses. Again, the *IFCITRy* is superior to *IFDITRy* in stabilising the real economy.

Furthermore, we evaluate the relevance of including exchange rate in the reaction function of a typical central bank of an oil-producing economy by computing the policy losses and the corresponding macroeconomic fluctuations associated with such rules. To this end, we include an exchange rate term in the *IFCITRy* and *IFDITRy* specifications to have *IFCITRyq* and *IFDITRy*q, respectively. We find that the policy losses associated with simple flexible rules that include exchange rate are generally lower, implying that such policies generate superior outcomes. Also, these rules are quite successful in stabilizing domestic inflation and interest rate under the CPI inflation based Taylor rule variants. However, they generate relatively higher volatilities of real variables and the CPI inflation, especially under the *IFCITRyq* . Once the exchange rate is added to the *IFDITRy,* it emerges better than its CPI inflation counterpart in stabilising domestic output and domestic inflation.

Finally, we examine the optimality of strict targeting rules, which are CPI inflation (*SCITR*), domestic inflation (*SDITR*) and nominal growth in gross domestic product (*SNGDPGT*). Table 2.6 indicates that, of these three, a central bank policy that strictly targets nominal growth in gross domestic product yields the lowest policy loss and performs well in stabilising non-oil output. However, it yields inferior outcomes in terms of interest rate stabilisation. Under strict CPI inflation targeting regime (*SCITR*), CPI inflation is completely stabilized while domestic inflation is fully stabilized under the strict domestic inflation targeting rule (*SDITR*). For a central bank that cares about stability in exchange rate, S*CITR* performs best within this group of strict targeters.

In conclusion, our results suggest that a flexible Taylor rule that features output, domestic inflation, exchange rate and interest rate inertia (*IFDITRyq*) represents an optimal strategy for an oil-producing, oil-dependent economy facing negative international oil price shocks. This is followed by *(IFDITRy*) and (*FDITR*y). This implies that focusing on domestic inflation as opposed to CPI-inflation generates superior policy outcomes. However, if the central bank has a dual mandate of maintaining stability in both output and prices, an aggregate CPI inflation-based Taylor rule represents a viable alternative.

Next, we evaluate the robustness of our findings across the three model variants: benchmark model -$mod1$, intermediate model - $mod2$, and the baseline model - $mod3$. Table 2.7 presents the losses for the three models under the alternative monetary policy rules. The optimised Taylor rule parameters for the policy loss calculations presented in Table 2.7 are shown in Tables A.3 - A.5, Appendix A.2.2. Our results show that the inclusion of capital to the Ferrero and Seneca (2019) model has significant implications for the choice of monetary policy rule in the small open economy. While a flexible domestic inflation based Taylor rule that features interest rate inertia, domestic output and exchange rate (*IFDITRyq*) represents the optimal monetary policy strategy under the benchmark (*mod1*) and intermediate (*mod2*) models, it yields inferior outcome under the baseline model (*mod3*). In other words, simple rules such as *DITR, FDITRy* and *SDITR* are superior to the *IFDITRyq* under the Ferrero and Seneca (2019) model. Also, Ferrero and Seneca (2019) showed that the inclusion of interest rate smoothing into the central bank's reaction function leads to increased loss, a finding that is confirmed under our baseline model, *mod3.* However, this conclusion is reversed once capital is added to the model (see columns 2 and 3 of Table 2.7). In other words, once capital is added to the model, the central bank achieves better macroeconomic stability by implementing gradual interest rate adjustments in response to an oil price shock.

Table 2.7: Losses under the three model variants

Regime	$mod1$	$mod2$	$mod3$
$CITR$	0.5977	0.3025	0.0130
$DITR$	0.3322	0.0359	0.0051
$FCITRy$	0.5963	0.2814	0.0101
$FDITRy$	0.3315	0.0359	0.0051
$IFCITRy$	0.5910	0.2186	0.0102
$IFCITRyq$	0.3894	0.0671	0.0056
$IFDITRy$	0.3275	0.0337	0.0055
$IFDITRyq$	0.3258	0.0332	0.0055
$SCITR$	0.7306	0.4143	0.0158
$SDITR$	0.3347	0.0359	0.0051
$SNGDPGT$	0.3340	0.0692	0.0085
$Commitment$	0.3252	0.0324	0.0051
$Discretion$	0.3821	0.0354	0.0056

We also find that Taylor rules which feature exchange rate perform quite well, especially under *mod1* and *mod*2, implying that the central bank of an oil-producing, oil-dependent, economy needs to pay attention to exchange rate developments in the face of a negative international oil price shock in order to minimise policy loss. In terms of the implications of adding output to the simple inflation-based rules, the three model variants confirm that such addition generate lower policy losses; a finding that is in line with the conclusion by Ferrero and Seneca (2019). As expected, optimal policy under commitment yields better policy outcomes across the three models compared to the case under discretionary policy.

2.4.5 Sensitivity analysis

In this section, we examine the sensitivity of the monetary policy analysis conducted above to changes in the loss function parameters specified in equation (2.56). 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 regards to its monetary stabilization objectives. The results presented in Tables 2.8 - 2.10 are based on the benchmark model, *mod*1.

Table 2.8 presents the outcomes of the sensitivity analysis for two inflation-based Taylor rules (*CITR* and *DITR*) and their flexible variants (*FCITRy* and *FDITRy*), which includes an output term. Following a negative international oil price shock, the best policy outcomes are recorded when the central bank places more weight on inflation in its loss function. Also, the policy outcomes under the domestic inflation based Taylor rules (i.e. *DITR* and *FDITRy*) are relatively insensitive to varying values of λ_π in the loss function. As in Ferrero and Seneca (2019), we find that the inclusion of an output term in the *CITR* reduces policy loss regardless of the parameter configuration, provided the weight placed on inflation is higher than the weights on interest rate and output in the central bank's loss function. However, the same is not true for *DITR* once the weight on inflation is greater than 1.0 while holding the weights placed on the other variables constant at 0.5. However, contrary to the findings by Ferrero and Seneca (2019), adding interest rate smoothing to *FCITRy* and *FDITRy* reduces loss regardless of the parameter settings in the central bank loss function.

Also, the sensitivity of our results to different parameter configurations in the central bank's loss function are evaluated under a scenario in which the reaction function of the monetary authority features interest rate inertia. The results are presented in Table 2.9. First, we find that relative to the benchmark parameter configuration (shown in the first row), a central bank that places equal weights on the three variables performs better. Second, the sensitivity analyses confirm our earlier findings that the inclusion of exchange rate in the reaction function of the central bank yields superior policy outcomes regardless of whether the policy rule is CPI or domestic-inflation based. Even with higher weights placed on either output or interest rate than inflation, the improved policy outcomes under the central bank reaction function that features exchange rate remains valid. Third, as is the case under the four earlier rules, increasing the weight on inflation in the loss function while holding the weights on the other variables fixed yields increased policy losses while increasing the weight on output performs even worse. However, placing higher weight on interest rate in the loss function leads to superior policy outcomes once an interest rate smoothing term is added to the CPI inflation-based central bank's reaction function (Table 2.9).

Table 2.8: Sensitivity analysis on loss function weights

Weights			**Loss**			
λ_π	λ_y	λ_r	*CITR*	*DITR*	*FCITRy*	*FDITRy*
1.0	0.5	0.2	0.5977	0.3322	0.5963	0.3315
0.5	0.5	0.5	0.5986	0.3421	0.5983	0.3417
1.0	0.5	0.5	0.7105	0.3431	0.7097	0.3429
1.5	0.5	0.5	0.8222	0.3435	0.8209	0.3441
2.0	0.5	0.5	0.9340	0.3437	0.9322	0.3442
0.5	1.0	0.5	0.8919	0.6565	0.8832	0.6531
0.5	1.5	0.5	1.1708	0.9585	1.1528	0.9497
0.5	2.0	0.5	1.4382	1.2490	1.4107	1.2328
0.5	0.5	1.0	0.7107	0.3601	0.7872	0.3601
0.5	0.5	1.5	0.8371	0.3761	0.9542	0.3761
0.5	0.5	2.0	1.1704	0.3921	1.1016	0.3921

In Table 2.10, we consider the case of strict inflation targeting central banks as well as the implications of optimal policy under commitment and discretion for the policy loss. Under different parameter configurations in the loss function, we uphold our earlier conclusion that a policy rule that strictly targets domestic inflation generally outperforms its CPI inflation-based counterpart. Also, we confirm that there are gains from commitment regardless of the parameter settings in the central bank's loss function. As in the previous rules, increasing the weight placed on output in the loss function while holding the weights for other variables constant yields worsening policy outcomes. Under the strict CPI inflation-based Taylor rule, the central bank generates better policy outcomes when it places higher weight on interest rate compared to the cases in which higher weights are placed on either inflation or output. However, with optimal policy under commitment, attaching higher and increasing weights on inflation in the loss function yields superior policy outcomes compared to the cases under which the weight on either output or interest rate is higher. Interestingly, when the central bank exercises discretion in the conduct of monetary policy, increasing the weight placed on inflation in the loss function leads to a reduction in the policy loss value.

Table 2.9: Sensitivity analysis on loss function weights (cont'd)

Weights			**Loss**			
λ_π	λ_y	λ_r	*IFCITRy*	*IFCITRyq*	*IFDITRy*	*IFDITRyq*
1.0	0.5	0.2	0.5910	0.3894	0.3275	0.3258
0.5	0.5	0.5	0.4786	0.3643	0.3276	0.3254
1.0	0.5	0.5	0.6325	0.4307	0.3316	0.3292
1.5	0.5	0.5	0.7738	0.4145	0.3332	0.3309
2.0	0.5	0.5	0.9061	0.4381	0.3341	0.3322
0.5	1.0	0.5	0.7718	0.6944	0.6336	0.6311
0.5	1.5	0.5	1.0560	0.9926	0.9248	0.9227
0.5	2.0	0.5	1.3292	1.2742	1.2026	1.2012
0.5	0.5	1.0	0.4906	0.3651	0.3331	0.3304
0.5	0.5	1.5	0.4975	0.3650	0.3375	0.3343
0.5	0.5	2.0	0.5029	0.3655	0.3412	0.3376

The results presented in Tables 2.8 - 2.10 show that when equal weight of 0.5 is attached to the three variables in the central bank's loss function, a flexible domestic inflation-based Taylor rule that features output, exchange rate and interest rate smoothing (*IFDITRyq*) yields the best policy outcome. This is followed by *IFDITRy* and *FDITR*y. This implies that, given an international oil price shock, monetary policy rules that target domestic inflation generally outperforms its CPI inflation-based counterparts. This is consistent with the findings of Ferrero and Seneca (2019).

Table 2.10: Sensitivity analysis on loss function weights (cont'd)

Weights			**Loss**			
λ_π	λ_y	λ_r	*SCITR*	*SDITR*	*Commitment*	*Discretion*
1.0	0.5	0.2	0.7306	0.3347	0.3252	0.3821
0.5	0.5	0.5	0.6123	0.3443	0.3295	0.5236
1.0	0.5	0.5	0.7980	0.3443	0.3254	0.3756
1.5	0.5	0.5	0.9837	0.3443	0.3260	0.3486
2.0	0.5	0.5	1.1694	0.3443	0.3266	0.3393
0.5	1.0	0.5	0.9266	0.6726	0.3610	1.1821
0.5	1.5	0.5	1.2408	1.0010	0.4196	2.3297
0.5	2.0	0.5	1.5550	1.3293	0.4997	3.8914
0.5	0.5	1.0	0.7247	0.3602	0.3302	0.5142
0.5	0.5	1.5	0.8371	0.3761	0.3309	0.5135
0.5	0.5	2.0	0.9495	0.3920	0.3318	0.5159

With an increase in the weight placed on inflation in the loss function from 0.5 to 2.0, *IFDITRyq* retains its position as the best policy rule followed by *IFDITRy* and *DITR*. Under a parameter configuration in which the weight on output is increased from 0.5 to 2.0 while holding the weights on the other variables constant at 0.5, we find that the *IFDITRyq* still yields the best policy outcomes followed by *IFDITRy* and *FDITRy*. Similarly, when the weight on interest rate is increased from 0.5 to 2.0 while holding the weights on the other variables constant at 0.5, the *IFDITRyq* yields the best policy outcomes while *IFDITRy* follows as the second best. The analyses conducted in this section suggests that our earlier conclusions are robust to changes in the parameters of the policy loss function. Thus, the central bank of an oil-exporting, oil-dependent economy minimizes policy loss in the face of oil price shocks by reacting to domestic inflation and maintaining a parameter configuration that places higher weight on inflation in its loss function[19].

[19]This contrary to the findings of Hove et al. (2015), who argued that targeting CPI inflation yields better welfare outcome in a commodity exporting economy of South Africa. It is important to note that Hove et al. (2015) abstract from capital accumulation while also assuming labour as the only factor input in the production technology of domestic firms.

2.5 Conclusion

In this paper, we study the macroeconomic implications of ignoring two key features, (i) capital accumulation and (ii) oil intensity of domestic output, in New-Keynesian models often used to analyse the impacts of an oil price shock and monetary policy in resource-rich economies. We rely on the small open economy model of Gali and Monacelli (2005), which was extended by Ferrero and Seneca (2019) to include an oil sector. The implications of these additional features for the response of the economy to an oil price shock are analysed by considering three model variants. First, a Ferrero and Seneca (2019) type model, referred to as $mod1$; which features capital accumulation, an investment adjustment cost and oil intensity of domestic output. Second, a version of $mod1$ that excludes oil intensity of domestic output, denoted as $mod2$. Last, a Gali and Monacelli (2005) type model that includes an oil sector as in Ferrero and Seneca (2019) referred to as $mod3$. This approach enables us to compare results across the different models. We calibrate the model to the Norwegian economy with most of the parameter values taken from Ferrero and Seneca (2019).

We report a number of useful results. First, we show that under our extended model, $mod1$, a negative shock to the international price of oil generates contractionary effects on domestic output through the reduction in demand for materials input by oil firms from the non-oil goods producing firms. This confirms the oil price shock propagation mechanism observed by Ferrero and Seneca (2019). However, we find that adding physical capital to Ferrero and Seneca's (2019) model amplifies the effects of an oil price shock on the domestic economy regardless of the monetary policy rule in place. This finding is consistent with the results of a similar study for an oil-importing economy of the US by Vásconez et al. (2015). Also, the duration of recession arising from a negative international oil price shock, which was found to last beyond 20 quarters in previous works such as Ferrero and Seneca (2019), is found to be substantially shorter in a model that includes capital (10 quarters). Second, the amplified response of the economy to an oil price shock generated under the model with physical capital is attenuated once we allow for oil intensity of domestic production. In addition, accounting for oil intensity shortens the duration of the oil shock-induced recession further to about 3 quarters.

Third, the monetary policy rule that responds to domestic inflation generates larger interest rate cuts compared to its CPI inflation counterpart. Consequently, it is more effective in reducing the size and duration of output contraction caused by the negative oil price shock. However, it generates higher volatility in prices and a more depreciated real exchange rate.

Contrary to the findings of Ferrero and Seneca (2019), allowing for interest rate inertia in the central bank's reaction function reduces policy loss under our benchmark model. Fourth, of the eleven alternative monetary policy rules considered under our benchmark model, a Taylor rule that features inflation rate, output, real exchange rate and interest rate inertia *(IFDITRyq)* emerges a superior strategy as it minimises the policy loss in the aftermath of a negative oil price shock. The inclusion of exchange rate in the Taylor rule improves performance, regardless of whether the policy rule responds to CPI inflation or domestic inflation. This is contrary to the findings of Taylor and Williams (2010). If the central bank's mandate includes both output and inflation stabilisation, a policy rule that responds to headline inflation represents a better anchor for monetary policy.

In summary, the addition of capital and oil intensity of domestic production has non-trivial implications for the response of the oil-producing economy to an oil price shock. Also, once capital is added to the baseline DSGE model, monetary policy rules that feature interest rate inertia and real exchange rate emerges as a superior strategy for minimising overall macroeconomic instability. These findings are robust to changes in the parameters of the central bank loss function. In particular, across different combinations of the loss function parameters, a Taylor rule that features domestic inflation, output, real exchange rate, and interest rate inertia represents an effective monetary policy response to a negative oil price shock. Thus, monetary policy analyses conducted based on DSGE models of oil-producing economies that abstract from capital accumulation should be interpreted with caution.

The benchmark model considered in this paper is useful for studying the macroeconomic impacts of an oil price shock as well as monetary policy in small open oil producing emerging economies. While the model characterises a typical oil producing economy, its features can be generalised for the analysis of most small open resource-rich economies. However, we acknowledge that adding a number of other features to the benchmark model developed in this paper may represent a useful exercise. First, the extent to which oil producing economies are dependent on oil as a source of energy may not have been adequately captured in our paper. Thus, including oil in the consumption basket of households as in Medina and Soto (2005) represents a useful extension for analysing the direct effects of oil price shocks on households consumption. It would also enable an evaluation of the appropriateness of core inflation-based monetary policy rule under our model set up. Second, the model ignores labour market rigidities and its potential implications for the response of the economy to an oil price shock. Third, the role of consumption habits (Dennis, 2009) is ignored. Fourth, our models ignore fuel subsidies, which is a common phenomenon among most small open oil producing emerging economies (Di Bella, Norton, Ntamatungiro, Ogawa, Samake and Santoro, 2015; Estache and Leipziger, 2009). Such subsidies have been associated with domestic price distortions, inefficient consumption, and large fiscal burdens (Coady et al., 2017; Sdralevich, Sab, Zouhar and Albertin, 2014). Fifth, we ignore the presence of hand-to-mouth consumers and its potential implications for monetary policy analysis (Gali, Pez-Salido and Valles, 2004). Finally, the role of fiscal policy is downplayed in our model; thus limiting its usefulness for the joint analysis of monetary and fiscal policies in small open resource rich economies. The decision to abstract from some of these features is driven by our intention to compare the results generated under our benchmark model to those reported by Ferrero and Seneca (2019). Thus, these possible extensions are left for the next chapter.

Chapter 3

Oil Price Shocks, Fuel Subsidies and Business Cycles in an Oil-Producing Emerging Economy

3.1 Introduction

Business cycles are an intrinsic feature of any economy. An interesting strand of the business cycle literature points to the fact that the sources of business cycles have evolved overtime. The documented sources range from the traditional total factor productivity shocks identified in the real business cycle models of the 1980s to more contemporary ones such as financial risks, excessive optimism and self-fulfilling prophecies that emerged in the aftermath of the last global economic crisis (Andrle, Bruha and Solmaz, 2017; Angeletos, Collard and Dellas, 2018; Spatafora and Sommer, 2007). Indeed, one of the legacies of the 2007/09 global financial crisis is the realization that business cycles generated in a relatively large economy can easily spread to other countries and generate non-trivial consequences for the global economy. Since, the sources and severity of business cycles fluctuations differ from one country to another (Agénor, McDermott and Prasad, 2000; Mehrara and Oskoui, 2007; Rand and Tarp, 2002), studies investigating business cycle dynamics in different economies are of significant interest to macroeconomists and policy makers.

In commodity-exporting and commodity-importing countries alike, terms of trade shocks - such as relating to oil price movements have been identified as a prominent source of business cycles (Bacchiocchi and Sarzaeem, 2015; Bergholt, Larsen and Seneca, 2017; Brown and Yücel, 2002; Engemann et al., 2011; Hamilton, 2008; Hollander et al., 2018; Mehrara and Oskoui, 2007; Mork et al., 1990). Almost four decades after Hamilton's (1983) influential paper, the consensus in theoretical and empirical literature is that oil price shocks are capable of generating non-trivial macroeconomic and welfare implications (Fueki, Higashi, Higashio, Nakajima, Ohyama and Tamanyu, 2018). To ameliorate the negative impacts of oil price shocks, fuel subsidy programmes have become popular, especially in oil-producing emerging economies (Di Bella et al., 2015; Estache and Leipziger, 2009). However, in recent times, there has been an increasing call for fuel subsidy reforms globally with policy-makers expressing concerns regarding the efficacy and fiscal implications of such programmes[1] (see, for example, Coady, 2015; Ebeke and Ngouana, 2015; Jakob, Chen, Fuss, Marxen and Edenhofer, 2015; Salehi-Isfahani, Wilson Stucki and Deutschmann, 2015; Sdralevich et al., 2014). It has been argued that, contrary to its intention, badly-targeted subsidy programmes have worsened the problem of inequality and generated macroeconomic imbalances. Consequently, a strand of the literature on oil-macroeconomy relationship has focused on investigating the macroeconomic implications of fuel subsidies in resource-rich countries (Adeniyi et al., 2011; Bazilian and Onyeji, 2012; Berument et al., 2010; Coady, 2015; Coady et al., 2017; Krane and Monaldi, 2017; Medina and Soto, 2005). Our research falls within this strand of the literature.

In this paper, we study the role of oil price shocks in driving business cycle dynamics of small open OPEEs with a fuel subsidy regime and a low oil refining capacity. We pay attention to the design of appropriate monetary policy response to an oil price shock under an economic environment that allows for additional price rigidities arising from a domestic fuel pricing rule. The following specific questions that have been ignored in literature are posed. First, what are the key sources of business cycle fluctuations in an oil-producing emerging economy with an inefficient fuel subsidy regime? Second, what are the macroeconomic implications of a fuel subsidy reform for the small open oil-producing economy[2]? Third, what is the appropriate monetary policy response to an oil price shock under an economy

[1] Clements, Coady, Fabrizio, Gupta, Alleyne and Sdralevich, 2013 lists the consequences of fuel subsidies to include: aggravating fiscal imbalances, crowding-out priority public spending, and depressing private investment, distorting resource allocation by encouraging excessive energy consumption, and accelerating the depletion of natural resources, amongst others.

[2] 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.

with incomplete pass-through of international oil prices to domestic fuel price? Fourth, how relevant is an export price-based monetary policy rule in stabilising the oil-producing emerging economy following an oil price shock? Fifth, how important is the nature of fiscal cyclicality in facilitating the achievement of monetary policy objectives? Sixth, does the presence of hand-to-mouth consumers matter for the economy's response to an oil price shock?

To address these questions, we develop a standard Two Agents New Keynesian (TANK) model that incorporates relevant features of a small open resource-rich emerging economy. We allow for Ricardian and hand-to-mouth consumers in order to reflect the limited access to financial markets by households in most emerging economies and generate empirically plausible response of private consumption to government spending shocks as enunciated by Galí, López-Salido and Vallés (2007). The model also features a well-specified fiscal sector that captures commodity revenues as well as a fuel subsidy regime, which is a common social safety net programme among oil-exporting emerging economies, such as Nigeria, Algeria, Venezuela, Saudi Arabia, e.t.c. (Allegret and Benkhodja, 2015). We include a commodity sector that exports crude oil to the rest of the world and whose revenues are shared by its owners: government and foreign investors (Algozhina, 2015). In order to reflect oil intensity of domestic output and capture the indirect effects of an oil price shock on domestic prices, we include oil in household consumption (Medina and Soto, 2005) and in the production function of domestic firms (Allegret and Benkhodja, 2015). In all, ten structural shocks are incorporated to drive the stochastic dynamics of the model.

We fit the model to Nigerian data via Bayesian methods using data on eleven macroeconomic variables covering the period 2000:Q2 - 2018:Q2. 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 high oil intensity of domestic output, inefficient fuel subsidies, low domestic oil refining capacity, substantial foreign direct investment in the oil sector, and the presence of hand-to-mouth consumers. Second, the few existing studies on the Nigerian economy have failed to reach a consensus regarding the macroeconomic implications of oil shocks and fuel subsidy reforms. Whereas Siddig, Aguiar, Grethe, Minor and Walmsley (2014) found that subsidy removal boosts the GDP, Ocheni (2015) showed that such policy reform hurts economic growth and reduce household income. While the discrepancies in findings could be due to differences in methodological approaches adopted by the studies, we argue that a proper assessment of the effects of subsidy reforms under an inefficient subsidy regime requires a knowledge of the degree of pass-through from international oil price to domestic retail price of fuel. Third, no previous study has investigated business cycle dynamics in Nigeria using an estimated Dynamic Stochastic General Equilibrium (DSGE) model that accounts for the country's fuel subsidy regime[3]. Thus, using Nigerian data allows us to: (i) identify business cycle drivers in a country with an inefficient fuel subsidy regime (ii) assess the macroeconomic implications of potential fuel subsidy reforms in Nigeria and (iii) explore the relevance of alternative monetary policy rules in stabilising the economy after an oil price shock.

A number of interesting results are reported. First, our results show that output fluctuations are driven mainly by oil and monetary policy shocks in the short run (1-4 quarters) and domestic supply shocks in the medium term. Particularly, oil shocks account for about 23 per cent of variations in output up to the fifth year, while fiscal policy appears muted. On the other hand, monetary and domestic supply shocks jointly account for around 72 per cent of short run variations in aggregate inflation while oil shocks play a less prominent role due to the low pass-through effect arising from the fuel subsidy regime. We find that a negative oil price shock generates a persistent negative impact on the GDP and a short-lived positive effect on headline inflation consistent with the findings of Ferrero and Seneca (2019) for the Norwegian economy.

Second, we estimate that about 43 per cent of changes to international oil prices is transmitted into domestic fuel price in Nigeria. Following a negative oil price shock, a zero-subsidy regime generates lower output contraction, higher private consumption, lower headline inflation, but higher real exchange rate depreciation in the short run. These results imply that the fuel subsidy regime accentuates the contractionary effects of an adverse oil price shock while also constraining the capacity of fiscal policy to drive output growth in the long run.

Third, we confirm the trade-off between inflation and output stabilisation highlighted in Ferrero and Seneca (2019). Given an oil price shock, core inflation-based monetary policy rule outperforms its competitors in stabilising prices and exchange rate but leads to output instability in the short run. However, a domestic inflation-based monetary policy rule ap-

[3]The existing studies 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 (Bazilian and Onyeji, 2012). These approaches are limited in terms of their usefulness for studying business cycle dynamics and conducting monetary policy analysis.

pears to represent a useful strategy for stabilising output. An export price targeting rule reverses the contractionary effects of an adverse terms of trade shock at the expense of overall domestic stability (Vogel, Hohberger and Herz, 2015). It is important that these trade-offs are considered by the CBN in the design of monetary policy response to an oil price shock. Based on results from our monetary policy analysis using a specified central bank loss function, we find that the core inflation-based monetary policy reaction function that features output and real exchange rate represents an optimal strategy for stabilising the Nigerian economy in the aftermath of an oil price shock. Our obtained policy ranking is robust to alternative assumptions regarding the inclusion/exclusion of fuel subsidy regime in our model.

Fourth, our simulation results support the view that a counter-cyclical fiscal policy aids the effectiveness of monetary policy in stabilising both real and nominal variables following an oil price shock. This highlights the need for effective interaction between monetary and fiscal policies. The presence of hand-to-mouth consumers amplifies the contractionary effects of lower oil prices on output and consumption in the oil-producing economy. Also, following a negative oil price shock, the inflationary pressures resulting from exchange rate depreciation are ameliorated in the absence of hand-to-mouth consumers.

This paper is organized into 7 sections. In Section 2, we present a brief stylised fact on the relevance of oil to the Nigerian economy. Section 3 presents a summary of related literature. Section 4 describes the theoretical model by elucidating the economic environments and deriving the optimality conditions guiding the decisions of the various agents in the model economy. The estimation procedure as well as the data are discussed in Section 5. In Section 6, we present the estimation results and discuss them in the context of the questions earlier posed. Finally, some concluding remarks and policy implications are offered in Section 7. Detailed derivations of the equilibrium conditions as well as some useful results are presented in Appendix B.

3.2 The Nigerian Economy and Oil: Stylised Facts

Oil plays important roles in the Nigerian economy, contributing about a third of the country's gross domestic product (GDP) in the 1980s and 1990s. Although its share of the economy has waned in the subsequent decades due to declining oil prices and the changing structure of the economy, the oil and gas sector still accounts for about 11.2 per cent of the GDP during the period 2010 - 2018 (Table 3.1). Also, the contribution of oil to government revenue has remained quite high, increasing from 70.2 per cent during the 1980s to about 80.0 per cent in the period 2000 - 2009.

In terms of trade, oil accounts for about 93.1 per cent of exports and 24.4 per cent of imports during the period 2010-2018. The share of refined oil in the country's total imports has increased over time, rising from about 9.0 per cent in the 1980s to about 24.4 per cent during 2010 - 2018[4]. This is reflective of increasing oil intensity in the country, as households and firms depend on fuel as the source of energy for their economic activities. Also, it reflects the low domestic oil refining capacity in the economy, which stood at about 16 per cent during the period 2010-2018. Figure 3.1 shows that the average capacity utilisation rate of the country's three oil refineries have been poor, volatile and dwindling during 1997 - 2018[5].

Table 3.1: 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	21.30	24.41
Oil refining capacity utilisation	-	40.78	28.68	15.97

Nigeria's dependence on crude oil exports and fuel imports implies that volatility in the global crude oil market is of significant consequence for her economy. For instance, the decline in global crude oil prices which began in the early 2014 generated deleterious effects on the economy as fiscal revenues declined, foreign exchange earnings plummeted, and foreign exchange market pressure worsened. Since the economy relies substantially on imports for its intermediate inputs, the scarcity of foreign exchange resulting from falling oil prices constitute a negative productivity shock to the economy. Consequently, output growth declined steadily from 2014 in tandem with the falling oil price and the economy slipped into a recession in 2016 (Figure 3.2). This tends to suggest that the Nigerian economy, as is the case for most small open resource-rich emerging economies, is largely susceptible to business cycles initiated in other economies.

[4]About 91 per cent of Nigeria's fuel requirement is imported from the rest of the world due to poor domestic refining capacity.

[5]Data was sourced from various editions of Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin

The Nigerian government introduced a fuel subsidy regime in the 1980s as part of strategies for cushioning the macroeconomic and welfare impacts of oil price shocks on the economy. Under this arrangement, the government regulates the domestic price of fuel and pays domestic marketers the difference between the regulated domestic price and the Expected Open Market Price (EOMP), which is determined by the country's Petroleum Products Pricing and Regulatory Agency (PPPRA)[6]. It is estimated that about N10 trillion (approximately US$55.13 billion, at an average exchange rate of N181.39/US$) was spent in fuel subsidy payments during the period 2006-2018 (Budgit, 2019).

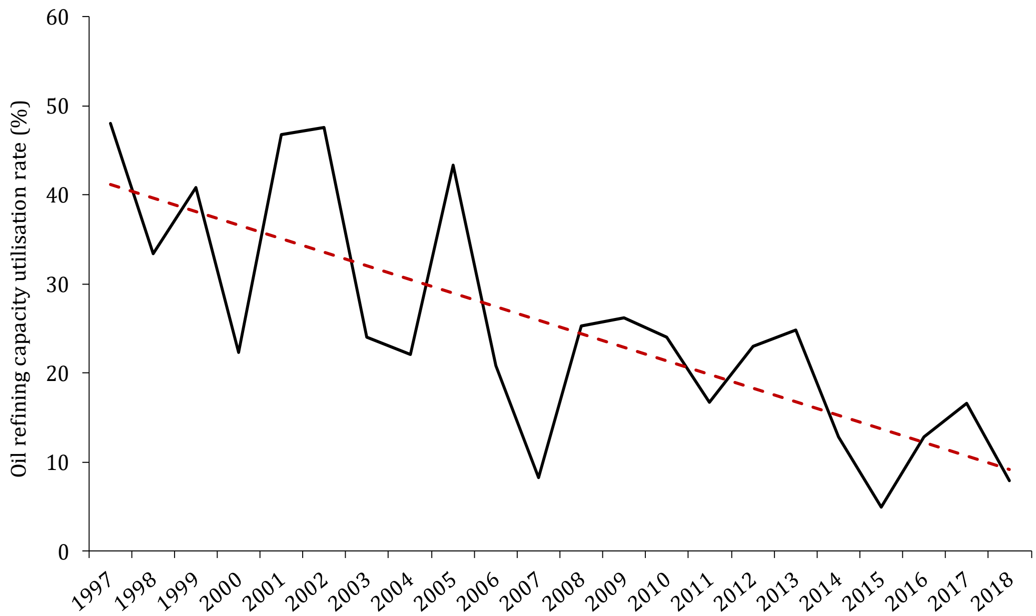

Figure 3.1: Domestic oil refining capacity utilisation rate, 1997 – 2018

The mismatch between the domestic demand for petroleum products and the domestic oil refining capacity explains the growth in fuel imports over the years. Thus, Nigeria is a net exporter of crude oil and a net importer of refined fuel, causing the economy to remain highly vulnerable to the vagaries of the international oil market. This unique feature of the economy complicates the process of subsidy reforms in the country as previous attempts have been largely resisted. A number of studies have focused on examining the implications of fuel subsidy for the economy. It has been reported that Nigeria's subsidy regime distorts fiscal

[6]This agency was established in 2003 to amongst others design the pricing policy of petroleum products in Nigeria

planning, encourages inefficient consumption, and increases inequality as richer households benefit more (Siddig et al., 2014; Soile and Mu, 2015; Umar and Umar, 2013). In terms of the impacts of subsidy reforms, Siddig et al. (2014) found that subsidy reduction increases the GDP and reduces household income. Other studies have argued that that fuel subsidy removal in Nigeria could cause inflation and reduce economic welfare (Adenikinju, 2009); hurt economic growth and reduce household income (Ocheni, 2015); and make firms less competitive (Bazilian and Onyeji, 2012). Thus, there is yet to be a consensus on the output effect of subsidy removal in the country.

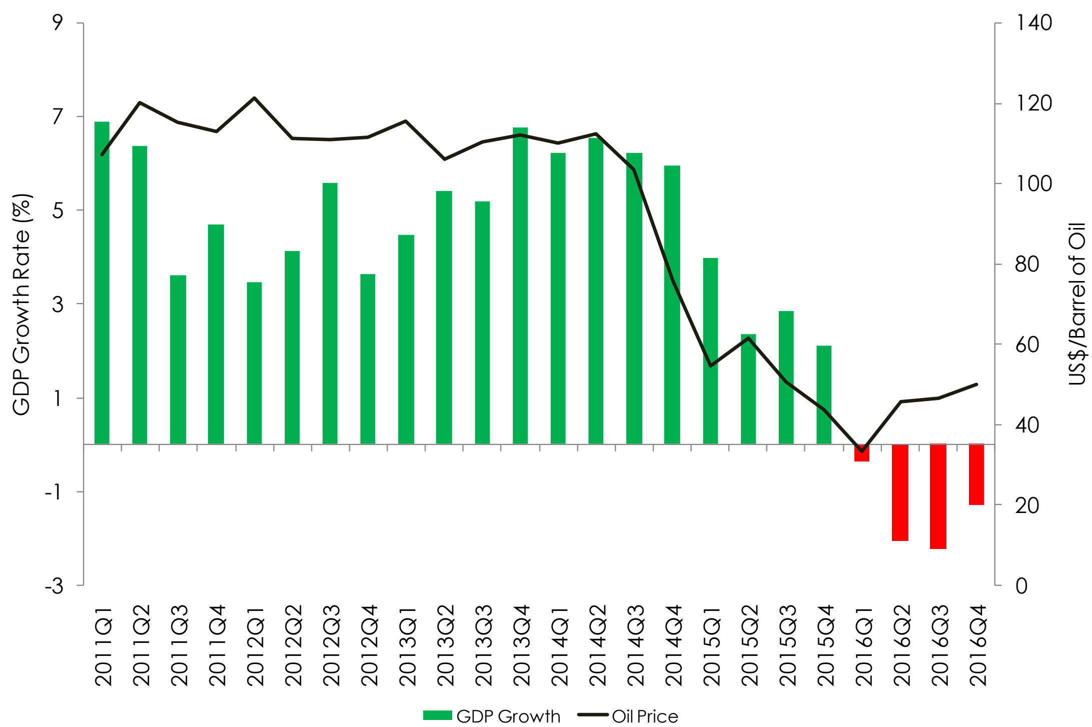

Figure 3.2: Quarterly crude oil price and real GDP growth in Nigeria, 2011Q1 – 2016Q4

Figure 3.3 presents Nigeria's GDP growth and the contribution of its components during the period 2011Q1-2018Q2. The figure shows that output growth trended downwards during the period, with negative growth rates recorded in 2016 and the first quarter of 2017. It is also clear from the figure that growth was above its linear trend during the periods 2013Q2 – 2015Q1 and 2017Q3 – 2018Q2 while it stayed below trend during the periods 2011Q3 – 2012Q2 and 2015Q4 – 2017Q2. Figure 3.3 also shows that the country's business cycles are subject to irregular behaviour in terms of size and space. For instance, the below-trend output growth for 2011Q3 – 2012Q2 is shorter and less severe than that of 2015Q4 – 2017Q2. The sources of these sort of irregularities in the evolution of real GDP growth (often regarded as business cycle fluctuations) are of interest to this paper.

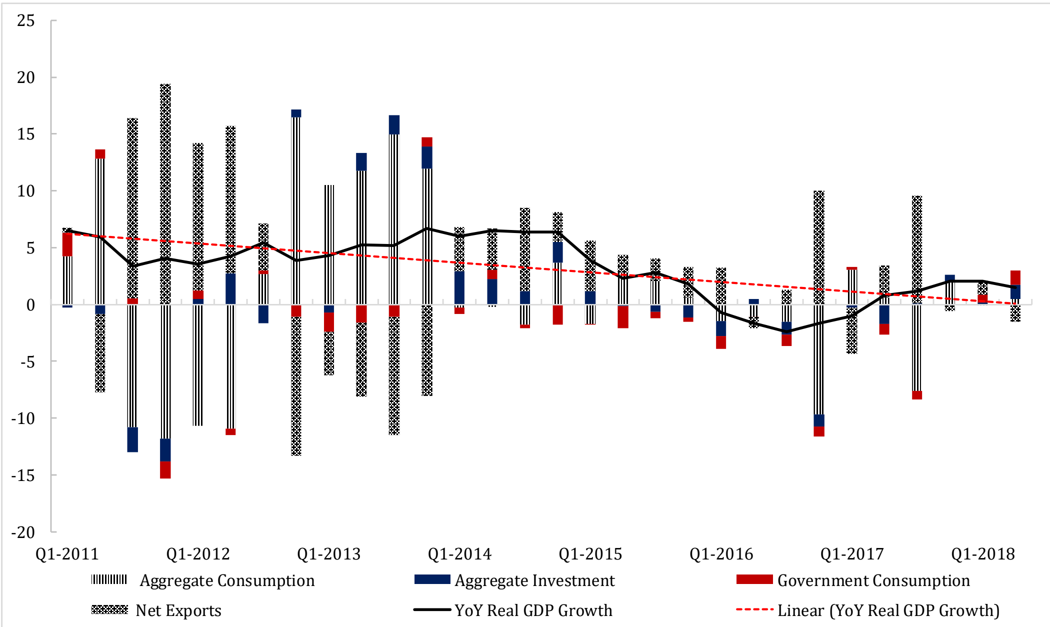

Figure 3.3: Contribution of output components to GDP growth, 2011 - 2018

A decomposition of output growth according to its various components further shows that aggregate consumption and net exports are the key sources of GDP growth in Nigeria. The average output growth of 4.7 per cent recorded in the pre-recession period of 2011Q1 – 2015Q4 was largely accounted for by aggregate consumption as its share in GDP stood at 62.8 per cent (Table 3.2).

Table 3.2: Components of output, 2011 - 2018

Component of GDP	2011Q1-2015Q4		2016Q1 -2018Q2	
	Average share in GDP (%)	Contribution to GDP growth (%)	Average share in GDP (%)	Contribution to GDP growth (%)
Consumption	62.8	2.3	60.0	-1.5
Investment	15.6	0.4	15.4	-0.3
Government	7.0	-0.3	4.5	-0.3
Net exports	14.6	2.3	20.0	2.1
Total	100.0	4.72	100.0	0.01

On the other hand, while the other components of GDP recorded negative growth rates in the 2016Q1 -2018Q2 period, net exports (with a share of GDP at 20.0 per cent) grew by 2.1 per cent. Thus, the positive average GDP growth of about 0.01 per cent recorded during the period was exports-led, further highlighting the economy's vulnerability to external shocks. Finally, we note from Table 3.2 that changes in the average GDP growth are not uniformly distributed over the components of aggregate demand.

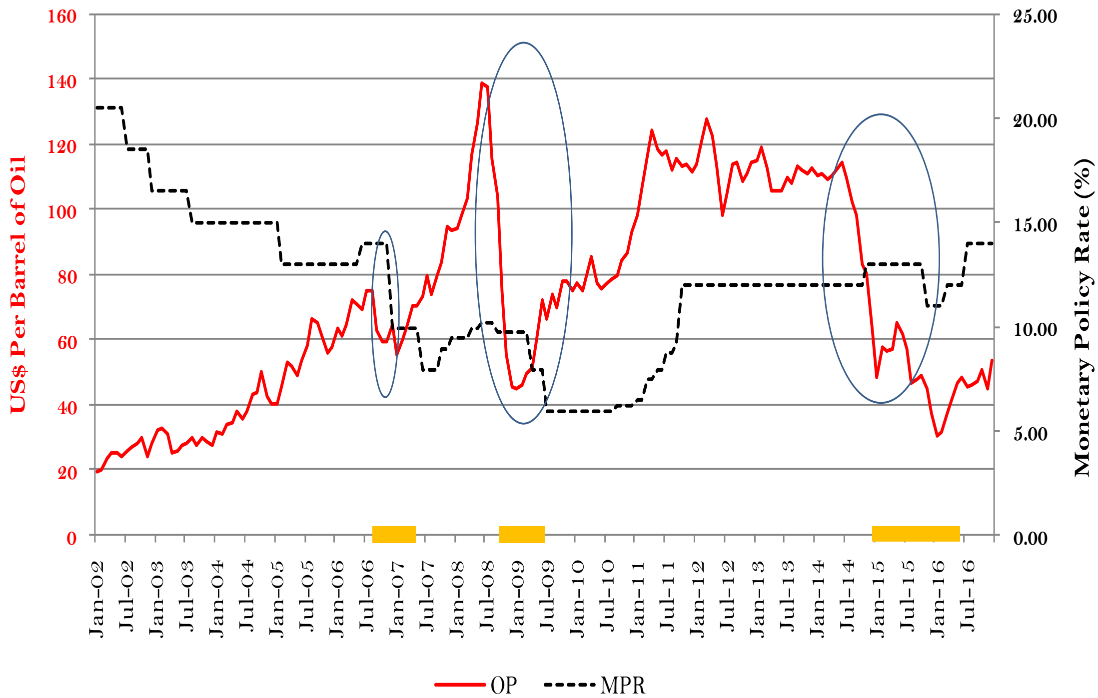

Figure 3.4: Crude oil price and Nigeria's monetary policy rate, 2002 - 2016

In terms of monetary policy response, Figure 3.4 shows the time series plot of crude oil price (OP) and the monetary policy rate (MPR) of the Central Bank of Nigeria (CBN) during the period 2002 – 2016. As indicated by the circles, episodes of substantial decline in the price of crude oil recorded during the years 2006, 2008 and 2014 were followed by interest rate cuts (albeit with some inertia), suggestive of a counter-cyclical monetary policy stance.

3.3 Summary of Related Literature

The oil price shock of 1973 and the subsequent recession in the US led to the resurgence of studies investigating the oil-macroeconomy nexus. The debate has developed along several dimensions with the key strands focusing on (i) the macroeconomic implications of oil shocks, (ii) the oil price shock transmission mechanism and (iii) the appropriate policy responses for ameliorating the impacts of the shocks. The results and policy prescriptions are varied depending on the circumstance of the economy in question (oil-importing versus oil-exporting), the nature and persistence of the oil shock, and the type of policy response to the shock.

In terms of the first strand of the literature identified above, there is considerable evidence supporting the view that oil price shocks generate non-trivial impacts on output, prices and asset prices (Bergholt and Larsen, 2016; Berument et al., 2010; Cashin, Mohaddes, Raissi and Raissi, 2014; Cunado and De Gracia, 2005; Engemann et al., 2011; Ferrero and Seneca, 2019; Hamilton, 1983; Hollander et al., 2018; Hooker, 1996; Kilian, 2008; Mork et al., 1990; Romero, 2008). However, the nature and severity of the impacts depend on whether the economy in question is a net oil-exporter or a net oil-importer (Cashin et al., 2014). In the case of net oil-importing countries, oil price increases have been associated with output losses and inflationary pressures. This sort of stagflationary effects have been reported by studies such as Balke, Brown and Yücel (2002); Barsky and Kilian (2001); Engemann et al. (2011); Hamilton (1983, 2008); Hollander et al. (2018); Hooker (1996); Kilian (2008); Leduc and Sill (2004); Lorusso and Pieroni (2018); Medina and Soto (2005); Mehlum, Moene and Torvik (2006); Mork (1989) and Vásconez et al. (2015). For instance, in furtherance of the findings earlier reported in his 1983 seminal paper, Hamilton (2008) demonstrated that nine out of the ten post-World War II recessions in the US occurred after oil price increases. According to Ferderer (1996), Hamilton's findings have been upheld by several other studies using alternative data, estimation procedure, and other countries. For example, in a study of seven countries, Engemann et al. (2011) show that oil price shocks increase the probability of recession in most of the countries[7]. They argued that for the US, the probability of a recession following an oil price shock increases by about 50 percentage points after four quarters and up to 90 percentage points after eight quarters.

Contrary to the findings for oil-importing countries, positive oil price shocks have been reported to boost output in oil exporting countries (see for instance Abayomi, Adam and

[7]The countries studied are Australia, Canada, France, Japan, Norway, United Kingdom, and the United States

Alumbugu, 2015; Adeniyi et al., 2011; Akinleye and Ekpo, 2013; Akinlo, 2012; Benkhodja, 2014; Bergholt and Larsen, 2016; Bergholt et al., 2017; Bjørnland, 2009; Ferrero and Seneca, 2019; Huseynov and Ahmadov, 2014; Iklaga, 2017; Romero, 2008; Sadeghi, 2017). In a study for Norway, Bergholt et al. (2017) found that a positive oil price shock boosts economic activities with the real GDP growth reaching a peak of 0.6 per cent after about 12 quarters. The study emphasised the "supply chain channel" under which the increased profitability of the oil firms following a positive oil price shock causes economic activities to increase in the non-oil sector. Thus, aggregate consumption, investment and manufacturing output increase while prices decline in response to an oil price increase[8]. A number of empirical studies have also documented similar findings for some less developed oil-producing economies (see Adeniyi et al., 2011; Berument et al., 2010; Mehrara and Oskoui, 2007).

In terms of the transmission mechanism of oil price shocks, a number of channels have been identified in literature. These include the output channel, the income channel, and the real balance channel (Brown and Yücel, 2002; Ferderer, 1996; Holmes and Wang, 2003). The output channel relates to a supply side shock that emphasises the role of oil and capital as complementary inputs in the production process. Under this channel, firms adjust to an oil price increase by reducing the amount of both oil and capital inputs used in the production; thus, causing output to decline (Brown and Yücel, 2002; Ferderer, 1996). The income channel occurs through the transfer of income from oil-importing countries to the oil-exporting ones following an increase in oil price (Brown and Yücel, 2002; Dohner, 1981; Romero, 2008). Such income transfers imply a reduction in aggregate demand in oil-importing countries, which causes economic recessions. The real balance channel posits that oil price increases generate inflationary outcomes that reduce the quantity of real balances in the system, which in turn causes economic recessions via monetary channels (Ferderer, 1996). Studies such as Barsky and Kilian (2001); Bernanke et al. (1997); Herrera and Pesavento (2009); Kilian (2010); Leduc and Sill (2004) and Kormilitsina (2011) have also emphasised the indirect effects of oil price shocks on output through the role of money supply. They argue that the output losses often associated with oil price shocks are partly attributable to the counter-inflationary response of monetary policy to such shocks[9]. The arguments contained in Bernanke et al. (1997) and other related studies highlight the need for carefully calibrated policy responses to oil price shocks.

[8]Similar findings were also reported by Ferrero and Seneca (2019) using a calibrated DSGE model.

[9]A few studies such as Kilian and Lewis (2011) belie this argument and posit that monetary policy response to oil price shocks should be driven by the underlying causes of the shock.

Several suggestions have been put forward by various studies on the appropriate response of monetary policy to oil price shocks. The policy prescriptions are often derived from the nature of the observed oil shock transmission mechanisms at play in a given country as well as the mandate of the central bank in question. While some studies have recommended interest rate hikes in response to a positive oil price shock (Allegret and Benkhodja, 2015), others have prescribed either monetary policy easing (Bergholt and Larsen, 2016; Shangle and Solaymani, 2020) or monetary policy restraint (Fischer, 1985). For instance, Ferrero and Seneca (2019) suggested that a reduction in interest rate represents an optimal monetary policy response to negative oil price shock in Norway - an oil-exporting country. They further cautioned that a central bank with a price stability mandate could implement an interest rate hike, albeit at the expense of worsening the contractionary effect of a negative oil price shock on output. In terms of monetary policy strategy, it was demonstrated that a domestic inflation based Taylor rule outperformed its CPI-based counterpart in stabilising output. However, in a similar study for Algeria - an oil exporting country with a fuel subsidy regime, Allegret and Benkhodja (2015) showed that the core inflation based monetary policy rule maximises welfare.

The literature review presented in this section reveals that positive oil price shocks generate stagflationary effects in oil-importing economies whereas oil-exporting countries tend to experience increased output via the income transfer channel. While most of the existing studies have focused on oil-importing developed countries, the literature is still quite scanty for oil-exporting emerging economies. Studies using the New Keynesian framework to investigate the impacts of oil price shocks on emerging economies with fuel subsidy regimes are particularly few. To our knowledge, the existing ones include Allegret and Benkhodja (2015) and Oladunni (2020). Allegret and Benkhodja (2015) developed a DSGE model that incorporates a fuel subsidy regime for the Algerian economy and found that a positive oil price shock increases aggregate output, investment and non-oil output while headline inflation rises, albeit weakly. On the other hand, Oladunni (2020) demonstrated based on a DSGE model for Nigeria that a negative oil price shock increases non-oil output while headline and core measures of inflation rise marginally. These results imply that there is no consensus among researchers on the macroeconomic impacts of oil price shocks on a typical oil-exporting country with a subsidy regime. In this chapter, we contribute to the literature on the implications of fuel subsidies and oil price shocks for business cycle dynamics in resource-rich emerging economies.

3.4 The Model

The model we develop in this paper is an extension of Gali and Monacelli (2005) and Ferrero and Seneca (2019). It incorporates: (i) an oil sector that is owned by government and foreign investors as in Algozhina (2015); (ii) oil in household consumption basket and firms' production technology as in Medina and Soto (2007) and Allegret and Benkhodja (2015); (iii) five different measures of inflation[10] as in Medina and Soto (2007); (iv) an inefficient financial sector as in Smets and Wouters (2007); (v) fiscal policy rule as in Algozhina (2015); (vi) a fuel pricing rule that connotes an implicit subsidy regime as in Allegret and Benkhodja (2015); and (vii) non-Ricardian consumers[11]. Furthermore, we allow for the law of one price gap in imports and by implication assume incomplete exchange rate pass-through into import prices (Monacelli, 2005; Senbeta, 2011). As standard in most DSGE models, we assume that wages as well as prices of domestically produced goods are sticky. Finally, an investment adjustment cost is incorporated into the model, a useful feature for generating the observed hump-shaped investment response to shocks.

The assumption that the household's utility function is inter-temporally separable is relaxed via the incorporation of consumption habits. Thus, we assume that household's consumption depends on the economy's aggregate consumption, a phenomenon often referred to as "keeping with the Joneses" in literature. This modification is premised on the empirical fact that households, having been accustomed to a certain consumption level, do not immediately alter their consumption pattern in the aftermath of a sudden shock to their income level. The incorporation of this feature helps to address the issues of excessive volatility in consumption and the exaggerated sensitivity of consumption to changing income levels (Boldrin, Christiano and Fisher, 2001).

The presence of non-Ricardian consumers relaxes the usual assumption that all households rationally optimise their inter-temporal consumption in order to maximise utility. The assumption that households are rational optimisers is based on the life-cycle hypothesis in which household's consumption is expressed not as a function of total income, but as being dependent on the household's permanent income. This is underpinned by the assumption that all households have access to the financial market and can thus embark on inter-temporal consumption smoothing. However, empirical evidence shows that the permanent income hy-

[10] These are core inflation, oil inflation, imported inflation, domestic inflation, and total inflation.

[11] A survey conducted in 2018 showed that about 36.8 per cent of adults in Nigeria were financially excluded that year (EFInA, 2018).

pothesis can not be upheld in economies with imperfect capital and under-developed financial markets. These imperfections, which are quite prevalent in emerging economies, debar some households from engaging in inter-temporal optimisation as they are financially constrained. To accommodate this feature, we incorporate hand-to-mouth consumers and allow for a share of consumers to be non-Ricardian in a fashion akin to a Two Agent New-Keynesian (TANK) model described by Galí (2018). In their seminal work, Galí et al. (2007) showed that the incorporation of non-Ricardian agents has desirable implications for the response of private consumption to fiscal policy shocks.

Furthermore, we allow for law of one price gap in imports (occasioned by the ability of the monopolistically competitive importing firms to optimise their prices) and by implication assume incomplete exchange rate pass-through (Monacelli, 2005; Senbeta, 2011). Following Smets and Wouters (2007), we reflect the usual inefficiencies in the financial sector of most emerging economies by incorporating an exogenous risk premium in the return to bonds. In order to reflect the energy pricing realities and the attendant energy subsidy programmes in most emerging oil-exporting countries, we incorporate a fuel pricing rule as in Allegret and Benkhodja (2015). Thus, ours is a new Keynesian open-economy model enhanced with bells and whistles that are relevant to small open emerging economies in general and oil exporters in particular.

3.4.1 Graphical overview of the model

Figure 3.5 presents a bird's-eye view of the economy, highlighting the economic agents as well as the inter-relationships among them. The model economy is inhabited by seven agents: households, non-oil goods producing firms, final goods producers, import goods retailers, oil producing firms, fiscal authority and the central bank.

The final goods producers buy intermediate goods and transform them into final goods, which are either consumed by domestic households, the government, the oil firm, or exported to the foreign economy by way of non-oil exports. The intermediate goods firms produce differentiated goods by combining labour, capital, and imported refined oil; and they set their prices a la Calvo (1983). The imported goods retailers buy intermediate goods from the foreign economy, which are then combined by perfectly competitive assemblers into final foreign goods and sold to households and the government. The representative oil firm uses materials sourced from the domestic economy as well as capital sourced from government and foreign investors to produce crude oil, which is exported to the rest of the world at an exogenously determined price. The government imports refined fuel, which it sells to households and domestic intermediate firms at a price determined via a fuel pricing rule.

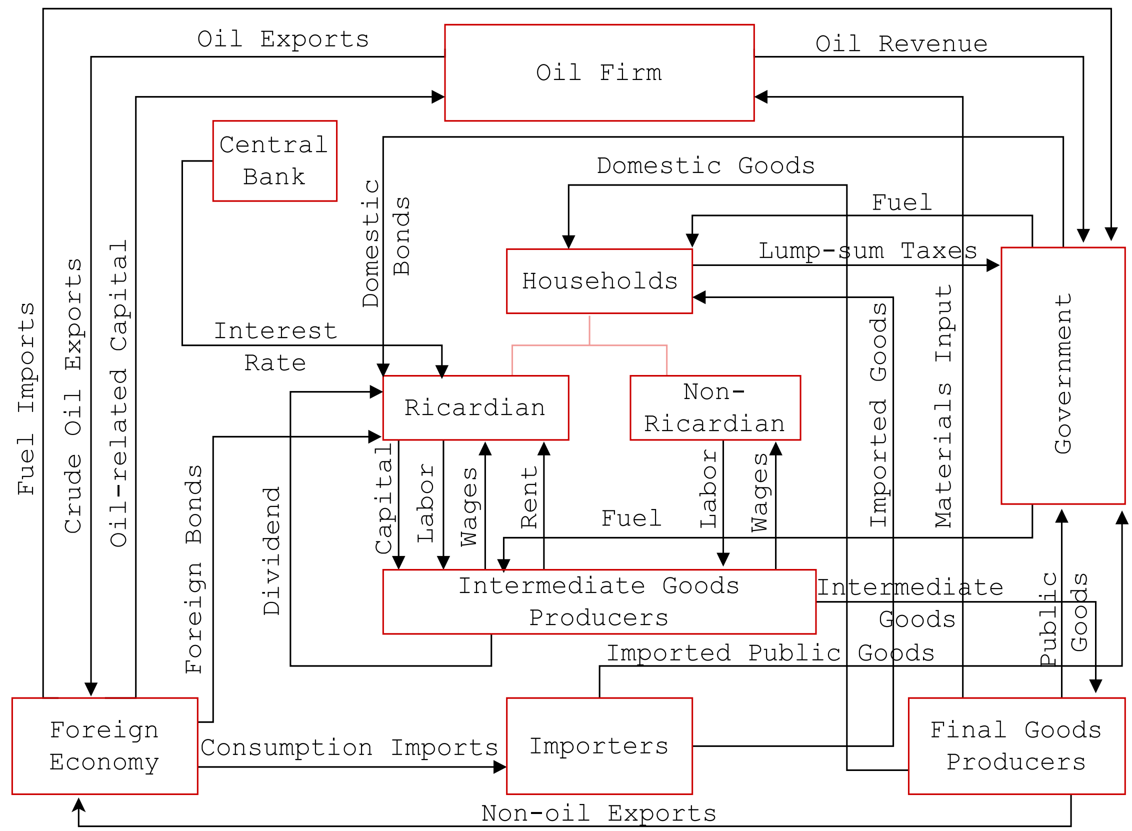

Figure 3.5: Flow chart of the model economy

Households consume goods (which include domestically produced goods, imported goods and fuel), supply labour to earn wages, and pay taxes to the government. However, only Ricardian consumers are able to save, invest in bonds and accumulate capital, subject to an investment adjustment cost. The accumulated capital is leased to non-oil domestic intermediate goods producing firms at a rental rate. The government receives tax revenues from households, oil revenues from the oil firm, and issues one period bonds. These revenues are used to purchase domestically produced and imported public goods as well as finance the energy subsidy programme. In our model, government consumption represents a key fiscal policy instrument available to government. The central bank acts as the monetary authority, setting interest rate based on a standard Taylor rule in order to achieve macroeconomic stability. Details regarding the economic environments within which each of the agents operates as well as the rules guiding their decisions are discussed next.

3.4.2 Households

The model features two types of households: Ricardian (R) and non-Ricardian or hand-to-mouth (NR). The former comprises a fraction (γ_R) of households who are optimisers and have access to financial markets. Each household j in this category can buy and sell financial assets without any form of constraints (Galí, 2018). Thus, they are able to smooth their consumption over time. The latter category, NR, represents the remaining fraction $(1-\gamma_R)$ who are non-optimisers. They completely consume their labour income within the period (Gabriel, Levine, Pearlman and Yang, 2010; Melina, Yang and Zanna, 2016). However, both categories of households have identical preferences as the representative household j derives utility from private consumption, C_t, as well as government consumption, $G_{c,t}$, and dis-utility from labour, N_t. Thus, the representative household j maximises an expected discounted utility function given by

$$U_0 = E_0 \sum_{s=0}^{\infty} \beta^s \left[\frac{\left(C_{t+s}\left(j\right) - \phi_c C_{t+s-1}\right)^{1-\sigma}}{1-\sigma} - \frac{N_{t+s}\left(j\right)^{1+\varphi}}{1+\varphi} + h(G_{c,t+s}) \right], \tag{3.1}$$

where E_0 denotes the mathematical expectation operator, $\beta \in (0,1)$ is a discount factor, σ is relative risk aversion coefficient, and $\varphi > 0$ is the inverse of the Frisch elasticity of labour supply. The utility derived by household from government spending, $h(G_{c,t})$, is taken as given, and it is merely included in the utility function as a reduced form way to motivate the incorporation of government spending into our model set up. Thus, since it is additively separable in equation (3.1), it does not affect household choices and does not matter for the equilibrium dynamics. While equation (3.1) is separable in both consumption goods and labour effort, we assume that consumption is subject to external habit formation, implying that the external habit stock is proportional to aggregate past consumption. The parameter $\phi_c \in (0,1)$ measures the degree of external habit formation in consumption, with $\phi_c = 0$ implying that there is no habit formation. By these assumptions, the utility of a representative household depends positively on the difference between the current level of individual consumption, $C_t\left(j\right)$, and the lagged economy-wide consumption level, C_{t-1} and negatively on the number of hours worked, $N_t\left(j\right)$.

Household consumption is a composite index comprising non-oil (referred to as core henceforth) consumption bundle, $C_{no,t}(j)$, and fuel consumption, $C_{o,t}(j)$:

$$C_t(j) = \left[(1-\gamma_o)^{\frac{1}{\eta_o}} \left(C_{no,t}(j) \right)^{\frac{\eta_o - 1}{\eta_o}} + \gamma_o^{\frac{1}{\eta_o}} \left(C_{o,t}(j) \right)^{\frac{\eta_o - 1}{\eta_o}} \right]^{\frac{\eta_o}{\eta_o - 1}}, \tag{3.2}$$

where parameter $\eta_o > 0$ measures the degree of substitution between core and fuel consumption and γ_o represents the share of domestic consumption devoted to fuel consumption, $C_{o,t}(j)$. Expenditure minimization subject to equation (3.2) yields the demand for core consumption, fuel consumption and the corresponding aggregate consumer price index as follows:

$$C_{no,t}(j) = (1-\gamma_o) \left[\frac{P_{no,t}}{P_t} \right]^{-\eta_o} C_t(j), \tag{3.3}$$

$$C_{o,t}(j) = \gamma_o \left[\frac{P_{ro,t}}{P_t} \right]^{-\eta_o} C_t(j), \tag{3.4}$$

$$P_t = \left[(1-\gamma_o) P_{no,t}^{1-\eta_o} + \gamma_o P_{ro,t}^{1-\eta_o} \right]^{\frac{1}{1-\eta_o}}, \tag{3.5}$$

where the price of fuel and core goods are denoted as $P_{ro,t}$ and $P_{no,t}$, respectively. The price of imported fuel is not simply the domestic currency price of fuel but rather a convex combination of the landing price of fuel and the domestic price of fuel in the previous period[12]. P_t is the aggregate consumer price index. Furthermore, core consumption bundle, $C_{no,t}(j)$ is defined as a composite index given by a constant elasticity of substitution (CES) aggregator that combines imported goods, $C_{f,t}(j)$, and domestically produced goods, $C_{h,t}(j)$, as follows:

$$C_{no,t}(j) = \left[(1-\gamma_c)^{\frac{1}{\eta_c}} \left(C_{h,t}(j) \right)^{\frac{\eta_c - 1}{\eta_c}} + \gamma_c^{\frac{1}{\eta_c}} \left(C_{f,t}(j) \right)^{\frac{\eta_c - 1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c - 1}}, \tag{3.6}$$

where $\eta_c > 0$ represents the elasticity of substitution between home and foreign goods in the core consumption basket and γ_c indicates the degree of trade openness of the domestic economy, measuring the share of domestic consumption devoted to imported foreign goods. The demands for $C_{h,t}(j)$ and $C_{f,t}(j)$ as well as the core consumption price index, $P_{no,t}$, are

[12]Following Allegret and Benkhodja (2015), $P_{ro,t}$ is determined based on a fuel pricing rule given as $P_{ro,t} = P_{ro,t-1}^{1-\nu} P_{lo,t}^{\nu}$ where the landing price of fuel, $P_{lo,t}$, is the current world price of fuel expressed in local currency.

determined by expenditure minimization subject to equation (3.6), yielding the following:

$$C_{h,t}(j) = (1-\gamma_c)\left[\frac{P_{h,t}}{P_{no,t}}\right]^{-\eta_c} C_{no,t}(j), \tag{3.7}$$

$$C_{f,t}(j) = \gamma_c \left[\frac{P_{f,t}}{P_{no,t}}\right]^{-\eta_c} C_{no,t}(j), \tag{3.8}$$

$$P_{no,t} = \left[(1-\gamma_c) P_{h,t}^{1-\eta_c} + \gamma_c P_{f,t}^{1-\eta_c}\right]^{\frac{1}{1-\eta_c}}, \tag{3.9}$$

where $P_{h,t}$ represents the price of domestically produced goods and $P_{f,t}$ is the price of imported goods.

Ricardian consumers

Each optimising household j makes inter-temporal consumption and savings decisions in a forward looking manner by maximising an expected discounted utility function given by

$$U_0^R = E_0 \sum_{s=0}^{\infty} \beta^s \left[\frac{\left(C_{t+s}^R(j) - \phi_c C_{t+s-1}\right)^{1-\sigma}}{1-\sigma} - \frac{N_{t+s}^R(j)^{1+\varphi}}{1+\varphi} + h(G_{c,t+s})\right] \tag{3.10}$$

where the parameters and variables in the equation above are as previously defined under equation (3.1) and the superscript R indicates that the household is Ricardian. Equation (3.10) is maximised subject to a per period budget constraint given by:

$$\begin{aligned} P_t C_t^R(j) + P_{i,t} I_{no,t}(j) + \frac{B_{t+1}(j)}{R_t \mu_t} + \frac{\varepsilon_t B_{t+1}^*(j)}{R_t^* \mu_t^*} \\ = W_t N_t^R(j) + R_{h,t} K_{h,t}(j) + B_t(j) + \varepsilon_t B_t^*(j) + D_t - TX_t. \end{aligned} \tag{3.11}$$

On the income side of equation (3.11), the Ricardian consumer supplies $N_t^R(j)$ hours of work at a nominal wage rate, W_t, earning a labour income, $W_t N_t^R(j)$. Second, the household owns an amount of non-oil capital, $K_{h,t}(j)$, which it leases to the domestic non-oil goods producing firms at a rental rate, $R_{h,t}$, to generate a capital income, $R_{h,t} K_{h,t}(j)$. Third, the household receives an aliquot share, D_t from the profits of the firms. The household also enters the period with the stock of nominal domestic bonds, $B_t(j)$, and foreign bonds, $B_t^*(j)$ maturing in period $t+1$. $B_{t+1}(j)$ and $B_{t+1}^*(j)$ represent the Ricardian household's investments in domestic and foreign bonds at the end of period t, respectively while the nominal exchange rate is denoted by ε_t. Each domestic bond pays a gross nominal rate of return, R_t in domestic currency while its foreign counterpart pays an exchange rate adjusted nominal rate of return, R_t^*.

Following Smets and Wouters (2007) and Hollander et al. (2018), we allow for domestic risk premium, μ_t over the monetary policy rate when households hold domestic assets as well as a stochastic disturbance term that represents the risk premium faced by households when borrowing abroad, μ_t^*. As described in Smets and Wouters (2007), the disturbance term, μ_t, is a wedge between the central bank controlled interest rate and the return on assets held by households. Thus, a positive shock to the domestic risk premium has the potentials of reducing consumption and increasing the cost of capital. It is assumed that μ_t and μ_t^* evolve as first order autoregressive, or $AR(1)$, processes. The income received by the household is used to finance the purchase of consumption, $C_t^R(j)$, and non-oil investments, $I_{no,t}(j)$, goods. P_t is the aggregate Consumer Price Index (CPI) in the domestic economy while $P_{i,t}$ represents the price index of investment goods. Lastly, TX_t represents per-capita lump-sum net taxes from the government.

As with consumption, non-oil investment goods, $I_{no,t}$, in equation (3.11) comprise domestically produced investment goods, $I_{h,t}$, and foreign-produced investment goods, $I_{f,t}$, which are combined using a CES aggregator given by:

$$I_{no,t}(j) = \left[(1-\gamma_i)^{\frac{1}{\eta_i}} \left(I_{h,t}(j)\right)^{\frac{\eta_i-1}{\eta_i}} + \gamma_i^{\frac{1}{\eta_i}} \left(I_{f,t}(j)\right)^{\frac{\eta_i-1}{\eta_i}} \right]^{\frac{\eta_i}{\eta_i-1}}, \tag{3.12}$$

where γ_i is the share of imports in aggregate non-oil investment goods and η_i is the elasticity of intra-temporal substitution between domestic and imported investment goods. Cost minimisation by the representative Ricardian household subject to equation (3.12) yields the demand equations for home and foreign imported investment goods as follows:

$$I_{h,t} = (1-\gamma_i) \left[\frac{P_{h,t}}{P_{i,t}}\right]^{-\eta_i} I_{no,t}, \tag{3.13}$$

$$I_{f,t} = \gamma_i \left[\frac{P_{f,t}}{P_{i,t}}\right]^{-\eta_i} I_{no,t} \tag{3.14}$$

and the corresponding aggregate investment price deflator, $P_{I,t}$, is given by:

$$P_{i,t} = \left[(1-\gamma_i) P_{h,t}^{1-\eta_i} + \gamma_i P_{f,t}^{1-\eta_i} \right]^{\frac{1}{1-\eta_i}}. \tag{3.15}$$

Furthermore, the Ricardian household accumulates non-oil capital based on the following process:

$$K_{h,t+1}(j) = (1-\delta_h) K_{h,t}(j) + I_{no,t}(j)\left[1 - S\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)}\right)\right], \tag{3.16}$$

where parameter $0 < \delta_h < 1$ represents the rate at which capital depreciates. The investment adjustment cost function, $S\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)}\right)$, is defined as:

$$S\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)}\right) = \frac{\chi}{2}\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)} - 1\right)^2, \tag{3.17}$$

where the parameter $\chi \geq 0$ governs the size of the adjustment cost. Putting equation (3.17) into (3.16), we can rewrite the capital accumulation equation as follows:

$$K_{h,t+1}(j) = (1-\delta_h) K_{h,t}(j) + I_{no,t}(j)\left[1 - \frac{\chi}{2}\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)} - 1\right)^2\right]. \tag{3.18}$$

Overall, the representative Ricardian household maximises equation (3.1) subject to a per period nominal budget constraint (equation 3.11) and a capital accumulation process (equation 3.18) by choosing $\left\{C_t^R(j), B_{t+1}(j), B_{t+1}^*(j), K_{h,t+1}(j), I_{no,t}(j)\right\}_{s=0}^{\infty}$. We allow the Lagrangian multipliers associated with the budget constraint and the capital accumulation process to be $\lambda_{C,t}^R$ and $\lambda_{K,t}^R$, respectively. The relevant first order conditions enable us to derive the equations for consumption Euler (equation 3.19), demand for foreign bonds (equation 3.20), supply of capital (equation 3.21) and demand for investment (equation 3.22) as follows:

$$\frac{1}{R_t \mu_t} = \beta E_t\left[\left(\frac{C_{t+1}^R(j) - \phi_c C_t}{C_t^R(j) - \phi_c C_{t-1}}\right)^{-\sigma} \frac{1}{\pi_{t+1}}\right], \tag{3.19}$$

$$\frac{1}{R_t^* \mu_t^*} = \beta E_t\left[\frac{\varepsilon_{t+1}}{\varepsilon_t}\left(\frac{C_{t+1}^R(j) - \phi_c C_t}{C_t^R(j) - \phi_c C_{t-1}}\right)^{-\sigma} \frac{1}{\pi_{t+1}}\right], \tag{3.20}$$

$$\lambda_{K,t}^R = \beta E_t\left[\frac{1}{\left(C_t^R(j) - \phi_c C_{t-1}\right)^{\sigma}} r_{h,t+1} + \lambda_{K,t+1}^R (1-\delta_h)\right], \tag{3.21}$$

$$\left(C_t^R(j) - \phi_c C_{t-1}\right)^{-\sigma} - \lambda_{K,t}^R \left[1 - \frac{\chi}{2} - \frac{3}{2}\chi\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)}\right)^2 + 2\chi\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)}\right)\right]$$
$$= \chi\beta E_t \lambda_{K,t+1}^R \left[\left(\frac{I_{no,t+1}(j)}{I_{no,t}(j)} - 1\right)\left(\frac{I_{no,t+1}(j)}{I_{no,t}(j)}\right)^2\right], \quad (3.22)$$

where $\pi_t = \frac{P_t}{P_{t-1}}$ is the CPI inflation and $r_{h,t} = \frac{R_{h,t}}{P_t}$ is the capital rental rate in real terms.

Non-Ricardian consumers

The non-Ricardian consumers are hand-to-mouth households and are thus incapable of intertemporal optimisation. The representative non-Ricardian consumer j chooses its consumption, C_t^{NR} by maximising:

$$U_0^{NR} = \frac{\left(C_{t+s}^{NR}(j) - \phi_c C_{t+s-1}\right)^{1-\sigma}}{1-\sigma} - \frac{N_{t+s}^{NR}(j)^{1+\varphi}}{1+\varphi} + h(G_{c,t+s}), \quad (3.23)$$

subject to the nominal budget constraint:

$$P_t C_t^{NR}(j) = W_t N_t^{NR}(j) - TX_t. \quad (3.24)$$

Allowing the Lagrangian multiplier associated with the budget constraint of the non-Ricardian household to be $\lambda_{C,t}^{NR}$, the first order condition for this problem with respect to $C_t^{NR}(j)$ is:

$$\lambda_{C,t}^{NR} = \frac{\left(C_t^{NR}(j) - \phi_c C_{t-1}\right)^{-\sigma}}{P_t}. \quad (3.25)$$

Labour supply and wage setting

We assume that the determination of wages is based on Calvo (1983) rule. Households sell their differentiated labour, $N_t(j)$, in a monopolistic market to a representative firm that aggregates the different labour types into a single labour input, N_t. Thus, the labour-aggregating firm uses the following technology:

$$N_t = \left[\int_0^1 N_t(j)^{\frac{\eta_w - 1}{\eta_w}} dj\right]^{\frac{\eta_w}{\eta_w - 1}}, \quad (3.26)$$

where parameter η_w is the elasticity of substitution between differentiated jobs. To derive the demand equation for differentiated labour, j, and the aggregate wage level, the labour-aggregating firm maximises its profit subject to equation (3.26). Thus, the demand for differentiated labour is:

$$N_t(j) = \left[\frac{W_t(j)}{W_t}\right]^{-\eta_w} N_t, \tag{3.27}$$

and the aggregate wage level is[13]:

$$W_t = \left[\int_0^1 W_t(j)^{1-\eta_w} \, dj\right]^{\frac{1}{1-\eta_w}}. \tag{3.28}$$

Following Calvo (1983), we assume that $1-\theta_w$ fraction of households are chosen at random to optimally set their wages in each period. The remaining fraction, θ_w, keep their wages at the previous period's level. Each household who is able to optimally reset its wage contract evaluates the disutility of labour relative to the utility arising from its labour income. Thus, the optimal wage setting problem involves maximising equation (3.1) subject to the household budget constraint as well as the demand for the differentiated labour (equation 3.27). This yields the optimal reset wage equation given by:

$$W_t^{\bullet}(j) = \left(\frac{\eta_w}{\eta_w - 1}\right) E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\frac{(N_{t+s}(j))^{\varphi}}{\lambda_{C,t+s}}\right], \tag{3.29}$$

where $W_t^{\bullet}(j)$ is the optimal reset wage, and θ_w measures the degree of nominal wage rigidity. The aggregate nominal wage rule is therefore of the form:

$$W_t = \left[\theta_w W_{t-1}^{1-\eta_w} + (1-\theta_w) W_t^{\bullet 1-\eta_w}\right]^{\frac{1}{1-\eta_w}}. \tag{3.30}$$

Finally, we aggregate consumption, C_t, and labour, N_t, for the Ricardian and non-Ricardian households as follows:

$$C_t = \gamma_R C_t^R + (1-\gamma_R) C_t^{NR}, \tag{3.31}$$

$$N_t = \gamma_R N_t^R + (1-\gamma_R) N_t^{NR}, \tag{3.32}$$

where $C_t^R = \int_0^1 C_t^R(j) \, dj$ and $N_t^R = \int_0^1 N_t^R(j) \, dj$ for each Ricardian household. Also $C_t^{NR} = \int_0^1$

[13] Following Medina and Soto (2016), we make a simplifying assumption that the non-Ricardian households set wages equal to the average wage set by the the Ricardian households.

$C_t^{NR}(j)\,dj$ and $N_t^{NR} = \int_0^1 N_t^{NR}(j)\,dj$ for each non-Ricardian household.

3.4.3 Non-oil goods producing firms

Final-goods firms: Final goods are produced by a set of perfectly competitive firms for domestic use ($Y_{h,t}$) and exports ($Y_{h,t}^*$). Accordingly, these firms use their respective aggregation technologies to bundle domestically produced differentiated goods, $Y_{h,t}(z_h)$, meant for the domestic market and $Y_{h,t}^*(z_h)$ meant for the export market. In bundling domestic intermediate varieties for the domestic market, the final-good firm pursues the following objective:

$$\max_{Y_{h,t}(z_h)} \Pi_{h,t}(z_h) = P_{h,t}Y_{h,t} - \int_0^1 P_{h,t}(z_h)\,Y_{h,t}(z_h)\,dz_h, \tag{3.33}$$

subject to a constant returns to scale technology

$$Y_{h,t} = \left[\int_0^1 Y_{h,t}(z_h)^{\frac{\epsilon_h - 1}{\epsilon_h}}\,dz_h\right]^{\frac{\epsilon_h}{\epsilon_h - 1}}, \tag{3.34}$$

where $P_{h,t}(z_h)$ is the price charged on intermediate goods, $Y_{h,t}(z_h)$, $P_{h,t}$ is the domestic price index, and the parameter $\epsilon_h > 1$ represents the elasticity of substitution among different intermediate goods. The first-order condition for the above optimization problem yields the standard downward sloping demand function for intermediate inputs given by:

$$Y_{h,t}(z_h) = \left[\frac{P_{h,t}(z_h)}{P_{h,t}}\right]^{-\epsilon_h} Y_{h,t}, \tag{3.35}$$

and the corresponding price aggregator for final goods sold domestically:

$$P_{h,t} = \left[\int_0^1 P_{h,t}(z_h)^{1-\epsilon_h}\,dz_h\right]^{\frac{1}{1-\epsilon_h}}. \tag{3.36}$$

Analogously, the demand function of the final goods firms seeking to assemble intermediate varieties for the export market is given by:

$$Y_{h,t}^*(z_h) = \left[\frac{P_{h,t}^*(z_h)}{P_{h,t}^*}\right]^{-\epsilon_h} Y_{h,t}^*, \tag{3.37}$$

and the corresponding price aggregator for non-oil exportable goods is:

$$P_{h,t}^{*} = \left[\int_{0}^{1} P_{h,t}^{*}\left(z_h\right)^{1-\epsilon_h} dz_h\right]^{\frac{1}{1-\epsilon_h}}, \tag{3.38}$$

where $P_{h,t}^{*}\left(z_h\right)$ is the price charged on export-bound intermediate goods $Y_{h,t}^{*}\left(z_h\right)$.

Intermediate-goods firms: There is a continuum of intermediate goods firms, indexed by $z_h \in [0,1]$ producing differentiated goods in a monopolistically competitive environment. Each representative intermediate-goods firm uses a constant returns to scale technology that combines three inputs: capital, refined oil and labour as follows:

$$Y_{h,t}\left(z_h\right) = A_{h,t} K_{h,t}\left(z_h\right)^{\alpha_h^k} O_{h,t}\left(z_h\right)^{\alpha_h^o} N_t\left(z_h\right)^{\alpha_h^n}, \tag{3.39}$$

where $Y_{h,t}\left(z_h\right)$ is the output of the intermediate firm z_h, $K_{h,t}\left(z_h\right)$ represents capital input, $O_{h,t}\left(z_h\right)$ is oil input, and $N_t\left(z_h\right)$ denotes the amount of labour input employed. The parameters $1 > \alpha_h^k > 0$, $1 > \alpha_h^o > 0$ and $1 > \alpha_h^n > 0$ are elasticities of an intermediate firm's output with respect to capital, oil and labour inputs, respectively. By our assumption of constant returns to scale, $\alpha_h^k + \alpha_h^o + \alpha_h^n = 1$. We assume that the total factor productivity, $A_{h,t}$, follows a first order autoregressive process of the form: $A_{h,t} = \left(A_{h,t-1}\right)^{\rho_{A_h}} \exp\left(\xi_t^{A_h}\right)$. The optimization problem of the intermediate goods producers is solved in two stages. In the first stage, each firm chooses its input factors to minimize total cost given by:

$$\min_{N_t(z_h), K_{h,t}(z_h), O_t(z_h)} W_t N_t\left(z_h\right) + R_{h,t} K_{h,t}\left(z_h\right) + P_{ro,t} O_t\left(z_h\right), \tag{3.40}$$

subject to equation (3.39). This yields the optimal input combinations as follows:

$$\frac{K_{h,t}\left(z_h\right)}{N_t\left(z_h\right)} = \frac{\alpha_h^k w_t}{\alpha_h^n r_{h,t}}, \tag{3.41}$$

$$\frac{O_{h,t}\left(z_h\right)}{N_t\left(z_h\right)} = \frac{\alpha_h^o w_t}{\alpha_h^n p_{ro,t}}, \tag{3.42}$$

where $r_{h,t} = \frac{R_{h,t}}{P_t}$ is the real rental rate on capital, $p_{ro,t} = \frac{P_{ro,t}}{P_t}$ is the real domestic price of fuel (which is determined based on a pricing rule that limits the pass-through effect of international oil price to domestic price), and $w_t = \frac{W_t}{P_t}$ is the real wage. Substituting the input demands into the firm's production technology, equation (3.39), yields an expression for the real marginal cost:

$$mc_t = \frac{1}{A_{h,t} p_{h,t}} \left(\frac{r_{h,t}}{\alpha_h^k} \right)^{\alpha_h^k} \left(\frac{p_{ro,t}}{\alpha_h^o} \right)^{\alpha_h^o} \left(\frac{w_t}{\alpha_h^n} \right)^{\alpha_h^n}, \tag{3.43}$$

where $mc_t = \frac{MC_t}{P_t}$ is the real marginal cost and $p_{h,t} = \frac{P_{h,t}}{P_t}$ is the real price of domestically produced goods. In the second stage, the intermediate goods producer who qualifies to choose its price does so by maximizing its expected discounted profit. Following Calvo (1983) staggered pricing model, we allow a proportion of the intermediate goods producing firms, $(1-\theta_h)$, to optimally reset their prices in any given period while the other fraction, θ_h, who are unable to re-optimise their prices maintain the price as at last fixing. Thus, profit maximisation subject to the demand for intermediate goods (equation 3.35) yields the optimal reset price, $P_{h,t}^{\bullet}$:

$$P_{h,t}^{\bullet} = \frac{\epsilon_h}{\epsilon_h - 1} \frac{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_h)^s P_{h,t+s} Y_{h,t+s} mc_{t+s}}{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_h)^s Y_{h,t+s}}, \tag{3.44}$$

where $\theta_h \in [0,1]$ is an index of price stickiness (Calvo, 1983). It then follows that the evolution of price level for domestically produced goods meant for the domestic market is given by a law of motion:

$$P_{h,t} = \left[\theta_h P_{h,t-1}^{1-\epsilon_h} + (1-\theta_h) \left(P_{h,t}^{\bullet} \right)^{1-\epsilon_h} \right]^{\frac{1}{1-\epsilon_h}}, \tag{3.45}$$

In an analogous manner, profit maximisation subject to the demand for differentiated exportable goods (3.37) yields the optimal reset price for domestically produced goods meant for the export market as follows:

$$P_{h,t}^{*\bullet} = \frac{\epsilon_h}{\epsilon_h - 1} \frac{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_{hf})^s P_{h,t+s}^{*} Y_{h,t+s}^{*} mc_{t+s}}{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_{hf})^s \varepsilon_{t+s} Y_{h,t+s}^{*}}, \tag{3.46}$$

where $P_{h,t}^{*\bullet}$ is the optimal reset price for the intermediate good meant for the export market and θ_{hf} is the Calvo parameter for such commodity.

3.4.4 Import goods retailers

In order to accommodate incomplete exchange rate pass-through into import prices in the short run, we introduce local currency pricing (Medina and Soto, 2005). We consider a set of competitive assemblers that produce a final foreign good, $Y_{f,t}$, which is consumed by households and used for accumulating new capital goods. To produce $Y_{f,t}$, the competitive assemblers combine a continuum of differentiated imported varieties, $Y_{f,t}(z_f)$ using a Dixit-Stiglitz aggregation technology:

$$Y_{f,t} = \left[\int_0^1 Y_{f,t}(z_f)^{\frac{\epsilon_f - 1}{\epsilon_f}} dz_f \right]^{\frac{\epsilon_f}{\epsilon_f - 1}}, \tag{3.47}$$

where the parameter $\epsilon_f > 1$ represents the elasticity of substitution among different imported goods. With $P_{f,t}$ being the price index for imported goods and $P_{f,t}(z_f)$, the price charged on an imported intermediate product, the optimisation problem of the firm involves choosing $Y_{f,t}(z_f)$ by maximising its profit function:

$$\Pi_{f,t}(z_f) = P_{f,t} Y_{f,t} - \int_0^1 P_{f,t}(z_f) Y_{f,t}(z_f) dz_f, \tag{3.48}$$

subject to the aggregation technology, equation (3.47). The first-order condition for the above optimisation problem yields a downward sloping demand function for imported intermediate goods:

$$Y_{f,t}(z_f) = \left[\frac{P_{f,t}(j)}{P_{f,t}} \right]^{-\epsilon_f} Y_{f,t}, \tag{3.49}$$

Substituting equation (3.49) into (3.47) yields the pricing rule for imported goods as follows:

$$P_{f,t} = \left[\int_0^1 P_{f,t}(z_f)^{1-\epsilon_f} dz_f \right]^{\frac{1}{1-\epsilon_f}}. \tag{3.50}$$

Each imported goods retailer has monopoly power to determine the domestic price of its varieties, albeit infrequently as in Calvo (1983). The frequency at which prices can be optimally reset is guided by a price stickiness parameter, θ_f. Thus, an importing firm has a probability, θ_f, of keeping the price of its good fixed in the next period and a probability, $1 - \theta_f$, of optimally resetting its price. For a firm that can reset its price, $P^{\bullet}_{f,t}(z_f)$, it does so by maximising the present value of expected profits given by:

$$\max_{P^{\bullet}_{f,t}(z_f)} E_t \sum_{s=0}^{\infty} (\beta\theta_f)^s Y_{f,t}(z_f) \left[P^{\bullet}_{f,t}(z_f) - \varepsilon_{t+s} P^{*}_{f,t+s}\right], \tag{3.51}$$

subject to the demand for the imported variety in equation (3.49). Making use of the equation for law of one price gap (shown in equation 3.62 under section 3.4.6) in the above equation, the optimal reset price is derived as follows:

$$P^{\bullet}_{f,t} = \frac{\epsilon_f}{\epsilon_f - 1} \frac{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_f)^s P_{h,t+s} Y_{h,t+s} \Psi_{t+s}}{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_f)^s Y_{f,t+s}}. \tag{3.52}$$

By the law of large numbers, the pricing rule for imported goods based on equation (3.50) is given by:

$$P_{f,t} = \left[\theta_f P_{f,t-1}^{1-\epsilon_f} + (1-\theta_f)\left(P^{\bullet}_{f,t}\right)^{1-\epsilon_f}\right]^{\frac{1}{1-\epsilon_f}}. \tag{3.53}$$

3.4.5 Oil producing firm

We assume that the oil firm operates under perfect competition, combining technology ($A_{o,t}$), materials sourced from the domestic economy (M_t) and oil-related capital ($K_{o,t}$). The produced oil, $Y_{o,t}$, is exported to the rest of the world at a price determined at the international crude oil market. In our model, we modify the oil sector in Ferrero and Seneca (2019) by introducing oil-related capital into the production technology of the oil firm. Therefore, the oil firm's decision problem involves choosing its production inputs by maximising a profit function given by:

$$\mathit{\Pi}_{o,t} = \varepsilon_t P^{*}_{o,t} Y_{o,t} - R_{o,t} K_{o,t} - P_{h,t} M_t, \tag{3.54}$$

subject to a constant return to scale Cobb-Douglas extraction technology:

$$Y_{o,t} = A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m}, \tag{3.55}$$

where $P^{*}_{o,t}$ is the international price of oil and $R_{o,t}$ is the rental rate on oil-related capital. The parameters α_o^k and $\alpha_o^m \in (0,1)$ represent the elasticities of oil output with respect to oil-related capital and material inputs, respectively and $\alpha_o^k + \alpha_o^m = 1$. Maximising equation

(3.54) subject to equation (3.55) yields optimal demands for oil-related capital, $K_{o,t}$, and materials inputs, M_t, as follows:

$$K_{o,t} = \frac{\alpha_o^k q_t p_{o,t}^* Y_{o,t}}{r_{o,t}}, \tag{3.56}$$

$$M_t = \frac{\alpha_o^m q_t p_{o,t}^* Y_{o,t}}{p_{h,t}}, \tag{3.57}$$

where $p_{o,t}^* = \frac{P_{o,t}^*}{P_t}, r_{o,t} = \frac{R_{o,t}}{P_t}, p_{h,t} = \frac{P_{h,t}}{P_t}$ and q_t is the real exchange rate. As in Algozhina (2015), we assume that the oil firm, which is jointly owned by foreign direct investors and the government, receives its profits net of royalties levied on production quantity at a rate given by τ. Following Algozhina (2015), we assume that the oil-related capital, $K_{o,t}$ is accumulated by foreign direct investment, FDI_t^* as follows:

$$K_{o,t} = (1 - \delta_o) K_{o,t-1} + FDI_t^*, \tag{3.58}$$

where δ_o represents the rate at which oil-related capital depreciates. Foreign direct investment responds to international oil price as follows:

$$FDI_t^* = \left(FDI_{t-1}^*\right)^{\rho_{fdi}} \left(p_{o,t}^*\right)^{1-\rho_{fdi}}, \tag{3.59}$$

where the parameter ρ_{fdi} measures the degree of smoothing in the accumulation of foreign direct investment. The real international price of oil and oil technology follow $AR(1)$ processes with exogenous shocks as follows:

$$p_{o,t}^* = \left(p_{o,t-1}^*\right)^{\rho_o} \exp\left(\xi_t^{p_o^*}\right), \tag{3.60}$$

$$A_{o,t} = \left(A_{o,t-1}\right)^{\rho_{A_o}} \exp\left(\xi_t^{A_o}\right). \tag{3.61}$$

3.4.6 Open economy features

The model we consider is a small open economy in which activities in the foreign economy are not impacted by developments in the domestic economy and are thus taken as exogenous. We proceed in this section to enunciate the interactions between the domestic economy and the foreign economy.

Real exchange rate, terms of trade and incomplete pass-through

We assume law of one price gap as in Monacelli (2005) such that importing firms have some power in the determination of the prices of goods they import and distribute. The law of one price gap, Ψ_t, is given by the ratio of foreign price index in terms of domestic currency to the domestic currency price of imports:

$$\Psi_t = \frac{\varepsilon_t P_t^*}{P_{f,t}}, \tag{3.62}$$

where P_t^* is aggregate consumer price index of the foreign economy and $P_{f,t}$ is the average price of imported goods in domestic currency. The nominal exchange rate is denoted as ε_t. The law of one price gap, Ψ_t, takes the value of one if the law of one price (LOP) holds. However, while we assume that LOP does not hold for imports, it does hold for exports.

The real exchange rate, q_t, is defined as the ratio of price index of the rest of the world (in terms of domestic currency) to the aggregate domestic price index as follows:

$$q_t = \frac{\varepsilon_t P_t^*}{P_t}. \tag{3.63}$$

Making use of the definition of real exchange rate in equation 3.63, we can re-write the equation for the law of one price gap (equation 3.62) as:

$$\Psi_t = \frac{q_t}{p_{f,t}}, \tag{3.64}$$

where $p_{f,t} = \frac{P_{f,t}}{P_t}$ denotes the real price of imported goods. Also, log-linearising equation (3.63) and taking the rate of change yields an equation for the evolution of the real exchange rate, q_t, shown in equation (B.152), Appendix B.3. In the small open economy, the terms of trade, S_t , is an important relationship and it measures the competitiveness of the economy. We define the terms of trade of the domestic economy as the domestic currency price of imports, $P_{f,t}$, relative to the export price (price of domestically produced tradable goods), $P_{h,t}$. This is given by:

$$S_t = \frac{P_{f,t}}{P_{h,t}}, \tag{3.65}$$

and log-linearised as in equation (B.153), Appendix B.3.

International risk sharing

In order to link domestic consumption with foreign consumption, we assume that agents in the rest of the world have access to the same set of bonds and share the same preferences with their domestic counterparts. Thus, the Euler equation for the domestic economy and foreign economies can be combined as follows:

$$1 = \beta E_t \left[\left(\frac{C^R_{t+1}(j) - \phi_c C_t}{C^R_t(j) - \phi_c C_{t-1}} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right] = \beta E_t \left[\left(\frac{C^*_{t+1}(j) - \phi_c C^*_t}{C^*_t(j) - \phi_c C^*_{t-1}} \right)^{-\sigma} \frac{\varepsilon_t}{\varepsilon_{t+1}} \frac{P^*_t}{P^*_{t+1}} \right] \tag{3.66}$$

Following Gali and Monacelli (2005), we make use of the definition of the real exchange rate, q_t, in equation (3.63) to derive the international risk sharing equation as follows:

$$\begin{aligned} 1 =& E_t \left[\left(\frac{C^R_{t+1}(j) - \phi_c C_t}{C^R_t(j) - \phi_c C_{t-1}} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \left(\frac{C^*_{t+1}(j) - \phi_c C^*_t}{C^*_t(j) - \phi_c C^*_{t-1}} \right)^{\sigma} \frac{\varepsilon_{t+1}}{\varepsilon_t} \frac{P^*_{t+1}}{P^*_t} \right], \\ \left(C^R_t(j) - \phi_c C_{t-1} \right)^{-\sigma} =& E_t \left[\left(\frac{C^*_{t+1}(j) - \phi_c C^*_t}{C^R_{t+1}(j) - \phi_c C_t} \right)^{\sigma} \left(C^*_t(j) - \phi_c C^*_{t-1} \right)^{-\sigma} \left(\frac{q_{t+1}}{q_t} \right) \right], \end{aligned}$$

$$\begin{aligned} \left(C^R_t(j) - \phi_c C_{t-1} \right) &= E_t \left[\frac{C^R_{t+1}(j) - \phi_c C_t}{\left(C^*_{t+1}(j) - \phi_c C^*_t \right) q_{t+1}^{\frac{1}{\sigma}}} \right] q_t^{\frac{1}{\sigma}} \left(C^*_t(j) - \phi_c C^*_{t-1} \right), \\ C^R_t(j) - \phi_c C_{t-1} &= \varrho q_t^{\frac{1}{\sigma}} \left(C^*_t(j) - \phi_c C^*_{t-1} \right), \end{aligned} \tag{3.67}$$

where ϱ represents a constant that depends on the relative initial conditions in asset holdings given by $\varrho \equiv E_t \left[\frac{C^R_{t+1}(j) - \phi_c C_t}{\left(C^*_{t+1}(j) - \phi_c C^*_t \right) q_{t+1}^{\frac{1}{\sigma}}} \right]$.

Uncovered interest parity

The assumption of complete asset market allows us to derive the link between domestic and foreign interest rates through the uncovered interest parity condition given by:

$$R_t = R^*_t E_t \left(\frac{\varepsilon_{t+1}}{\varepsilon_t} \right) \Phi_t, \tag{3.68}$$

where equations (3.19) and (3.20) have been combined to derive equation (3.68). R_t and R_t^* are the gross nominal interest rate on domestic bonds and foreign bonds, respectively while $\Phi_t = (\mu_t^*/\mu_t)$ is the exchange rate premium. A positive shock to Φ_t lowers the expected future nominal exchange rate in the small open economy (Hollander et al., 2018).

3.4.7 Fiscal authority

The government collects lump-sum tax, TX_t, receives oil revenues in form of royalties from oil firms, OR_t, and issues one period bonds that results in a net debt position, B_t. These receipts are used to finance a given government expenditure on public goods, $G_{c,t}$, effect fuel subsidy payments, OS_t, and make interest and principal payments amounting to $\frac{B_{t+1}}{R_t}$. Consequently, we assume the government respects a budget constraint given by:

$$TX_t + OR_t + B_t = P_{g,t}G_{c,t} + OS_t + \frac{B_{t+1}}{R_t}. \tag{3.69}$$

Government consumption basket consists of imported foreign goods, $G_{f,t}$, and domestically produced goods, $G_{h,t}$:

$$G_{c,t} = \left[(1-\gamma_g)^{\frac{1}{\eta_g}} G_{h,t}^{\frac{\eta_g-1}{\eta_g}} + \gamma_g^{\frac{1}{\eta_g}} G_{f,t}^{\frac{\eta_g-1}{\eta_g}}\right]^{\frac{\eta_g}{\eta_g-1}}, \tag{3.70}$$

where η_g is the elasticity of substitution between home and foreign goods consumed by government and γ_g is the share of foreign goods in government's consumption basket. Cost minimisation by government subject to equation (3.70) yields the demands for home and foreign goods as follows:

$$G_{h,t} = (1-\gamma_g)\left(\frac{P_{h,t}}{P_{g,t}}\right)^{-\eta_g} G_{c,t}, \tag{3.71}$$

$$G_{f,t} = \gamma_g \left(\frac{P_{f,t}}{P_{g,t}}\right)^{-\eta_g} G_{c,t}, \tag{3.72}$$

and the corresponding government consumption price index is given by:

$$P_{g,t} = \left[(1-\gamma_g) P_{h,t}^{1-\eta_g} + \gamma_g P_{f,t}^{1-\eta_g}\right]^{\frac{1}{1-\eta_g}}, \tag{3.73}$$

where $P_{g,t}$ is the deflator of government expenditure. Government consumption is a key fiscal policy instrument available to government in the model and its evolution is given by:

$$\frac{g_{c,t}}{\overline{g_c}} = \left(\frac{g_{c,t-1}}{\overline{g_c}}\right)^{\rho_g} \left[\left(\frac{y_t}{\overline{y}}\right)^{\omega_{gy}} \left(\frac{b_{t-1}}{\overline{b}}\right)^{-\omega_b} \left(\frac{or_t}{\overline{or}}\right)^{\omega_{or}}\right]^{1-\rho_g} \exp\left(\xi_t^{G_c}\right) \tag{3.74}$$

where parameter ρ_g is the government consumption smoothing parameter, while ω_{gy}, ω_b and ω_{or} are government consumption feedback coefficients with respect to GDP, domestic debt and oil revenues, respectively. The feedback parameter, ω_{gy}, defines the cyclicality of government spending and $\varepsilon_t^{G_c}$ represents government spending shock.

In order to incorporate fuel consumption subsidies, we assume that the price paid by consumers for fuel is different from the supply cost that would have prevailed in the absence of subsidies. The supply cost is the opportunity cost, which corresponds to the spot price in international market adjusted to take into account the cost of transport and distribution. In Nigeria, fuel subsidy has been in place since the 1980s. It is often perceived as a de facto entitlement and seen as a sort of generalized "in-kind" transfer that addresses the citizens' expectations of sharing in the country's resource. The government also justifies the continued provisioning of the energy subsidy by the need to shield the economy from shocks caused by large swings in commodity prices.

The economy has a low oil refining capacity. Consequently, we assume that refined oil (fuel), O_t, is produced abroad and imported into the domestic economy (Allegret and Benkhodja, 2015). The government imports fuel at a foreign price $P_{o,t}^*$ (denominated in foreign currency) and sells to the domestic market at a regulated price, $P_{ro,t}$, based on a fuel pricing rule:

$$P_{ro,t} = P_{ro,t-1}^{1-\nu} P_{lo,t}^{\nu}, \tag{3.75}$$

where the landing price of imported fuel, $P_{lo,t}$, is given by[14]:

$$P_{lo,t} = \varepsilon_t \frac{P_{o,t}^*}{P_t^*} \Psi_t^o. \tag{3.76}$$

The variable $P_{o,t}^*$ is the foreign currency price of oil abroad, ε_t is the nominal exchange rate and Ψ_t^o is the law of one price gap associated with the price of imported fuel. In our model, Ψ_t^o captures inefficiencies in the pricing of fuel in the domestic economy. A positive shock to Ψ_t^o increases domestic fuel price and increases subsidy payments (Equations (3.75) and

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

(3.77)). The parameter $0 < \nu < 1$ captures the pass-through effect of international price of oil to the domestic fuel price. Therefore, it governs the level to which government subsidises fuel consumption. A value of $\nu = 1$ corresponds to a situation where there is complete pass-through and the subsidy regime seizes to exist. On the other hand, a value of $\nu = 0$ implies that the domestic price of fuel is fully stabilised. The fuel subsidy payment by government is given by the difference between the value of fuel imports (in domestic currency) and the amount realised from fuel sales in the domestic economy:

$$OS_t = \left(P_{lo,t} - P_{ro,t}\right) O_t, \tag{3.77}$$

where total imported fuel, O_t, comprises fuel consumption by households to satisfy their energy demands, $C_{o,t}$, and consumption by domestic firms for the production of non-oil goods, $O_{h,t}$.

On the revenue side of the budget constraint, the government collects lump-sum taxes and oil revenues. The amount of oil revenue accruing to government is given by:

$$OR_t = \tau \varepsilon_t P^*_{o,t} Y_{o,t}, \tag{3.78}$$

where τ is the royalty rate on oil production quantity. Since fiscal debt clears the government's budget constraint, an additional equation is required for lump-sum taxes, TX_t. This is specified as:

$$\frac{tx_t}{\overline{tx}} = \left(\frac{b_{t-1}}{\overline{b}}\right)^{\varphi_b} \left(\frac{or_t}{\overline{or}}\right)^{\varphi_{or}} \left(\frac{os_t}{\overline{os}}\right)^{\varphi_{os}} \left(\frac{g_{c,t-1}}{\overline{g}_c}\right)^{\varphi_g}, \tag{3.79}$$

where the parameters φ_b , φ_g , φ_{os} and φ_{or} represent the responses of lump-sum tax to lagged fiscal debt, lagged government consumption, fuel subsidy payments and oil revenue, respectively. The variables in equations (3.74) and (3.79) represent their respective ratios to the nominal GDP, such that $g_t = \frac{G_t}{P_t Y_t}$, $b_t = \frac{B_t}{P_t Y_t}$, $or_t = \frac{OR_t}{P_t Y_t}$, $os_t = \frac{OS_t}{P_t Y_t}$ and $tx_t = \frac{TX_t}{P_t Y_t}$. The bars denote steady state levels of the variables.

3.4.8 Monetary authority

We assume that in setting the short term nominal interest rate (R_t), the central bank follows a simple Taylor rule by gradually responding to aggregate inflation (π_t), domestic output

$(Y_{h,t})$, and the real exchange rate (q_t) as follows:

$$\frac{R_t}{\overline{R}} = \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_r} \left[\left(\frac{\pi_t}{\overline{\pi}}\right)^{\omega_\pi} \left(\frac{Y_{h,t}}{\overline{Y_h}}\right)^{\omega_y} \left(\frac{q_t}{\overline{q}}\right)^{\omega_q}\right]^{(1-\rho_r)} \exp\left(\xi_t^r\right). \tag{3.80}$$

where the bars denote steady state levels of the variables. The parameter ρ_r is the interest rate smoothing parameter capturing monetary policy inertia to structural shocks. The monetary policy feedback coefficients on inflation, output and real exchange rate are ω_π, ω_y and ω_q, respectively. The monetary policy shock, ξ_t^r, is assumed independent and identically distributed (*iid*). In line with one of our objectives, we vary the monetary policy reaction function in equation (3.80) to obtain three other variants in other to examine the responses of key macroeconomic variables to an oil price shock under alternative monetary policy rules[15]. These alternative monetary policy rules are specified in Table 3.3 in log-linear form.

Table 3.3: Alternative Taylor rule specifications

Taylor Rule (TR)	Specification
Total inflation-based TR	$\widetilde{R}_t = \rho_r\widetilde{R}_{t-1} + (1-\rho_r)\left[\omega_\pi\widetilde{\pi}_t + \omega_y\widetilde{y}_{h,t} + \omega_q\widetilde{q}_t\right]$
Core inflation-based TR	$\widetilde{R}_t = \rho_r\widetilde{R}_{t-1} + (1-\rho_r)\left[\omega_{\pi_{no}}\widetilde{\pi}_{no,t} + \omega_y\widetilde{y}_{h,t} + \omega_q\widetilde{q}_t\right]$
Domestic inflation-based TR	$\widetilde{R}_t = \rho_r\widetilde{R}_{t-1} + (1-\rho_r)\left[\omega_{\pi_h}\widetilde{\pi}_{h,t} + \omega_y\widetilde{y}_{h,t} + \omega_q\widetilde{q}_t\right]$
Export price-based TR	$\widetilde{R}_t = \rho_r\widetilde{R}_{t-1} + (1-\rho_r)\left[\omega_{\pi_o}\left((1-\Theta_o)\widetilde{\pi}_{h,t} + \Theta_o\widetilde{\pi}_t^o\right) + \omega_y\widetilde{y}_{h,t}\right]$

Thus, in addition to a Taylor rule that responds to aggregate inflation (total inflation-based TR) specified above, we consider cases in which the policy-controlled interest rate responds to core inflation (core inflation-based TR) and domestic inflation (domestic inflation-based TR). For oil exporting economies whose headline inflation measure features oil, it is a natural exercise to evaluate the stabilisation roles of the total inflation-based TR and the core inflation-based TR in the economy. Finally, we analyse a variant of the Taylor rule that incorporates commodity export price (export price-based TR) in line with the argument canvassed by Frankel (2003). Oil inflation in domestic currency is represented by $\pi_t^o = \Delta p_{o,t}^* + \Delta q_t$ while the weights Θ_o and $(1-\Theta_o)$ represent the shares of oil and core goods in the aggregate GDP, respectively. This is as in Algozhina (2015).

[15] The results are presented in section 3.6.5.

3.4.9 Market clearing and aggregation

The aggregate demand equations derive from the model set up, where domestic output ($Y_{h,t}$) is absorbed by aggregate domestic consumption (which comprises consumption of domestically produced goods by households - $C_{h,t}$, materials input used up by oil producing firms - M_t, and consumption of domestically produced goods by government - $G_{h,t}$); non-oil exports ($C^*_{h,t}$); and domestic investment[16] ($I_{h,t}$). The domestic resource constraint is therefore given by:

$$P_{h,t}Y_{h,t} = P_{h,t}C_{h,t} + \varepsilon_t P^*_{h,t}C^*_{h,t} + P_{h,t}M_t + P_{h,t}I_{h,t} + P_{h,t}G_{h,t}. \tag{3.81}$$

On the other hand, the aggregate nominal GDP, which combines oil GDP ($Y_{o,t}$) and non-oil GDP ($Y_{h,t}$) is given by:

$$P_tY_t = P_{h,t}Y_{h,t} + \varepsilon_t P^*_{o,t}Y_{o,t} + IM_t = P_{h,t}C_{h,t} + P_{h,t}M_t + P_{h,t}I_{h,t} + P_{h,t}G_{h,t} + NX_t. \tag{3.82}$$

and net exports (NX_t) is given by:

$$NX_t = EX_t - IM_t, \tag{3.83}$$

where EX_t is aggregate exports and IM_t represents aggregate imports. Aggregate exports, EX_t, comprises oil exports ($EX_{o,t}$ measured as $\varepsilon_t P^*_{o,t}Y_{o,t}$) and non-oil exports ($EX_{no,t}$ measured as $\varepsilon_t P^*_{h,t}C^*_{h,t}$) and is specified as:

$$EX_t = \varepsilon_t P^*_{o,t}Y_{o,t} + \varepsilon_t P^*_{h,t}C^*_{h,t}. \tag{3.84}$$

Aggregate imports, IM_t, comprises oil imports ($IM_{o,t}$ measured as $P_{lo,t}O_t$) and non-oil imports ($IM_{no,t}$ measured as $P_{f,t}Y_{f,t}$) and is specified as:

$$IM_t = P_{lo,t}O_t + P_{f,t}Y_{f,t}, \tag{3.85}$$

where the aggregate amount of imported non-oil goods is given as $Y_{f,t} = C_{f,t} + I_{f,t} + G_{f,t}$.

Since the economy is open and we assume there is no external reserves accumulation by the central bank, the current account is set equal to the financial account. We therefore

[16] Which is used to augment the stock of physical capital available for use in the production process in period $t + 1$

obtain the following expression for the Balance of Payments (BOP):

$$\frac{q_t b_t^*}{R_t^* \mu_t^*} = q_t b_{t-1}^* + nx_t - (1-\tau)\, q_t p_{o,t}^* y_{o,t} + q_t fdi_t^*. \tag{3.86}$$

where $b_t^* = \frac{B_t^*}{P_t Y_t}$, $nx_t = \frac{NX_t}{P_t Y_t}$, $p_{o,t}^* y_{o,t} = \frac{P_{o,t}^* Y_{o,t}}{P_t Y_t}$ and $fdi_t^* = \frac{FDI_t^*}{P_t Y_t}$. The labour and capital markets clear as follows:

$$N_t = \int_0^1 N_t^R (j)\, dj + \int_0^1 N_t^{NR} (j)\, dj \qquad \text{and} \qquad K_{h,t} = \int_0^1 K_{h,t} (j)\, dj.$$

3.4.10 Rest of the world

The demand for domestic goods by the foreign economy, $C_{h,t}^*$, is given by:

$$C_{h,t}^* = \gamma^* \left(\frac{P_{h,t}^*}{P_t^*} \right)^{-\eta^*} C_t^*, \tag{3.87}$$

where $P_{h,t}^*$ is the price of domestic goods in foreign currency, P_t^* is the aggregate consumer price index in the foreign economy, and C_t^* is aggregate foreign consumption. The parameter, η^*, represents the foreign price elasticity of demand for domestic goods while the share of domestic goods in foreign consumption is captured by γ^*.

The IS curve for the foreign economy is specified as:

$$\frac{1}{R_t^* \mu_t^*} = \beta E_t \left[\left(\frac{C_{t+1}^* (j) - \phi_c^* C_t^*}{C_t^* (j) - \phi_c^* C_{t-1}^*} \right)^{-\sigma_c^*} \frac{1}{\pi_{t+1}^*} \right], \tag{3.88}$$

where ϕ_c^* is the habit formation parameter in the foreign economy and σ^* is the relative risk aversion coefficient. The variables C_t^*, R_t^* and π_t^* represent consumption, interest rate and inflation rate in the foreign economy. The central bank reaction function for the foreign economy is as follows:

$$\frac{R_t^*}{\overline{R^*}} = \left(\frac{R_{t-1}^*}{\overline{R^*}} \right)^{\rho_{r^*}} \left[\left(\frac{\pi_t^*}{\overline{\pi^*}} \right)^{\omega_{\pi^*}} \left(\frac{Y_{h,t}^*}{\overline{Y_h^*}} \right)^{\omega_{y^*}} \right]^{1-\rho_{r^*}} \exp\left(\xi_t^{r^*} \right), \tag{3.89}$$

where the bars denote the steady state levels of the variables and $\xi_t^{r^*}$ represents monetary policy shock in the foreign economy. The parameter ρ_{r^*} represents the interest rate smoothing parameter in the foreign economy while ω_{π^*} and ω_{y^*} are the feedback coefficients for inflation and output, respectively. Inflation rate in the foreign economy is assumed to follow $AR\,(1)$ process with an exogenous shock as follows:

$$\pi_t^* = \left(\pi_{t-1}^*\right)^{\rho_{\pi^*}} \exp\left(\xi_t^{\pi^*}\right). \tag{3.90}$$

Overall, the small open economy model developed in this section is driven by ten stochastic shocks: real international oil price ($\xi_t^{p_o^*}$), oil sector productivity ($\xi_t^{a_o}$), law of one price gap in oil price ($\xi_t^{\psi^o}$), domestic total factor productivity ($\xi_t^{a_h}$), domestic monetary policy (ξ_t^r), fiscal policy (ξ_t^g), domestic risk premium (ξ_t^μ), foreign monetary policy ($\xi_t^{r^*}$), foreign inflation ($\xi_t^{\pi^*}$), and foreign risk premium ($\xi_t^{\mu^*}$).

3.5 Model Estimation

3.5.1 Estimation methodology

The model developed in the previous section is estimated using Bayesian methodology outlined in Schorfheide (2000). This estimation strategy helps to combine robust micro foundations that are useful for policy analysis with an intuitive probabilistic distribution of the observables (Smets and Wouters, 2007). It allows us to estimate the key structural parameters of our model through the incorporation of additional information on the model parameters in the form of prior distributions. In conducting Bayesian estimation, the first step is to solve a system of linear rational expectations equations. To do this, we solve the system of log-linear rational expectations equations presented in Appendix B.3 and express the solution as a Vector Autoregressive (VAR) representation in z_t:

$$z_t = \Gamma_1(\Omega)z_{t-1} + \Gamma_2(\Omega)\xi_t, \tag{3.91}$$

where z_t is a vector containing the variables of the model expressed in log deviations from their steady state values and the vector ξ_t contains the exogenous disturbances that drive the model dynamics. The coefficient matrices $\Gamma_1(\Omega)$ and $\Gamma_2(\Omega)$ are non-linear functions of the structural parameters of the model. The parameter vector Ω collects the structural parameters governing the model dynamics, the coefficients in the policy rules and the standard deviation of shocks.

After obtaining the model solution, measurement equations are added in order to link the observable variables to the vector of state variables. Thus, we assume there is a vector g_t of observable variables that is of a lower dimension than z_t and related to the variables in our model via a measurement equation that can be written as:

$$g_t = Hz_t, \tag{3.92}$$

where H is a selection matrix containing ones and zeros that selects the observable variables from the vector z_t. The state space representation of g_t is given by equations (3.91) and (3.92). In our proposed model, the vector of observable variables is:

$$g_t \equiv \left[y_t, c_t, i_{no,t}, q_t, \pi_t, \pi_{no,t}, r_t, y_t^*, \pi_t^*, r_t^*, p_{o,t}^*\right]'$$

while the remaining variables are considered unobserved. The relevant measurement equations are specified in equation (3.93) below. Equation (3.93) allows us to construct the likelihood function[17] for the structural parameters via Kalman Filter[18]. The likelihood density is then combined with the prior distribution of the parameters in order to obtain the posterior density function[19]. In the final step, we numerically derive the posterior distribution of the parameters using Metropolis-Hastings Monte Carlo Markov Chain (MCMC) algorithm. We then simulate 3 million draws from the random walk Metropolis-Hastings, discarding 30 per cent of the first draws as burn-in. The covariance matrix is scaled to achieve an acceptance ratio that is within the 20 - 40 per cent often targetted by most practitioners (Herbst and Schorfheide, 2015)[20].

3.5.2 Data

The model is estimated using data for eleven macroeconomic variables spanning the period 2000Q2 - 2018Q2[21]. These comprise seven domestic variables, three foreign variables, and

[17] The likelihood function represents the probability of observing the data given the parameters. It is useful for updating our a priori beliefs about the model parameters, given the available data on observable variables (Herbst and Schorfheide, 2015).

[18] The Kalman Filter is a recursive forecasting procedure for the unobserved states given the observables in the linear state space form (Miao, 2014). We compute the Kalman Filter under the assumption of normally distributed disturbances.

[19] The posterior density summarizes what we know about the parameters after observing the data.

[20] This was achieved by setting the Metropolis-Hastings jump scale to 0.26 heuristically. The random walk Metropolis-Hastings algorithm computes the acceptance ratio as the number of accepted draws divided by the number of proposals.

[21] The choice of the estimation sample is largely influenced by data availability for the Nigerian economy.

the international price of oil. As earlier explained, Nigeria represents the small open economy in our model. The foreign economy consists of Nigeria's major trading partners of the Euro area, the United States, and India[22]. The domestic observables, which relate to the Nigerian economy are: per capita real domestic GDP ($y_{h,t}^{obs}$), per capita real consumption (c_t^{obs}), per capita real investment ($i_{no,t}^{obs}$), real effective exchange rate (q_t^{obs}), aggregate Consumer Price Index (p_t^{obs}), core Consumer Price Index ($p_{no,t}^{obs}$), and nominal interest rate (R_t^{obs}). Data set on these variables are sourced from the National Bureau of Statistics (NBS) and the Central Bank of Nigeria (CBN).

On the other hand, the foreign variables include trade-weighted foreign real GDP per capita (y_t^{*obs}), trade-weighted foreign aggregate CPI (P_t^{*obs}), trade-weighted foreign interest rate (R_t^{*obs}), and the international price of oil ($P_{o,t}^{*obs}$). The data set used for the computation of the trade-weighted foreign variables as well as the international price of oil ($P_{o,t}^{*obs}$) are retrieved from the Federal Reserve Bank of St. Louis (FRED) database and the International Financial Statistics (IFS) of the International Monetary Fund (IMF).

$$\begin{bmatrix} log\left(y_{h,t}^{obs}/y_{h,t-1}^{obs}\right) \\ log\left(c_t^{obs}/c_{t-1}^{obs}\right) \\ log\left(i_{no,t}^{obs}/i_{no,t-1}^{obs}\right) \\ log\left(q_t^{obs}/q_{t-1}^{obs}\right) \\ log\left(P_t^{obs}/P_{t-1}^{obs}\right) \\ log\left(P_{no,t}^{obs}/P_{no,t-1}^{obs}\right) \\ R_t^{obs}/4 \\ log\left(y_t^{*obs}/y_{t-1}^{*obs}\right) \\ log\left(P_t^{*obs}/P_{t-1}^{*obs}\right) \\ R_t^{*obs}/4 \\ log\left(P_{o,t}^{*obs}/P_{o,t-1}^{*obs}\right) \end{bmatrix} = \begin{bmatrix} y_{h,t} - y_{h,t-1} + \xi_t^{yobs} \\ c_t - c_{t-1} + \xi_t^{cobs} \\ i_{no,t} - i_{no,t-1} + \xi_t^{iobs} \\ q_t - q_{t-1} \\ \pi_t \\ \pi_{no,t} \\ R_t \\ y_t^* - y_{t-1}^* \\ \pi_t^* \\ R_t^* \\ p_{o,t}^* - p_{o,t-1}^* \end{bmatrix}, \tag{3.93}$$

Necessary transformations are conducted on the data set in order to make them model consistent. We demean and deseasonalise relevant variables using the TRAMO-SEATS procedure. Also, in line with their model counterparts, data on interest rate and inflation rate are expressed in quarterly terms. With the exception of the two interest rates, we measure the observables in log-differences. The relationships between each of the observed variables

[22]These three regions account for about 65 per cent of Nigeria's total external trade over the last two decades. In the normalised weights for the computation of foreign variables, the Euro area is predominant with a trade weight of 0.39 while the weights for the United States and India are 0.36 and 0.25, respectively.

and their model counterparts are presented in the measurement equation (3.93). In order to avoid the problem of stochastic singularity when evaluating the likelihood function, we balance the number of observables with the number of stochastic disturbances in our model by incorporating three measurement errors relating to output (ξ_t^{yobs}), consumption (ξ_t^{cobs}), and investment (ξ_t^{iobs}).

3.5.3 Model parameters

Parametrization

The values of calibrated parameters, which are kept fixed in the estimation process are derived from three sources. The first category are based on standard values assumed in the literature for small open economies as in Gali and Monacelli (2005) and resource-rich emerging economies such as Romero (2008), Wolden-Bache et al. (2008), Hove et al. (2015), Ferrero and Seneca (2019), and Iklaga (2017). These values are borrowed from related studies due to data paucity for the Nigerian economy. The second category are parametrized so as to match the corresponding data sample mean while the last set of parameters correspond to the implied steady state values from the model setup. The parametrization is done to fit quarterly data. Table 3.4 presents a list of these parameters and their values.

We set the discount factor, β, equal to 0.99 (Allegret and Benkhodja, 2015; Iklaga, 2017); the depreciation rate, δ, equal to 0.025 (Allegret and Benkhodja, 2015; Iklaga, 2017); share of imports in household's consumption, γ_c, equal to 0.35 based on sample data for Nigeria and close to 0.4 assumed by Gali and Monacelli (2005) and share of imports in household's investment, γ_i, equal to 0.2. We derive the share of fuel in household's consumption, γ_o, as 0.085 based on household consumption data for the sample period. The elasticity parameters in the firm's production functions are set as follows: elasticity of domestic output with respect to capital, $\alpha_h^k = 0.33$ (Rasaki and Malikane, 2015); elasticity of domestic output with respect to labour, $\alpha_h^n = 0.55$ (Ncube and Balma, 2017); elasticity of oil output with respect to capital, $\alpha_o^k = 0.7$ (Algozhina, 2015) and elasticity of oil output with respect to materials, $\alpha_o^m = 0.3$ (Algozhina, 2015; Ferrero and Seneca, 2019). The elasticity of substitution between foreign and domestic goods consumed by government, η_g, is set to 0.6 (Hollander et al., 2018); while the foreign economy's monetary policy reaction to inflation, ω_{π^*}, and output, ω_{y^*}, are set equal to 1.50 and 0.50, respectively (Hollander et al., 2018).

Table 3.4: Calibrated parameters

Parameter Definition	Symbol	Value
Discount factor	β	0.990
Depreciation rate	δ	0.025
Share of imports in household's consumption	γ_c	0.350
Share of fuel in household's consumption	γ_o	0.085
Share of imports in household's investment	γ_i	0.200
Calvo - wages	θ_w	0.750
Elasticity of domestic output with respect to capital	α_h^k	0.330
Elasticity of domestic output with respect to oil	α_h^o	0.120
Elasticity of domestic output with respect to labour	α_h^n	0.550
Elasticity of oil output with respect to capital	α_o^k	0.700
Elasticity of oil output with respect to materials	α_o^m	0.300
Share of imports in government's consumption	γ_g	0.120
Elasticity of substitution between foreign & domestic goods - Govt.	η_g	0.600
Response of public consumption to fiscal debt	ω_b	0.300
Response of public consumption to oil revenue	ω_{or}	0.800
Response of lump-sum taxes to fiscal debt	φ_b	0.400
Response of lump-sum taxes to government consumption	φ_g	0.950
Response of lump-sum taxes to fuel subsidy payments	φ_{os}	0.100
Response of lump-sum taxes to oil revenue	φ_{or}	0.300
Coefficient of inflation in Taylor Rule - foreign economy	ω_{π^*}	1.500
Coefficient of output in Taylor Rule - foreign economy	ω_{y^*}	0.500
Steady state ratios		
Consumption - output	C_H/Y_H	0.690
Investment - output	I_{NO}/Y_H	0.150
Domestic materials - output	M/Y_H	0.010
Government consumption - output	G_c/Y_H	0.070
Export - output	C_H^*/Y_H	0.070
Import - output	IM/Y_H	0.150

Most of the parameters relating to fiscal policy and the fuel pricing rule are based on Algozhina (2015) as follows: share of imports in government's consumption, $\gamma_g = 0.12$, response of public consumption to fiscal debt, $\omega_b = 0.30$, response of public consumption to oil revenue, $\omega_{or} = 0.80$, response of lump-sum taxes to fiscal debt, $\varphi_b = 0.40$, response of lump-sum taxes to government consumption, $\varphi_g = 0.95$, response of lump-sum taxes to fuel subsidy payments, $\varphi_{os} = 0.10$, and response of lump-sum taxes to oil revenue, $\varphi_{or} = 0.30$. Aggregate Nigerian data and implied model values are used to calibrate the remaining domestic economy steady-state parameters.

Prior moments

Table 3.6 presents our assumptions regarding the prior distributions of the estimated parameters. The priors for the small open economy are chosen based on calibration, the data and partly based on Iklaga (2017). On the other hand, the foreign priors are based on Smets and Wouters (2007). In cases where we have limited information to form a credible prior, we impose less informative priors; allowing the data to determine the location of the parameter.

We assume that the proportion of Ricardian consumers[23] (γ_R) is represented by a beta distribution with a mean of 0.6 and standard deviation of 0.10 (Iklaga, 2017; Ncube and Balma, 2017). The labour supply elasticity (φ) is set to 1.45 in line with Algozhina (2015) and assumed to follow a gamma distribution with a standard deviation of 0.10. The risk aversion parameter[24], (σ), is represented by an inverse gamma distribution with a mean of 2.0; consistent with Iklaga's (2017) assumption for Nigeria and higher than 1.5 assumed by Smets and Wouters (2007) for the US economy. The external habit parameter, ϕ_c, is represented by a beta distribution with a mean of 0.7 and standard deviation of 0.1 (Iklaga, 2017) while the investment adjustment cost parameter, χ, is represented by a gamma distribution with mean 4.0 and a relatively large standard deviation of 3.0 (Iklaga, 2017; Ncube and Balma, 2017). The intra-temporal elasticities are represented by gamma distributions. The elasticity of substitution between oil and non-oil (core) goods is set to a mean of 0.2 (Hollander et al., 2018; Medina and Soto, 2005) while the elasticity of substitution between domestic and foreign goods for consumption (η_c) and investment (η_i) are 0.6 each in line with Hollander et al. (2018).

The reaction coefficients in the monetary policy function are assumed to follow gamma distributions with the coefficient for inflation (ω_π) centered at 1.5 while the coefficients for output (ω_y) and exchange rate (ω_q) are each set to 0.125, respectively (Iklaga, 2017; Smets

[23] In 2018, about 36.8 per cent of adults in Nigeria were financially (EFInA, 2018).

[24] This parameter controls how households' savings/investment decision is affected by structural shocks.

and Wouters, 2007). Our assumptions regarding the Taylor rule coefficients imply that the central bank responds actively to inflation in line with its mandate of price stability. The fuel pricing rule parameter, ν, is set to follow a beta distribution with a mean of 0.3 in line with Allegret and Benkhodja (2015) and a standard deviation of 0.1. This means that 30 per cent of the variations in international oil price is transmitted to retail price of fuel.

The autoregressive coefficients for the exogenous disturbances are uniformly set to follow beta distributions centered at 0.50 in line with (Smets and Wouters, 2007). However, we assume larger standard deviations of 0.25 to reflect some level of uncertainty about the assumed parameter values. Finally, with regards to the distribution for the parameters of the shock processes, we allow for a relatively flat priors as in Medina and Soto (2007). Thus, an inverse gamma distribution with a mean of 0.10 and a standard deviation of 4.0 is assumed for each of the shock processes. While the assumed mean for the shocks are in line with Smets and Wouters (2007), the assumed standard deviation of 4.0 is much larger than 2.0 in Smets and Wouters (2007) and 3.0 in Medina and Soto (2007). As earlier explained, this is to reflect our uncertainty about the assumed priors and allow the data determine the parameter values.

3.6 Results

We simulate 3,000,000 draws each from two parallel chains of the the random walk Metropolis-Hastings, discarding the first 30 per cent of the draws as burn-in. The two chains yielded acceptance ratios of 30.4 and 30.6 per cent, respectively, implying that the two chains drew their samples from the same ergodic distribution. In this section, we present the posterior distributions of the estimated parameters and analyse the business cycle drivers of the small open oil-producing economy. Also, we analyse the Bayesian impulse responses, especially with respect to a 1.0 per cent negative oil price shock. To address our research question on the role of fuel subsidies, we used the estimated parameters to simulate two models under alternative assumptions regarding the pass-through effects of international oil price to the retail fuel price. Next, we examine the implications of the presence of hand-to-mouth consumers and fiscal cyclicality for the response of the economy to a number of shocks. Finally, we conduct some monetary policy analyses.

3.6.1 Business cycle moments

We evaluate the statistical moments produced by the estimated model vis-a-vis similar moments that characterise actual observations from the data. This helps to provide insights regarding the extent to which the model mimics the underlying characteristics of the Nigerian economy. Table 3.5 reports the standard deviation of some endogenous variables as well as their cross-correlations with aggregate output.

The estimated model reasonably replicates the volatilities in interest rate and the real exchange rate. However, it over-predicted the volatility in output and under-predicted the volatilities in headline and core measures of inflation. In line with expectation and the observed data, the core measure of inflation turns out less volatile than its headline counterpart. The performance with regard to output is a common outcome in studies of emerging economies (Iklaga, 2017).

Table 3.5: Data and model implied business cycle moments

	Total GDP	Headline inflation	Core inflation	Interest rate	Exchange rate
Standard Deviation					
Data	0.21	0.59	0.56	0.44	0.27
Model	1.01	0.22	0.21	0.41	0.27
Cross-correlation with Total GDP					
Data	1.00	0.02	0.07	-0.03	0.10
Model	1.00	0.03	0.04	-0.01	0.10

In the lower panel of Table 3.5, we present the cross-correlations between total GDP and the selected endogenous variables; namely: total inflation, core inflation, interest rate and real exchange rate. Generally, our estimated model reasonably predicts the cross-correlations between the selected endogenous variables and output. While the model over-predicts the correlation between output and headline inflation, the reverse is the case for core inflation. In line with observed data, the estimated model shows that core inflation is more correlated with output than headline inflation. The model closely mimics the observed positive correlation between output and the real exchange rate and the negative correlation between output and interest rate observed in the data.

3.6.2 Posterior moments

Table 3.6 reports the assumptions for the prior distribution of the estimated parameters, the posterior means, and the 90 per cent credible sets. The parameters in the utility function are estimated to be lower than their priors. For instance, at $\sigma = 1.4$, the estimated relative risk aversion parameter is lower than 2.0 initially assumed but slightly higher than 1.38 estimated by Smets and Wouters (2007) for the US economy. This implies that the savings/investment behaviour of households are more sensitive to structural shocks in Nigeria. Our estimate is also higher than the 1.07 obtained by Iklaga (2017) for the Nigerian economy. The estimated labour supply elasticity ($\varphi = 1.44$) is about the same value as the assumed prior of 1.45 while the estimated external habit parameter, ϕ_c, is 0.4 compared to the assumed prior of 0.7. The posterior mean for the share of Ricardian consumers, γ_R, is 0.69. This is higher than the estimate of 0.62 obtained by Iklaga (2017) for the period 2003-2015.

The elasticity of substitution between households' oil and non-oil consumption (η_o) is estimated at 0.19, which is same as 0.19 estimated 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 is $\eta_c = 0.61$,which is slightly higher than the value of 0.59 obtained by Hollander et al. (2018) for the South African economy. Also, the household's elasticity of intra-temporal substitution between domestically produced goods and imported investment goods is $\eta_i = 0.62$. The estimated Calvo price parameter for domestically produced goods, $\theta_h = 0.72$, is higher than the assumed prior of 0.70 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.

Turning to the fuel pricing rule, which governs the dynamics of the fuel consumption subsidy regime, our results show that the government bears more than half of the effects of international oil prices on domestic fuel price under its subsidy programme. The estimated pass-through parameter, $\nu = 0.43$, is higher than the value of 0.30 initially assumed. This implies an incomplete pass-through of international oil prices into domestic fuel price, as expected of an economy with a fuel subsidy programme. To our knowledge, this paper represents the first attempt at estimating such pass-through coefficient for an oil producing emerging economy with a fuel subsidy regime. In this paper, we argue that a proper analysis of the business cycle effects of an oil price shock under our model set up requires an understanding of the pass-through effects of international oil price to the retail price of fuel[25]. Our counterfactual simulations regarding the macroeconomic implications of the fuel subsidy regime for the resource-rich economy shown in sub-section 3.6.6 are based on alternative assumptions regarding the pass-through coefficient in the fuel pricing rule. Our benchmark simulation corresponds to the estimated value of the pass-through parameter ($\nu = 0.43$) while the alternative scenario is based on a value of unity, $\nu = 1$, implying complete pass-through of international oil price into retail fuel price.

The estimated Taylor rule suggests that the Central Bank of Nigeria (CBN) is quite active in containing inflationary pressure while also keeping an eye on output and exchange rate developments. The estimated CBN's reaction coefficient on inflation, $\omega_\pi = 2.86$, is higher than our assumed prior of 1.50, the 1.45 obtained by Iklaga (2017) and 1.405 estimated for an oil-importing economy of South Africa (Hollander et al., 2018). Furthermore, the estimated reaction coefficients on output, $\omega_y = 0.12$, and exchange rate, $\omega_q = 0.11$, are lower than their assumed prior of 0.125. Thus, in setting the policy rate, the monetary authority focuses on inflation and, in addition, pays attention to output and the exchange rate. The estimated interest rate smoothing parameter, $\rho_r = 0.22$, is low but comparable to the value of 0.21 obtained 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. Overall, the observed policy behaviour of the CBN is consistent with the findings of Richard and Olofin (2013) and Adebiyi and Mordi (2016). In terms of fiscal policy, the estimated posterior mean of the feedback parameter with respect to output, $\omega_{gy} = 0.35$, is lower than the assumed prior of 0.40 and suggests that government spending was pro-cyclical during the sample period. Also, the fiscal policy persistence parameter is estimated at 0.49, which is slightly lower than the assumed prior of 0.5.

Most of the shock processes are more persistent than assumed. The shocks with high persistent parameters include international oil price, $\rho_{p_o^*} = 0.92$; foreign risk premium, $\rho_{\mu^*} = 0.86$; domestic risk premium, $\rho_\mu = 0.79$; and domestic total factor productivity, $\rho_{a_h} = 0.77$. These shocks may account for the medium to long term forecast error variance of the real variables in our model (Smets and Wouters, 2007).

[25] While the domestic retail fuel price is administered by the federal government, the effective price paid by economic agents often differs from one part of the country to another. Such differences are usually amplified during periods of product scarcity as there is lack of institutional capacity to enforce country-wide compliance by fuel retailers. To capture this reality in our model, we assume that part of the changes to international price of fuel is unofficially passed to domestic consumers of fuel via a law of one price gap for fuel price.

Table 3.6: Prior and posterior estimates

Parameter	Prior distribution			Posterior distribution		
	Density	Mean	Std. Dev.	Mean	90% HPD Int.	
Structural parameters						
Ricardian consumers: γ_R	Beta	0.60	0.10	0.692	0.562	0.824
Labour supply elasticity: φ	Gamma	1.45	0.10	1.439	1.274	1.600
Relative risk aversion: σ	Inv. Gamma	2.00	0.40	1.409	1.109	1.694
External habit: ϕ_c	Beta	0.70	0.10	0.438	0.310	0.568
Investment adj. cost: χ	Gamma	4.00	3.00	6.181	1.751	10.490
Fuel pricing parameter: ν	Beta	0.30	0.10	0.429	0.190	0.640
Oil - core cons. elasticity: η_o	Gamma	0.20	0.10	0.188	0.044	0.328
For. - dom. cons. elasticity: η_c	Gamma	0.60	0.20	0.609	0.287	0.926
For. - dom. inv. elasticity: η_i	Gamma	0.60	0.20	0.615	0.286	0.933
Calvo - domestic prices: θ_h	Beta	0.70	0.10	0.719	0.620	0.826
Calvo - import prices: θ_f	Beta	0.70	0.10	0.691	0.525	0.860
Policy parameters						
Taylor, π: ω_π	Gamma	1.500	0.200	2.857	2.579	3.141
Taylor, y: ω_y	Gamma	0.125	0.050	0.118	0.043	0.191
Taylor, q: ω_q	Gamma	0.125	0.050	0.109	0.040	0.176
Taylor, smoothing: ρ_r	Beta	0.500	0.250	0.224	0.054	0.382
Fiscal, y : ω_{gy}	Normal	0.400	0.500	0.351	-0.470	1.184
Fiscal, smoothing: ρ_{g_c}	Beta	0.500	0.250	0.487	0.073	0.896
Autoregressive coefficients of shocks						
Dom. productivity: ρ_{a_h}	Beta	0.50	0.25	0.771	0.593	0.957
Oil productivity: ρ_{a_0}	Beta	0.50	0.25	0.502	0.100	0.905
Dom. risk premium: ρ_μ	Beta	0.50	0.25	0.786	0.703	0.871
Law of one price gap-oil: ρ_{ψ^o}	Beta	0.50	0.25	0.608	0.250	0.957
Int'l oil price shock: $\rho_{p_o^*}$	Beta	0.50	0.25	0.923	0.827	0.987
For. risk premium: ρ_{μ^*}	Beta	0.50	0.25	0.859	0.790	0.929
For. inflation: ρ^{π^*}	Beta	0.40	0.25	0.138	0.001	0.257
For. monetary policy: ρ_{r^*}	Beta	0.50	0.25	0.442	0.303	0.584
Standard deviation of shocks						
Dom. productivity: $\xi_t^{a_h}$	Inv. Gamma	0.10	4.00	0.246	0.105	0.407
Oil productivity:$\xi_t^{a_o}$	Inv. Gamma	0.10	4.00	0.076	0.024	0.133
Dom. risk premium: ξ_t^{μ}	Inv. Gamma	0.10	4.00	0.162	0.132	0.192
Dom. fiscal policy:$\xi_t^{g_c}$	Inv. Gamma	0.10	4.00	0.098	0.023	0.177
Law of one price gap-oil: $\xi_t^{\psi^o}$	Inv. Gamma	0.10	4.00	0.904	0.444	1.490
Dom. monetary policy: ξ_t^r	Inv. Gamma	0.10	4.00	0.379	0.300	0.455
Int'l oil price shock: $\xi_t^{p_o^*}$	Inv. Gamma	0.10	4.00	0.151	0.130	0.171
For. risk premium: $\xi_t^{\mu^*}$	Inv. Gamma	0.10	4.00	0.041	0.032	0.050
For. inflation: $\xi_t^{\pi^*}$	Inv. Gamma	0.01	4.00	0.005	0.004	0.006
For. monetary policy: $\xi_t^{r^*}$	Inv. Gamma	0.10	4.00	0.101	0.079	0.121

However, shocks relating to domestic monetary policy, fiscal policy and oil sector productivity are less persistent. At $\xi_t^{a_h} = 0.25$, the standard deviation of the domestic total factor productivity shock is relatively low, compared to the estimated standard deviation for shocks relating to law of one price gap for fuel price ($\xi_t^{\psi^o} = 0.90$), and domestic monetary policy ($\xi_t^r = 0.38$). At 0.90, the estimated standard deviation for the shock to law of one price gap for oil price is volatile, reflecting possible inefficiencies in the pricing of petroleum products in the country.

3.6.3 Bayesian impulse responses

In this section, we present the Bayesian impulse responses to four structural shocks relating to international oil price, total factor productivity, monetary policy, and fiscal policy. We consider the responses of the economy to a negative international oil price shock and positive innovations to domestic productivity, monetary policy, and fiscal policy.

The responses of the economy to 1.0 per cent negative international oil price shock is shown in Figure 3.6. Following a decline in oil prices, the oil firms become less profitable, leading to a reduction in the oil firms' demand for materials sourced from the domestic economy and a decline in oil output (as implied by equation 3.55). 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 releases 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 price and reduced marginal cost lead to an increase in non-oil GDP. However, the increase in non-oil output is suppressed initially due to the reduced demand for non-oil goods by the oil sector and the substitution effect that reduces household's demand for home and foreign goods in favour of oil.

Since the price of fuel features in the real marginal cost equation of domestic firms (equation 3.43), a negative oil price shock generates 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 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 a nutshell, a 1.0 per cent negative international oil price shock contracts aggregate GDP by about about 0.02 per cent upon impact, reduces domestic inflation, depreciates the real exchange rate, and increases headline as well as core measures of inflation. Consequently, the central bank of the small open resource-rich economy increases the interest rate in line with its inflation objective.

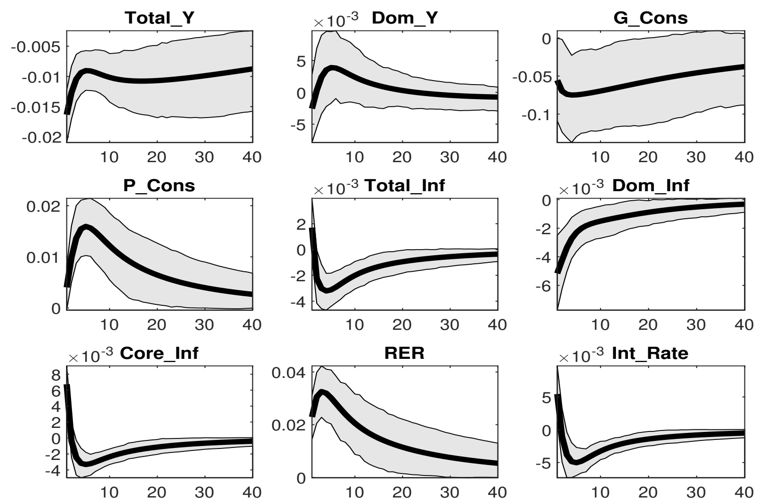

Figure 3.6: Bayesian impulse response to a negative oil price shock

Figure 3.7 shows that a positive total factor productivity shock leads to an increase in both headline GDP and non-oil output, albeit with an initially muted response by domestic output. All the measures of inflation decline, with domestic inflation recording the most impact. While domestic inflation fell upon impact, the response of headline inflation is initially muted as a consequence of the real exchange rate depreciation. In response to the lower inflationary pressure, the central bank cuts the interest rate. These results are consistent with the findings by Iklaga (2017) and Medina and Soto (2007). There is an initial decline in private consumption (partially due to the lower consumption of imported goods arising from the pass-through effects of exchange rate into import prices) while government consumption increases, suggestive of a crowding-out effect.

A positive monetary policy shock of 1.0 per cent contracts domestic output by about 0.05 per cent upon impact while also reining-in inflationary pressures. All measures of inflation decline with headline inflation recording the most impact. Also, the contractionary monetary policy reduces aggregate demand, causing an appreciation in the real exchange rate (Figure 3.8). We observe some degree of immediate exchange rate overshooting as the real exchange rate appreciates substantially below its long run level following a monetary policy shock that influences the interest rate differential between the domestic economy and the foreign economy (Dornbusch, 1976). An increase in the domestic interest rate generates increased capital inflows and appreciates the exchange rate as domestic assets become more attractive to foreign investors.

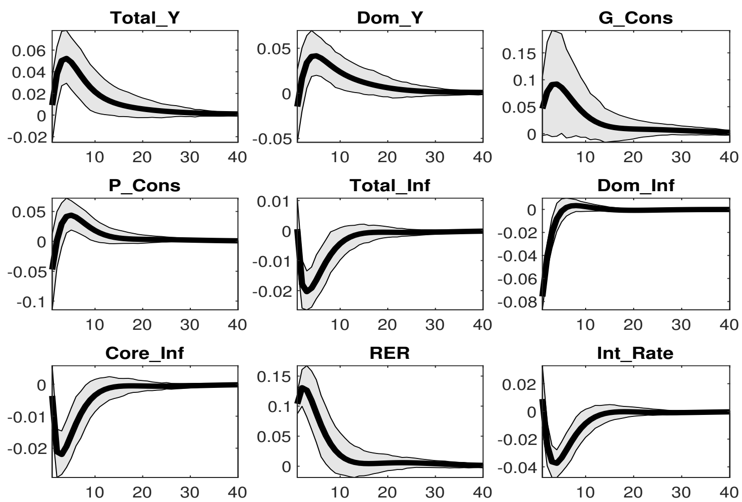

Figure 3.7: Bayesian impulse response to domestic technology shock

Lastly, Figure 3.9 shows that a 1.0 per cent positive shock to government spending stimulates the economy marginally, leading to a less than 0.01 per cent increase in domestic output upon impact and about 0.002 per cent increase in private consumption. Domestic inflation rises while the headline and core measures of inflation decline initially due to weak aggregate demand and lower import prices. Higher domestic prices causes a decline in the terms of trade and an appreciation of the real exchange rate, leading to lower core and headline inflation. Under an aggregate inflation-based Taylor rule, the initial decline in total inflation requires a temporary reduction in interest rate, followed by an upward adjustment in order to stabilise the economy. The observed positive response of private consumption to a positive fiscal policy shock is consistent with the outcomes expected under a model with hand-to-mouth consumers (Galí et al., 2007).

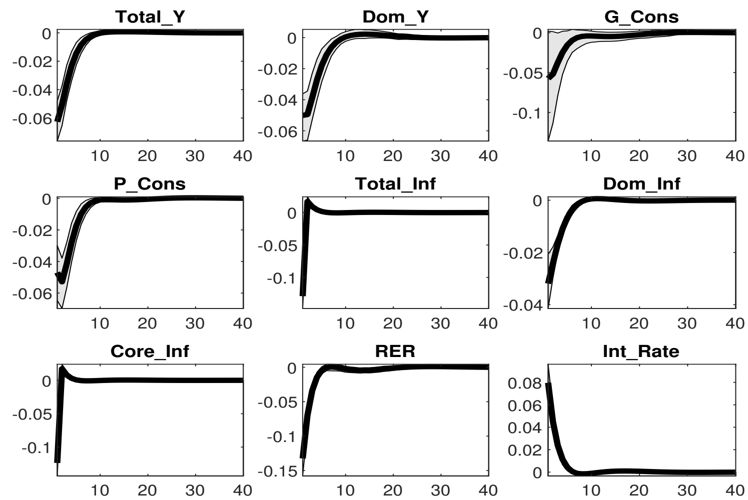

Figure 3.8: Bayesian impulse response to monetary policy shock

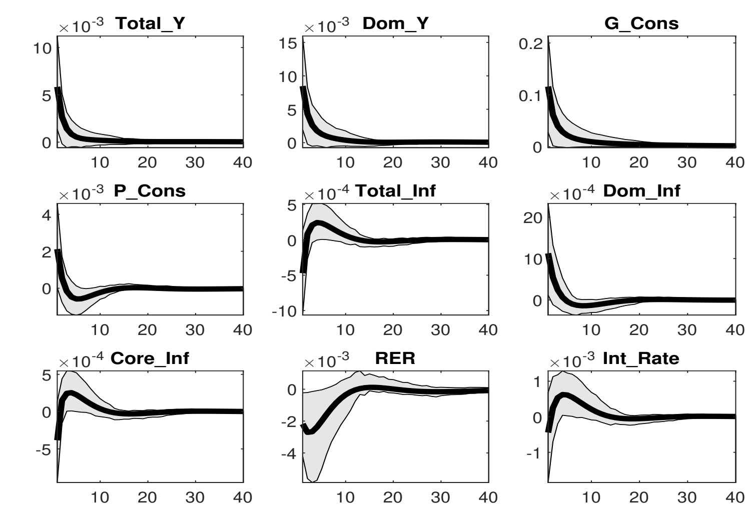

Figure 3.9: Bayesian impulse response to a fiscal policy shock

3.6.4 Business cycle drivers

In line with one of the research questions posed, the sources of business cycle fluctuations in the oil-producing emerging economy with a fuel subsidy regime are analysed in this section. The forecast error variance decomposition allows us to evaluate the relative contributions of the different structural shocks to variations in key endogenous variables, such as total GDP headline inflation, real exchange rate, and interest rate. In addition, we employ historical decomposition to disentangle the relative importance of the different shocks to changes in the observable variables during the sample period. For ease of presentation and analysis, we group the shocks under five categories: (i) oil shocks - comprising shocks to oil sector productivity, international oil price, and the law of one price gap for fuel; (ii) external shocks - comprising shocks to foreign inflation, foreign interest rate and external risk premium; (iii) domestic supply shocks - comprising shocks to domestic productivity and domestic risk premium; (iv) monetary policy shock; and (v) fiscal policy shock.

Forecast error variance decomposition

In Table 3.7, we report the forecast error variance decomposition of total GDP, real exchange rate, interest rate, CPI inflation, core inflation, domestic inflation and imported inflation. As earlier explained, the shocks are categorised into five groups, namely: oil-related shocks, external shocks, domestic shocks, monetary policy shock, and fiscal policy shock.

Total GDP: Monetary policy and oil shocks predominantly account for variations in total output in the short run (1-4 quarters) while domestic shocks are important in the medium- to long-term (5-20 quarters). The results show that the contribution of domestic shocks is quite strong and persistent, contributing about 46.4 per cent of the variations in total GDP in the first year and about 55.9 per cent up to the fifth year. However, in the first quarter, monetary policy shocks account for about 51.4 per cent while its contribution wanes steadily to about 19.6 per cent by the fifth year. The substantial contribution of monetary policy shock to the evolution of output derives from the policy-induced rigidity to domestic prices arising from the fuel subsidy regime. The subsidy regime distorts price signals, which limits the strength of market-driven adjustments mechanisms in the economy and creates added stabilisation roles for monetary policy. Fiscal policy is weak in driving aggregate demand due to the incidence of low domestic revenue mobilisation (arising from revenue substitution) as well as the implications of the inefficient fuel subsidy regime for fiscal budget. Thus, in the face of a contractionary response of output to negative oil price shocks, the central bank faces an output stabilisation objective in addition to its inflation objective. The CBN is also known for its developmental functions that cut across different sectors of the Nigerian economy; including financing growth-enhancing projects in agriculture, manufacturing, power, aviation, entertainment, etc. Table 3.7 also shows that the effect of oil shocks is non-trivial and relatively persistent as they contribute about 26.0 per cent in the first quarter and 22.5 per cent up to the fifth-year.

Headline inflation: The most important shock explaining variations in aggregate inflation (both in the short- and medium-term horizons) relates to monetary policy as it accounts for about 48.9 per cent of the forecast variance in the first quarter and 37.9 per cent up to the fifth year (Table 3.7). This implies that the monetary authority is quite effective in driving inflation dynamics in line with its primary mandate. Furthermore, domestic supply shocks (total factor productivity and domestic risk premium shocks) play a prominent role in explaining variations in aggregate inflation, with its contribution to the forecast variance increasing from 23.8 per cent in the first quarter to about 35.2 per cent by the fifth year. This shows that the effect of domestic supply shocks on the headline inflation is quite persistent.

Core, domestic and imports inflation: Our model set up allows us to disentangle the effects of shocks on the different components of inflation. In Table 3.7, the variance decompositions for core inflation, domestic inflation and imports inflation are reported. Across these three measures, the contributions of domestic shocks are quite dominant and persistent, with the largest effect manifesting in domestic inflation (it accounts for an average of about 84.7 per cent of the forecast variance in domestic inflation in the first 20 quarters). Monetary policy plays a dominant role in explaining variations in core inflation, implying that the CBN is quite successful at driving the dynamics of this measure of inflation both in the short- and medium-term horizons. However, when decomposed into its two components (domestic and imports inflation), we find that the monetary authority has a greater strength in containing imports inflation, probably due to a strong exchange rate channel of monetary policy. For instance, whereas monetary policy explains 32.2 per cent of the forecast variance in imports inflation during the first quarter, its contribution to domestic inflation is lower at about 16.7 per cent.

Real exchange rate: Domestic supply shocks (total factor productivity and domestic risk premium) account for about 50.0 per cent of the total variation in real exchange rate over the 1-5 year horizon.

Table 3.7: Forecast error variance decomposition of endogenous variables

Shock	1 quarter	1 year	2 years	5 years
Variance decomposition of total GDP (% contribution)				
Domestic supply shocks	18.39	46.43	55.80	55.86
External shocks	3.38	2.42	1.95	1.79
Oil shocks	26.00	21.37	20.04	22.53
Monetary policy shocks	51.37	29.46	21.95	19.58
Fiscal policy shocks	0.86	0.33	0.25	0.24
Variance decomposition of exchange rate (% contribution)				
Domestic supply shocks	26.64	48.66	51.54	50.67
External shocks	27.86	16.42	15.41	14.69
Oil shocks	12.42	16.89	17.91	20.51
Monetary policy shocks	33.06	17.98	15.04	14.04
Fiscal policy shocks	0.02	0.06	0.08	0.09
Variance decomposition of interest rate (% contribution)				
Domestic supply shocks	44.43	59.87	63.48	64.21
External shocks	48.22	32.37	29.26	28.57
Oil shocks	0.34	1.55	1.65	1.75
Monetary policy shocks	7.01	6.21	5.60	5.47
Fiscal policy shocks	0.00	0.00	0.00	0.01
Variance decomposition of headline inflation (% contribution)				
Domestic supply shocks	23.76	31.54	34.50	35.18
External shocks	26.93	26.39	25.22	24.89
Oil-related shocks	0.38	1.60	1.79	2.00
Monetary policy shocks	48.92	40.46	38.48	37.92
Fiscal policy shocks	0.00	0.00	0.00	0.00
Variance decomposition of core inflation (% contribution)				
Domestic supply shocks	24.31	32.57	35.42	36.02
External shocks	26.10	25.49	24.21	23.87
Oil-related shocks	1.30	2.67	3.22	3.54
Monetary policy shocks	48.29	39.27	37.15	36.56
Fiscal policy shocks	0.00	0.00	0.00	0.00
Variance decomposition of domestic inflation (% contribution)				
Domestic supply shocks	85.83	84.62	85.14	84.71
External shocks	0.80	1.28	1.37	1.49
Oil-related shocks	2.67	2.89	3.09	3.68
Monetary policy shocks	16.65	11.19	10.37	10.10
Fiscal policy shocks	0.03	0.03	0.02	0.02
Variance decomposition of imports inflation (% contribution)				
Domestic supply shocks	49.38	61.85	66.16	67.27
External shocks	16.71	11.96	10.11	9.54
Oil-related shocks	1.73	2.39	3.72	4.59
Monetary policy shocks	32.17	23.77	19.99	18.58
Fiscal policy shocks	0.02	0.02	0.02	0.02

However, in the first quarter, external shocks (foreign inflation, foreign interest rate and external risk premium shocks) and monetary policy innovations jointly explain about 60.9 per cent of exchange rate variations. Also, oil shocks account for a relatively substantial part of total variations over the horizons considered, ranging from 12.4 per cent in the first quarter to 20.5 per cent up to the fifth year. By the fifth year, oil price shocks constitute the second largest category of shocks explaining the variations in Naira exchange rate, after domestic shocks.

Interest rate: Domestic supply and external shocks are the key drivers of nominal interest rates, jointly accounting for over 90.0 per cent of the forecast variance across all the horizons considered. However, fiscal policy and oil price shocks contribute in a relatively negligible way. This observed behaviour is not unusual for a resource-rich emerging economy desirous of boosting growth; while also seeking to attract foreign capital in a bid to stabilise exchange rate and domestic prices.

Historical decomposition

In this section, the historical decompositions of total GDP, headline inflation, real effective exchange rate and the interest rate over the 2000:Q2 - 2018:Q2 period are presented. We have maintained the grouping of the shocks as in the previous sub-section.

Total GDP: The historical contributions of the five groups of shocks to the evolution of total GDP growth are shown in Figure 3.10. Over the sample period, aggregate output recorded two spikes, both occurring between 2000 and 2005. The first spike, which occurred in the second half of 2001 was largely caused by positive oil price shocks and monetary policy easing by the CBN. Similarly, the second episode of increased output growth occurring during the latter part of 2004 was driven by oil price shocks, monetary policy easing and improved domestic productivity. During the period 2005 - 2010, output growth remained relatively stable and above its average level with monetary policy shocks, domestic supply shocks and oil shocks playing important roles. The first negative output growth recorded over the sample period, which occurred in the third quarter of 2011, is largely explained by the monetary policy tightening of the CBN aimed at containing mounting inflationary pressures that arose in the aftermath of the global financial crisis. Also, domestic supply shocks as well as oil price shocks resulting from a slight dip in the international price of oil contributed to the negative output growth outcomes of 2011.

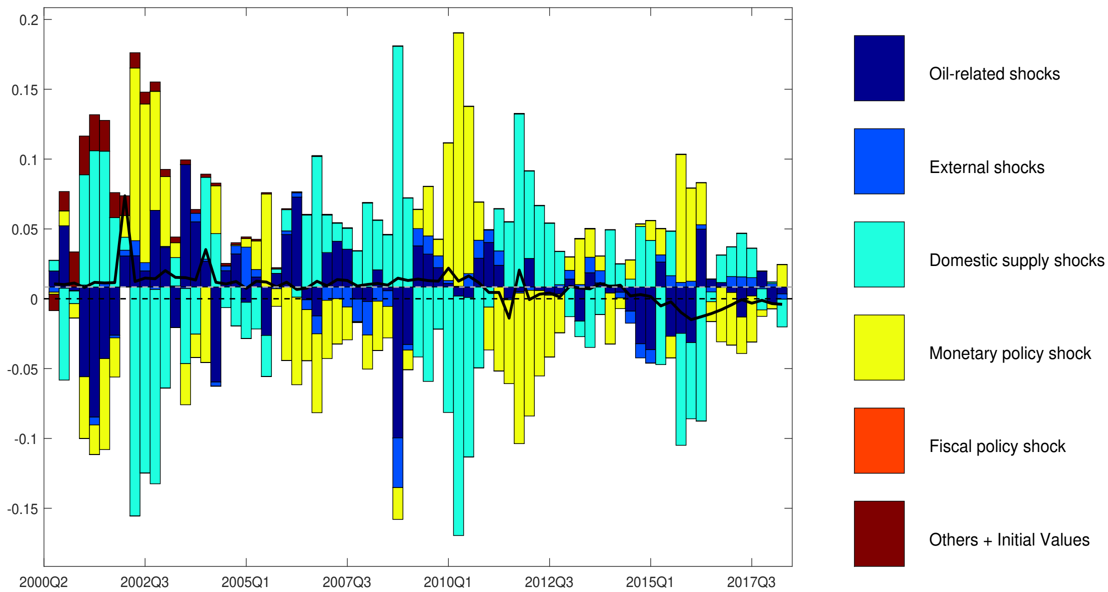

Figure 3.10: Historical decomposition of output

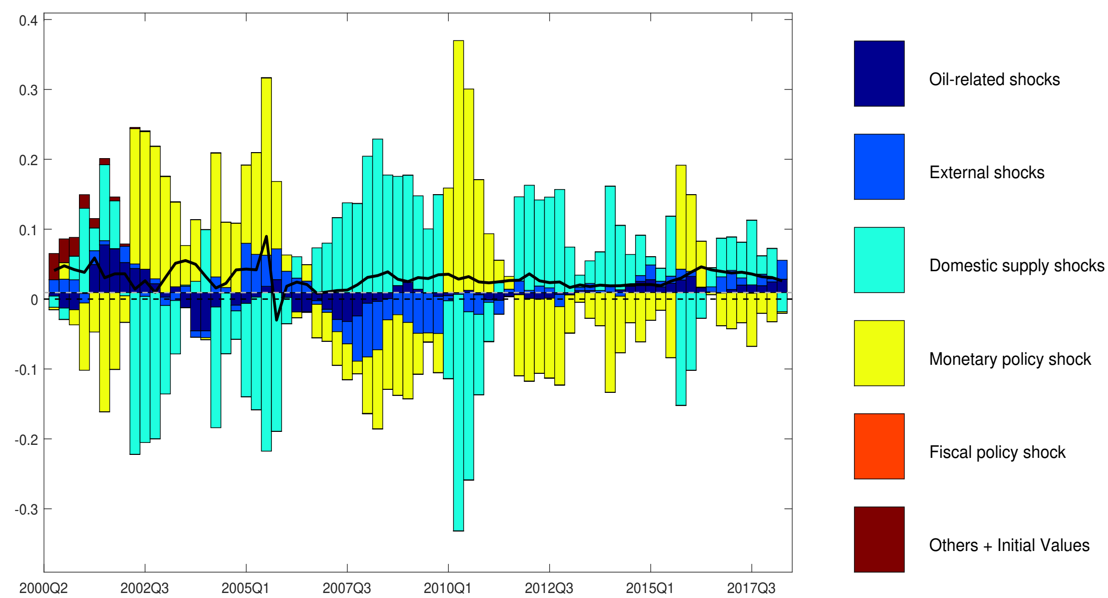

Figure 3.11: Historical decomposition of headline inflation

The declining output growth, which started gradually in 2014 and led into a recession in 2016 is principally explained by oil price shocks and domestic supply shocks while monetary policy seems to play a stabilising role during the period. The negative oil price shock of the period 2014-2016 led to lower oil earnings, rapid depletion in the country's foreign exchange reserves and caused severe foreign exchange supply constraints. Thus, the negative domestic supply shocks experienced during the recession was largely driven by lower total factor productivity of domestic firms, occasioned partly by their inability to source foreign exchange to import necessary production inputs. A striking observation from the analysis of the historical decomposition of output growth during the sample period is that the two negative growth outcomes were partially explained by oil price shocks.

Headline inflation: Figure 3.11 shows the historical decomposition of aggregate inflation. Overall, monetary and domestic shocks largely account for the evolution of CPI inflation during the sample period. While oil-related shocks played prominent roles during the period 2000-2010, monetary and domestic supply shocks are more predominant in the period 2011-2018. The increased inflationary trend experienced during the 2004-2005 period is attributable to negative domestic supply shocks as well as external and monetary policy shocks. Towards the end of the sample period, aggregate inflation declined steadily in response to a hawkish monetary policy stance of the CBN, aimed at counteracting the inflationary effect of exchange rate depreciation recorded during the period.

Real exchange rate: Oil-related shocks as well as monetary policy innovations played non-trivial roles in the evolution of real exchange rate during the sample period. Prior to the 2008/09 global financial crisis, the exchange rate exhibited high volatility, which was mainly attributable to oil shocks and domestic supply shocks (i.e. total factor productivity). The sharp depreciation recorded during the global financial crisis was subsequently met with higher oil prices and monetary policy tightening by the CBN. Thus, a combination of favourable oil prices and positive monetary policy innovations explained the appreciation of the exchange rate between 2009 and 2010. Subsequently, the exchange rate remained relatively stable till the first half of 2015 when a sharp depreciation was again recorded, owing to oil shocks, domestic supply innovations and external shocks. The massive depreciation in the exchange rate in the period 2015-17 is principally explained by domestic supply shocks and oil-related disturbances. During this period, the oil price crashed from about US$102/barrel in the third quarter of 2014 to US$50/barrel in the second quarter of 2017.

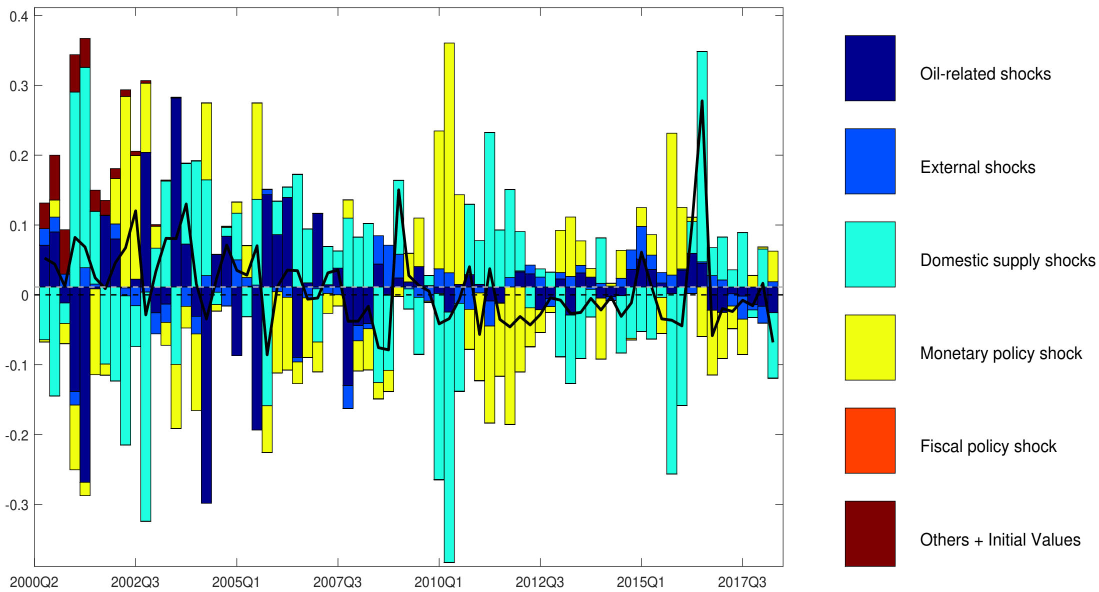

Figure 3.12: Historical decomposition of real exchange rate

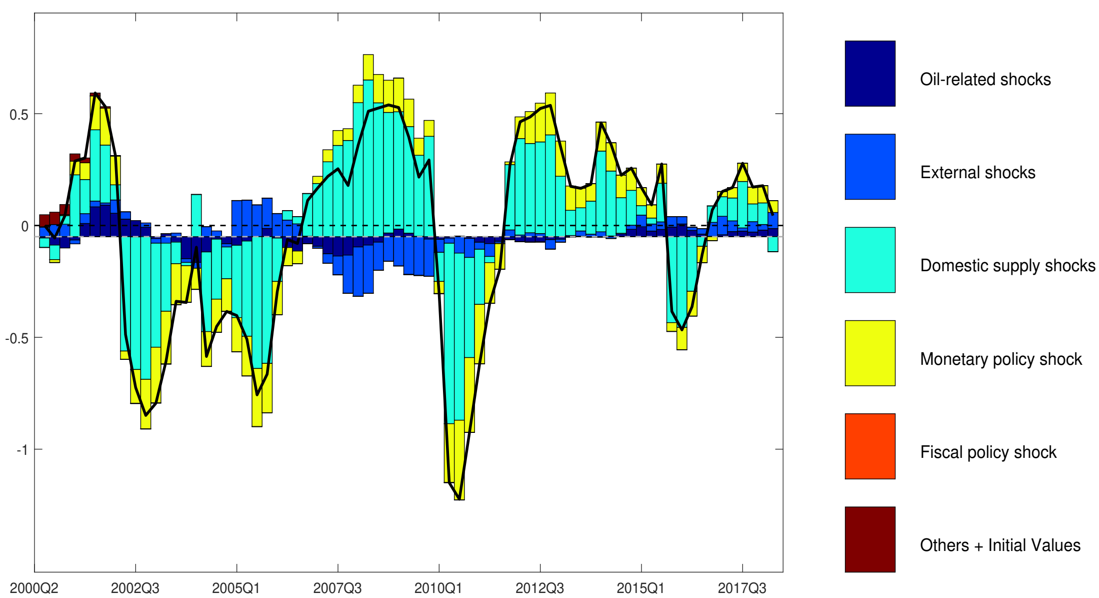

Figure 3.13: Historical decomposition of interest rate

The consequent reduction in oil earnings during the period led to scarcity of foreign exchange and substantial depletion in the country's stock of external reserves. Faced with a near currency crisis situation, the CBN devalued the domestic currency (Naira) and restricted certain categories of importers from accessing the official window for foreign exchange supply. Some stability was subsequently restored to the foreign exchange market owing to a rebound in the price of crude oil in the third quarter of 2017 and the hawkish monetary policy stance of the CBN during the period.

Interest rate: The historical decomposition of interest rate over the sample period is shown in Figure 3.13. Similar to the findings of Hollander et al. (2018) for the South-African economy, our results indicate that monetary policy and domestic supply (largely risk premium shocks) shocks play non-trivial roles in the evolution of the nominal interest rate. In addition, external shocks (i.e. foreign inflation and external risk premium shocks) play relatively significant roles in explaining the hawkish monetary policy stance of the CBN during the period of the global financial crisis.

3.6.5 Monetary policy analysis

In this section, we analyse the dynamic responses of selected macroeconomic variables to a negative oil price shock under four alternative monetary policy rules. These are: (i) total inflation-based policy rule, (ii) core inflation-based policy rule, (iii) domestic inflation-based policy rule, and (iv) an export-price-based monetary policy rule of Frankel (2003). The monetary policy reaction functions corresponding to the alternative rules are specified in Table 3.3.

Figure 3.14 shows the impulse responses of the economy to 1.0 per cent negative international oil price shock under the alternative monetary policy rules. With the exception of the outcomes recorded under an export price-based Taylor rule, a negative shock to the international price of oil yields a highly persistent contractionary effects on total GDP, lasting over 40 quarters. Headline inflation rises upon impact owing to the higher imported inflation caused by the depreciated real exchange rate. A negative oil price shock causes real marginal cost to fall, leading to a decline in domestic inflation and an increase in domestic output. These observed model dynamics are qualitatively similar under the headline, core and domestic inflation-based policy rules, with only a few exceptions.

In quantitative terms, the domestic inflation-based Taylor rule outperforms its headline and core inflation counterparts in terms of boosting total GDP, domestic output and private consumption following a negative oil price shock. On the other hand, both the core inflation-based monetary policy rule and its headline inflation counterpart yield larger contractions in total GDP following a negative shock to international oil price (Figure 3.14). The relatively worse outcomes in output under the core and headline inflation-based Taylor rules are due to the immediate contractionary monetary policy action taken by the central bank following the oil shock (Bernanke et al., 1997). However, under the domestic inflation-based Taylor rule, a negative oil price shock requires an interest rate cut. Such expansionary monetary policy helps to ameliorate the contraction in aggregate GDP arising from the adverse oil price shock. Also, higher levels of domestic output (non-oil GDP) and private consumption are recorded under the domestic inflation-based monetary policy rule.

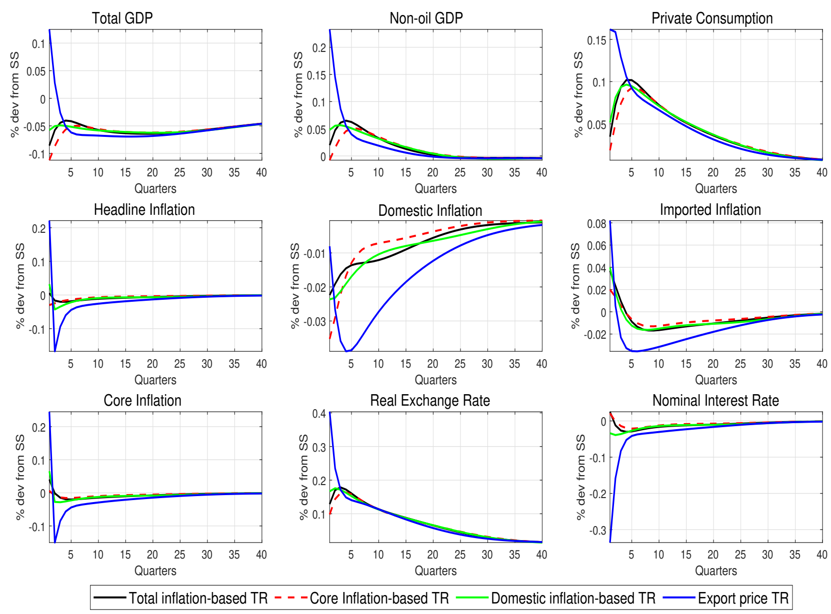

Figure 3.14: Estimated impulse responses to a negative international oil price shock under alternative monetary policy rules

Furthermore, Figure 3.14 shows that 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 an export price-based Taylor rule that features domestic output and the export price of oil reverses the contractionary effects of a negative terms of trade shock recorded under the other rules. It however amplifies the initial increase in headline inflation due to a more depreciated real exchange rate and a higher exchange rate pass-through into inflation (Figure 3.14). 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.

Furthermore, we conduct policy ranking based on a measure of systemic stability represented by an inter-temporal loss function of the central bank. As indicated by Woodford (2002), 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. Thus, following Hunt (2006); Laxton and Pesenti (2003); Nisticò (2012) and Hove et al. (2015), we assume that the central bank's inter-temporal loss can be defined as a discounted weighted sum of the unconditional variances of inflation, output and real exchange rate changes as follows:

$$Loss_0 = E_o \sum_{t=0}^{\infty} \beta^t \left[\widetilde{\pi}_t^2 + \lambda_q \Delta \widetilde{q}_t^2 + \lambda_y \widetilde{y}_{h,t}^2 \right], \tag{3.94}$$

where $\lambda_y \geq 0$ and $\lambda_q \geq 0$ are parameters representing the degree of central bank's dislike for output volatility, $\widetilde{y}_t^2$, and real exchange rate variability, $\Delta\widetilde{q}_t^2$, respectively. The first two terms in equation (3.94) represent the costs associated with nominal fluctuations while the third term stands for the costs associated with real fluctuations (Taylor and Williams, 2010).

Panel (A) of Table 3.8 reports macroeconomic fluctuations associated with alternative monetary policy rules under a model with fuel subsidies. The corresponding optimised simple rule parameters are reported in Table 3.9. In terms of output stabilisation, the domestic inflation-based rule yields superior outcomes compared to the other competing rules. However, it yields inferior outcomes in terms of price, exchange rate and interest rate stabilisation. Following a negative oil price shock, the core inflation-based Taylor rule is useful for stabilising prices (headline inflation, core inflation, real exchange rate, and interest rate) followed by the total inflation-based monetary policy rule. Thus, while the core inflation-based Taylor rule represents a useful strategy for stabilising the nominal variables in the aftermath of an oil price shock, its domestic inflation-based counterpart yields superior outcomes in terms of output stabilisation.

The export price targeting rule, though useful for managing the contractionary effects of a negative oil price shock on output (Figure 3.14), generates a fairly elevated domestic macroeconomic instability (Table 3.8). These findings are consistent with the simulation results of Vogel et al. (2015), which showed that pegging the export price comes at the cost of loosing overall domestic stability. Also, while the domestic inflation-based Taylor rule ameliorates the contractionary impact of a negative oil price shock on output (Figure 3.14), it generates a relatively higher level of macroeconomic instability compared to the other rules.

In panel (B) of Table 3.8, we report the macroeconomic fluctuations and policy losses associated with the alternative monetary policy rule under a model that allows for complete pass-through of international oil price to domestic fuel price - i. e. absence of fuel subsidy. The domestic inflation-based Taylor rule retains its usefulness as a strategy for stabilising aggregate output, even after a potential fuel subsidy reform. Also, as found under the subsidy regime, the core inflation-based monetary policy rule yields superior outcomes in stabilising core inflation, real exchange rate and interest rate under the no-subsidy regime. However, while the core inflation-based Taylor rule out-performs its headline inflation counterpart in stabilising total inflation under the subsidy regime, a monetary policy rule that features a broader measure of inflation (i.e. headline inflation-based Taylor rule) yields superior outcomes under a no-subsidy regime. The effectiveness of core inflation based Taylor is called to question once domestic price rigidity induced by the fuel subsidy regime is removed.

Table 3.8: Macroeconomic fluctuations and losses under alternative monetary policy rules

Monetary policy rules	*Standard Deviations (%)*					Policy loss
	$\widetilde{y}_t$	$\widetilde{\pi}_t$	$\widetilde{\pi}_{no,t}$	$\widetilde{q}_t$	$\widetilde{R}_t$	
(A) Policy ranking under a model with fuel consumption subsidy						
Headline inflation-based rule	0.1728	0.0018	0.0042	0.3238	0.0055	0.0208
Core inflation-based rule	0.1831	0.0015	0.0009	0.2983	0.0026	0.0151
Domestic inflation-based rule	0.1696	0.0049	0.0080	0.3259	0.0060	0.0252
Export-price-based rule	0.2034	0.0083	0.0048	0.2690	0.0040	0.0161
(B) Policy ranking under a model outwith fuel consumption subsidy						
Headline inflation-based rule	0.1789	0.0018	0.0061	0.3353	0.0059	0.0242
Core inflation-based rule	0.1872	0.0051	0.0007	0.3050	0.0022	0.0199
Domestic inflation-based rule	0.1769	0.0020	0.0086	0.3410	0.0082	0.0268
Export-price-based rule	0.2048	0.0109	0.0053	0.2819	0.0054	0.0203

In the last column of Table 3.8, we report policy losses associated with the alternative monetary policy rules considered in this paper. 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 is followed by the export-price-based monetary policy rule with a loss function value of 0.0161. The worst performer is the domestic inflation-based Taylor rule. 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 like Nigeria, exchange rate plays a vital role in driving inflation dynamics. Thus, an inflation measure that ignores the effects of exchange rate may not represent an appropriate anchor for monetary policy design in such economies. Also, as shown in panels (A) and (B) of Table 3.9, the core inflation-based Taylor rule assigns higher weight to real exchange rate than its domestic inflation-based counterpart. In Table 3.8, we demonstrate that the policy rankings are not sensitive to alternative assumptions regarding the degree of pass-through from international oil price to domestic prices. In other words, the core inflation-based monetary policy rule ranks best regardless of whether we feature fuel subsidies in our model or not. However, we note that the core inflation-based Taylor rule exhibits higher interest rate inertia and assigns greater weights to output following a fuel subsidy reform (Table 3.9). On the other hand, it places less weights on inflation and real exchange rate compared to the values recorded under the model with a subsidy regime.

Table 3.9: Optimised simple rule parameters

Parameters	ρ_r	ω_π	ω_y	ω_q	Policy loss
(A) Optimised policy parameters under fuel consumption subsidy					
Total inflation-based rule	0.2408	2.8660	0.1262	0.0478	0.0208
Core inflation-based rule	0.2286	2.8626	0.1125	0.0402	0.0151
Domestic inflation-based rule	0.2680	2.8555	0.1195	0.0317	0.0252
Export-price-based rule	0.9688	2.5431	0.6824	0.1092	0.0161
(B) Optimised policy parameters in the absence of fuel consumption subsidy					
Total inflation-based rule	0.2424	2.8610	0.1238	0.0405	0.0242
Core inflation-based rule	0.2311	2.8617	0.1174	0.0326	0.0199
Domestic inflation-based rule	0.2971	2.8451	0.1465	0.0233	0.0268
Export-price-based rule	0.9598	2.5398	0.7565	0.1092	0.0203

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 Central Bank of Nigeria faces a trade-off in the achievement of price stability and output growth following a negative shock to international oil price. It is important that the CBN is aware of these policy trade-offs while designing monetary policy strategies for responding to emerging shocks. Also, 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.

3.6.6 Macroeconomic implications of fuel subsidy

In this sub-section, we simulate two economies based on different assumptions regarding the size of the pass-through effect of international oil price into the retail price of fuel. The first economy is based on our empirical model under which the pass-through parameter is estimated at $\nu = 0.43$. The second economy is based on a model simulated under an assumption of complete pass-through, such that $\nu = 1$ (i.e. a no subsidy regime). The responses of the economy to 1.0 per cent negative shock to real international oil price under these two alternative economies are presented in Figure 3.15.

Following a 1.0 per cent negative real oil price shock, aggregate GDP in the domestic economy contracts under both models. However, the contraction under a model with fuel subsidies ($\nu = 0.43$) is more severe in the short run. In other words, removing the fuel subsidy ameliorates the contractionary effects of a negative oil price shock on output in the small open resource-rich economy. Non-oil GDP increases in the aftermath of a negative oil price shock due to the associated lower real marginal cost faced by the firms as well as the increased aggregate demand arising from additional income that is available to households. Also, the amplified terms of trade effects arising from lower domestic prices boosts private consumption and non-oil GDP. Thus, private consumption rises. As found for aggregate GDP, the model without fuel subsidies ($\nu = 1$) generates higher growth in non-oil GDP and private consumption. In other words, the increases in non-oil output and private consumption associated with a negative oil price shock are higher under an economy without fuel subsidies, compared to the case for an economy with a fuel subsidy regime. These results are in line with the findings of Siddig et al. (2014). Thus, in response to a negative oil price shock, the economy with a fuel subsidy regime records higher decline in total GDP, lower private consumption and higher aggregate inflation in the short run. The initial higher output loss and increased headline inflation under the model with fuel subsidy may not be unconnected with the inefficiencies usually associated with energy price subsidy programmes in oil-producing emerging economies (Clements, Mooij, Gupta and Keen, 2015).

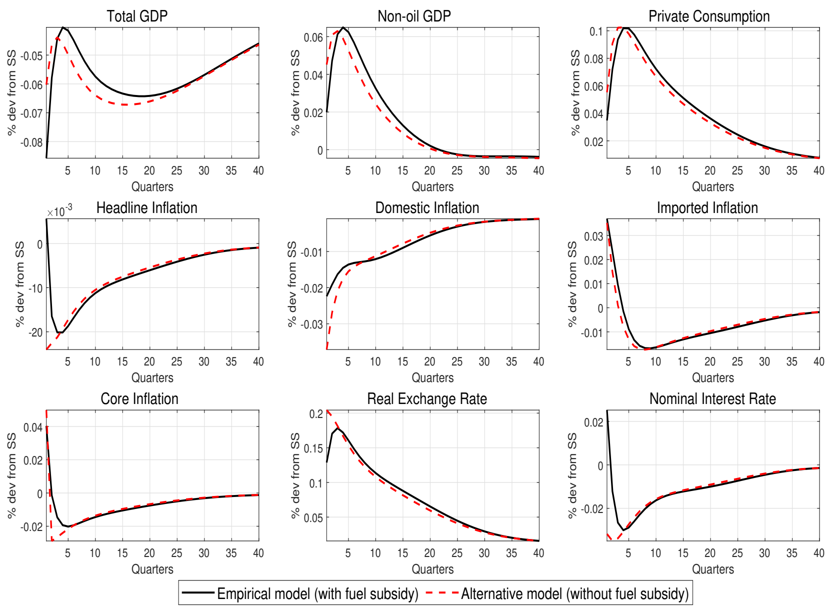

Figure 3.15: Estimated impulse responses to negative international oil price shock under the estimated and alternative domestic fuel pricing rules

Given a negative oil price shock, Figure 3.15 shows that domestic inflation declines more under a model without fuel subsidies ($\nu = 1$), owing to the complete pass-through effect of international oil prices into the retail price of fuel. The effects of the negative oil price shock are fully reflected in firms' real marginal cost, leading to a downward adjustment in the prices of domestically produced goods. In other words, the fuel subsidy regime adds additional stickiness to the evolution of domestic prices, which causes domestic inflation to be rigid downwards in the face of a negative oil price shock. The behaviour of imported and core measures of inflation are quite similar in both qualitative and quantitative terms. However, the immediate impact of a negative oil price shock on headline inflation differs under the two models. Upon impact, headline inflation declines under the model without fuel subsidy while the decline is delayed under the empirical model. The delayed response of headline inflation under the model with fuel subsidy can be explained by the low pass-through effect of international oil price to domestic prices. Though the real exchange rate depreciates more under the model without fuel subsidies, the inflationary impacts of such depreciation on headline inflation is more than offset by the reduction in domestic inflation under such a regime (i.e. $\nu = 1$). On the other hand, the inflationary effects of exchange rate depreciation cause headline inflation to rise under the economy with fuel subsidies ($\nu = 0.43$) since domestic inflation is sticky downwards.

Consequently, the monetary authority of the economy with a fuel subsidy regime increases interest rate following a negative oil price shock, a move that pushes the economy further into recession (Figure 3.15). On the other hand, the monetary authority of an economy without a fuel subsidy regime faces no inflation threats following a negative oil price. It, therefore, cuts rates in order to boost aggregate demand and increase domestic output. Of course, such a move causes an immediate exchange rate overshooting as against the case under the benchmark model where a delayed overshooting is observed (Figure 3.15). These results provide useful insights into the macroeconomic implications of potential fuel subsidy reforms in Nigeria.

Table 3.10: Variances of selected variables under alternative fuel pricing rules

Model	Empirical model ($\nu = 0.43$)	Alternative model ($\nu = 1$)
Aggregate GDP	0.1769	0.1841
Non-oil GDP	0.0281	0.0245
Private consumption	0.1060	0.1016
Headline inflation	0.0033	0.0038
Core inflation	0.0055	0.0076
Domestic inflation	0.0032	0.0046
Imported inflation	0.0058	0.0053
Real exchange rate	0.3208	0.3307
Interest rate	0.0076	0.0089

Furthermore, we investigate the level of macroeconomic instabilities associated with fuel subsidy removal by reporting the variances of selected macroeconomic variables under the empirical ($\nu = 0.43$) and alternative ($\nu = 1$) models in Table 3.10. It can be seen from the table that, given an oil price shock, the alternative model is associated with slightly higher volatility in aggregate GDP, headline inflation, core inflation, domestic inflation, real exchange rate, and the nominal interest rate. On the other hand, non-oil GDP, private consumption, and imported inflation are insignificantly less volatile under a no subsidy regime.

Overall, the results of our counterfactual simulations indicate that the extant fuel subsidy regime in Nigeria has non-trivial implications for the economy's response to an oil price shock. In view of the macroeconomic instabilities observed under the alternative model, this paper cautions that potential future subsidy reforms must be cautiously implemented.

Table 3.11: Variances of selected variables in the absence of fuel price subsidies

Fuel subsidy	Hand-to-mouth	Total GDP	Headline inflation	Interest rate	RER
No	Yes	0.1841	0.0038	0.0089	0.3307
No	No	0.1818	0.0038	0.0103	0.2801

Next, we investigate whether the presence of hand-to-mouth consumers aggravate the macroeconomic fluctuations associated with potential fuel subsidy reforms. Table 3.11 presents the variances of selected endogenous variables following a 1.0 per cent negative oil price shock under two alternative models - i.e. with and without hand-to-mouth consumers. Our results show that in the absence of fuel subsidies, the GDP and real exchange rate are less volatile under the model without hand-to-mouth consumers. In other words, the oil-producing emerging economy with a significant amount of hand-to-mouth consumers is likely to experience greater macroeconomic instabilities in the aftermath of a fuel subsidy removal. This result has implications for financial inclusion programmes being implemented by resource-rich countries as well as the sequencing of energy subsidy reforms in those economies.

3.6.7 Oil price shock and fiscal cyclicality

In this subsection, we examine the implications of fiscal cyclicality for the response of the economy to an oil price shock under a total inflation-based Taylor rule. To this end, we simulate two economies: (i) the empirical model, which is based on the estimated fiscal cyclicality parameter of $\omega_{gy} = 0.35$, implying fiscal pro-cyclicality; and (ii) an alternative model, which is based on a fiscal cyclicality parameter of $\omega_{gy} = -0.35$, implying a counter-cyclical fiscal policy. Figure 3.16 shows the responses of selected endogenous variables to a negative international oil price shock under these two fiscal policy regimes. Quite noticeable departures are found in the responses of GDP, domestic output, private consumption, domestic inflation and the exchange rate. In terms of output, a counter-cyclical fiscal policy ameliorates the contractionary effects of a negative oil price shock on GDP while also generating higher domestic output. However, lower private consumption is recorded in about the fourth quarter, probably due to some crowding out effects of government consumption.

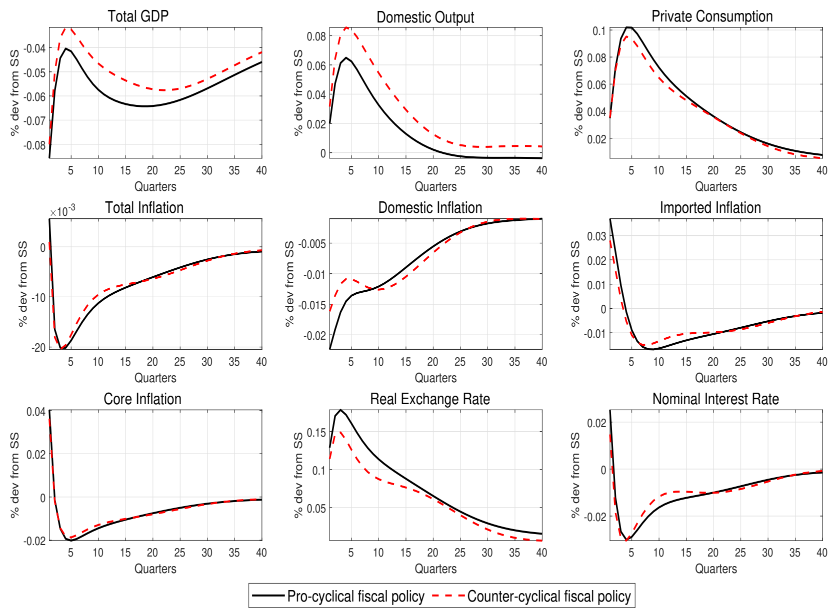

Figure 3.16: Estimated impulse responses to negative international oil price shock under different stance of fiscal policy

In addition, a counter-cyclical fiscal policy stance generates lower exchange rate depreciation in the aftermath of a negative oil price shock. Upon impact, a 1.0 per cent negative shock to real international oil price causes domestic inflation to decline by 2 basis points under a pro-cyclical fiscal policy and 1.5 basis points under a counter-cyclical fiscal policy (this is attributable to the inflationary pressures generated by the counter-cyclicality of government spending in response to falling total GDP).

Table 3.12: Variances of selected variables under alternative fiscal policy regimes

Model	Total GDP	Total inf.	Int. rate	RER	Core inf.	Consumption
$\omega_{gy} = 0.35$	0.1769	0.0033	0.0076	0.3208	0.0055	0.1060
$\omega_{gy} = -0.35$	0.1408	0.0030	0.0063	0.2147	0.0047	0.0907

Table 3.12 shows that, following a negative oil price shock, lower macroeconomic instabilities are recorded under a counter-cyclical fiscal policy. These results suggest that monetary

policy may be more successful at stabilising both prices and output under a counter-cyclical fiscal regime. Thus, our results support the view that there are gains from counter-cyclical fiscal policy measures in resource-rich emerging economies facing an adverse terms of trade shock.

3.6.8 Role of hand-to-mouth consumers

In order to assess the implications of hand-to-mouth consumers for our model dynamics, we re-estimated the model parameters with the assumption that all consumers are Ricardian. Table 3.13 shows the estimated parameters. First, the parameters in the utility function - relative risk aversion and labour supply elasticity, are slightly higher under the model without hand-to-mouth consumers. These are in line with the findings reported by Iklaga (2017). Also, the estimated consumption habit parameter is higher under the model without hand-to-mouth consumers. Second, the Calvo price parameter is higher for domestic goods than imported goods across the two models.

Third, the central bank focuses less on inflation under the model without hand-to-mouth consumers ($\omega_\pi = 2.81$) compared to the outcomes under the model with hand-to-mouth consumers ($\omega_\pi = 2.86$). However, the central bank reaction coefficients to output and exchange rate are higher under the model without hand-to-mouth consumers. These imply that monetary policy responds less to inflation but more to output and exchange rate under the model where all the agents are Ricardian. Fourth, in terms of fiscal policy, the estimated fiscal cyclicality parameter shows that government spending is more pro-cyclical under the model with hand-to-mouth consumers. Fifth, both monetary and fiscal policy are less persistent under the model with non-Ricardian consumers. While the estimated standard deviation of external shock variables are similar across the two models, most of the domestic shock variables exhibit higher standard deviations under the model without hand-to-mouth consumers.

Next, we analyse the implications of the presence of hand-to-mouth consumers for the responses of selected endogenous variables to three exogenous disturbances relating to oil price, monetary policy and fiscal policy. In Figure 3.17, we present the impulse responses to 1.0 per cent negative international oil price shock under the model with and without hand-to-mouth consumers. The model dynamics are qualitatively similar under the two models. However, the present of hand-to-mouth consumers seem to amplify the contractionary effects of a negative oil price shock on output.

Table 3.13: Priors and posterior estimates for model with and without hand-to-mouth consumers

Parameter	Hand-to-mouth			No hand-to-mouth		
	Mean	90% HPD Int.		Mean	90% HPD Int.	
Structural parameters						
Ricardian consumers: γ_R	0.692	0.562	0.824	1.000	-	
Labour supply elasticity: φ	1.439	1.274	1.600	1.449	1.287	1.614
Relative risk aversion: σ	1.409	1.109	1.694	1.423	1.124	1.710
External habit: ϕ_c	0.438	0.310	0.568	0.439	0.309	0.569
Investment adj. cost: χ	6.181	1.751	10.490	6.460	1.888	10.872
Fuel pricing parameter: ν	0.429	0.190	0.640	0.420	0.198	0.624
Oil - core cons. elasticity: η_o	0.188	0.044	0.328	0.198	0.045	0.344
For. - dom. cons. elasticity: η_c	0.609	0.287	0.926	0.600	0.280	0.910
For. - dom. inv. elasticity: η_i	0.615	0.286	0.933	0.602	0.276	0.912
Calvo - domestic goods: θ_h	0.719	0.620	0.826	0.782	0.672	0.896
Calvo - imported goods: θ_f	0.691	0.525	0.860	0.696	0.533	0.865
Policy parameters						
Taylor, π: ω_π	2.857	2.579	3.141	2.810	2.495	3.141
Taylor, y: ω_y	0.118	0.043	0.191	0.131	0.047	0.213
Taylor, q: ω_q	0.109	0.040	0.176	0.123	0.045	0.198
Fiscal, yo: ω_{yo}	0.351	-0.470	1.184	0.339	-0.490	1.172
Autoregressive coefficients of shocks						
Dom. productivity: ρ_{a_h}	0.771	0.593	0.957	0.596	0.206	0.921
Oil productivity: ρ_{a_0}	0.502	0.100	0.905	0.502	0.109	0.913
Dom. risk premium: ρ_μ	0.786	0.703	0.871	0.767	0.677	0.859
Dom. fiscal policy: ρ_{g_c}	0.487	0.073	0.896	0.502	0.105	0.931
Law of one price gap-oil: ρ_{ψ^o}	0.608	0.250	0.957	0.591	0.262	0.894
Dom. monetary policy: ρ_r	0.224	0.054	0.382	0.249	0.072	0.415
Int'l oil price shock: $\rho_{p_o^*}$	0.923	0.827	0.987	0.926	0.870	0.989
For. risk premium: ρ_{μ^*}	0.859	0.790	0.929	0.861	0.791	0.933
For. inflation: ρ^{π^*}	0.138	0.001	0.257	0.138	0.001	0.257
For. monetary policy: ρ_{r^*}	0.442	0.303	0.584	0.440	0.299	0.582
Standard deviation of shocks						
Dom. productivity: $\xi_t^{a_h}$	0.246	0.105	0.407	0.685	0.127	1.739
Oil productivity:$\xi_t^{a_o}$	0.076	0.024	0.133	0.080	0.023	0.146
Dom. risk premium: ξ_t^{μ}	0.162	0.132	0.192	0.167	0.134	0.200
Dom. fiscal policy:$\xi_t^{g_c}$	0.098	0.023	0.177	0.083	0.023	0.152
Law of one price gap-oil: $\xi_t^{\psi^o}$	0.904	0.444	1.490	0.897	0.457	1.431
Dom. monetary policy: ξ_t^{r}	0.379	0.300	0.455	0.371	0.292	0.448
Int'l oil price shock: $\xi_t^{p_o^*}$	0.151	0.130	0.171	0.151	0.130	0.171
For. risk premium: $\xi_t^{\mu^*}$	0.041	0.032	0.050	0.041	0.032	0.050
For. inflation: $\xi_t^{\pi^*}$	0.005	0.004	0.006	0.005	0.004	0.006
For. monetary policy: $\xi_t^{r^*}$	0.101	0.079	0.121	0.101	0.079	0.122

In other words, the presence of hand-to-mouth consumers in our model generates deeper recessions following a negative oil price shock. This finding implies that financial inclusion programmes are capable of boosting economic resilience and growth in oil-producing emerging economies facing negative terms of trade shocks (Sethi and Acharya, 2018).

Furthermore, following a negative oil price shock, the model with hand-to-mouth consumers generates lower domestic prices but higher exchange rate depreciation in about the first two quarters. Thus, inflationary pressures resulting from exchange rate depreciation are ameliorated under the model without hand-to-mouth consumers. Figure 3.18 shows that, under the model with hand-to-mouth consumers, private consumption rises in response to a positive fiscal policy shock. However, the model without hand-to-mouth consumers generates a negative response of private consumption to a government spending shock. Thus, under our model set up, we confirm Galí et al. (2007)'s proposition that incorporating non-Ricardian consumers help generate a positive response of private consumption to a positive government spending shock. Turning to the implications of the presence of hand-to-mouth consumers for the model response to monetary policy shocks, Figure 3.19 indicates very minor departures across the selected endogenous variables, with the exception of private consumption.

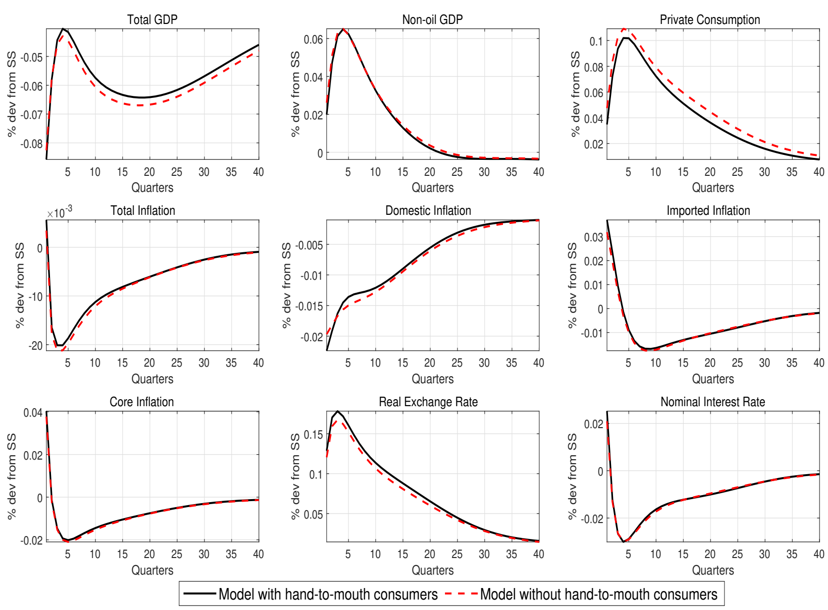

Figure 3.17: Estimated impulse responses to negative international oil price shock under a model with and without hand-to-mouth consumers.

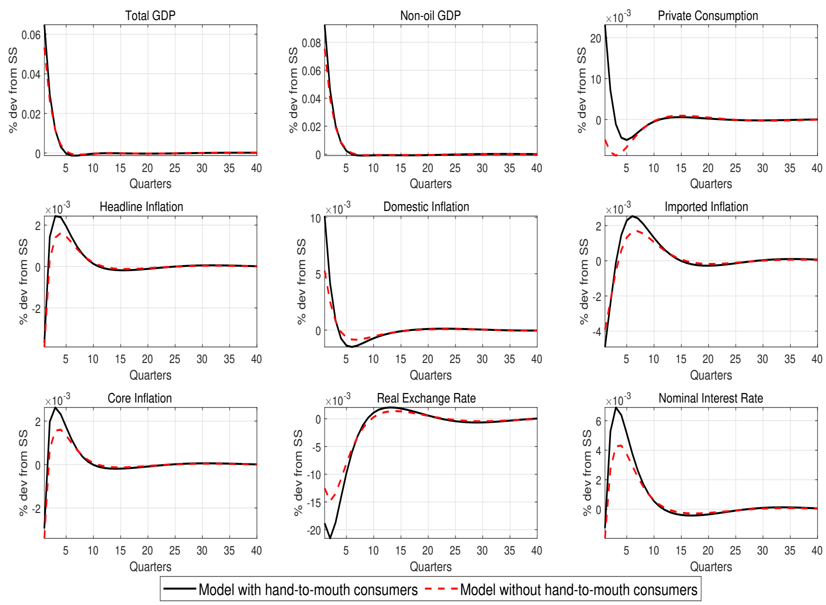

Figure 3.18: Estimated impulse responses to government spending shock under a model with and without hand-to-mouth consumers.

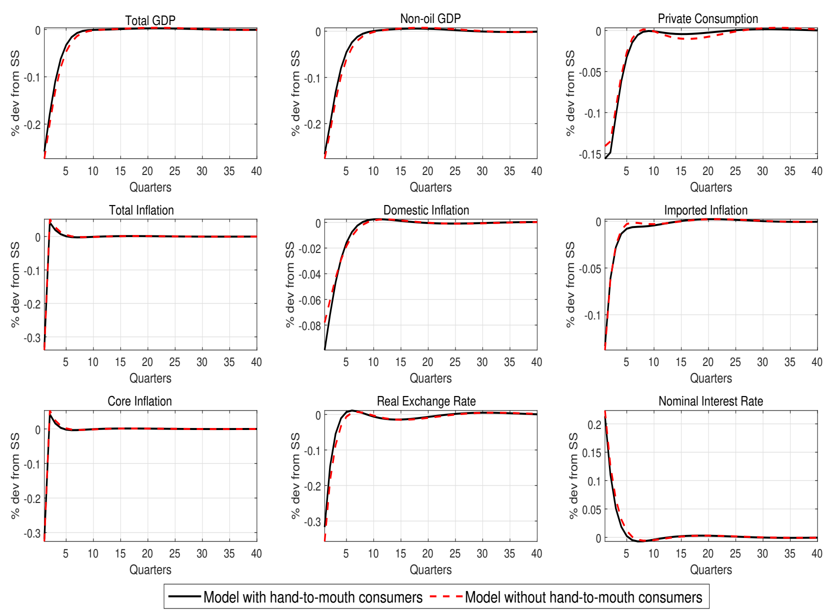

Figure 3.19: Estimated impulse responses to a monetary policy shock under a model with and without hand-to-mouth consumers.

In Figure 3.19, the responses of the economy to a positive monetary policy shock are qualitatively similar under the model with and outwith hand-to-mouth consumers. However, a positive monetary policy shock causes bigger reduction in private consumption under the model with hand-to-mouth consumers while domestic inflation declines more. Upon impact, the contractionary monetary policy causes aggregate private consumption to decline more under the model with hand-to-mouth consumers as fewer people are able to smoothen their consumption. This implies a larger reduction in the demand for domestic goods, which causes domestic inflation to fall more compared to the case under the model outwith hand-to-mouth consumers.

3.7 Conclusion

In this paper, we investigate the roles of oil price shocks and fuel subsidies in driving business cycles of a resource-rich emerging economy. We set up a suitable TANK model that takes cognisance of a number of important features. These include (i) additional price rigidity arising from a fuel subsidy regime (ii) high dependence on oil (iii) presence of hand-to-mouth consumers (iv) oil-driven fiscal policy and (v) inefficient financial sector. The model is estimated via Bayesian method using Nigerian data for the period 2000:Q2-2018:Q2. Based on the estimated model, we analyse business cycle fluctuations in the resource-rich economy; evaluate the relevance of certain model features, including the fuel subsidy regime; and conduct some monetary policy exercises.

We find that monetary policy shocks and oil price movements are important drivers of output in the short run (1-4 quarters) while domestic supply shocks (such as, productivity and domestic risk premium shocks) explain most of the fluctuations in the medium- to long-term horizons. Particularly, the contribution of oil shocks to output variations is about 21 per cent in the short run, while they also account for about 23 per cent by the twentieth quarter.

On the other hand, inflation dynamics are largely driven by monetary policy and domestic supply shocks both in the short- and medium-term horizons. In particular, monetary policy shock plays a dominant role in explaining the forecast variance of headline and core inflation as it contributes an average of about 38.0 and 36.6 per cent, respectively, up to the fifth year. This tends to imply that monetary policy is active in containing inflationary pressures during the sample period. However, oil shocks play a less prominent role due to the low pass-through effects arising from the extant fuel subsidy regime in the country. A further disaggregation of core inflation into its domestic and imported components shows that monetary policy contributes more to the evolution of the latter than the former. In terms of historical decomposition, we find that episodes of output contractions over the sample period (including the 2016 economic recession) are generally associated with oil and domestic supply shocks. Also, the high inflationary episode of 2004-2005 is attributable to negative domestic supply shocks as well as external and monetary policy shocks.

A negative international oil price shock generates non-trivial and persistent contractionary impacts on total output (GDP), lasting over 40 quarters. The oil firm's profit declines in response to lower oil prices, leading to a reduction in its demands for capital and material inputs as well as a fall in oil revenues available to government. Domestic output falls initially owing to the reduced demand for materials produced by domestic non-oil producing firms. The non-oil goods producing firms in turn reduce their input demand; which, coupled with lower oil prices, lead to lower marginal cost. Thus, domestic inflation falls while imported inflation rises due to the depreciation of the exchange rate. However, private consumption of domestic goods rises due to increased terms of trade which causes domestic goods to be cheaper compared to imported goods. Following a negative oil price shock, domestic inflation-based monetary rule requires an interest rate cut while its core and headline inflation counterparts elicit a contractionary monetary policy. Thus, the domestic inflation-based Taylor rule ameliorates the contractionary impact of a negative oil price shock on output while the core inflation-based variant is more successful at moderating the associated headline inflation and exchange rate depreciation.

We estimate that about 43 per cent of changes to international oil prices is transmitted into domestic fuel price in Nigeria. The presence of fuel subsidy adds additional stickiness to domestic prices which in turn alters the dynamics of aggregate inflation and indeed, the response of monetary policy to an oil price shock. Having shown that the size of the pass-through parameter governs the dynamics of fuel subsidy payments, we simulate two models based on different assumptions regarding the parameter. Our results show that the contractionary effects of a negative oil price shock on output is ameliorated under the model without fuel subsidies. Abolishing the fuel subsidy regime has fiscal, growth, and welfare implications. We caution that future reforms must necessarily accommodate the deployment of well-targeted safety nets as well as the evolution of sustainable adjustment mechanisms. The paper, however, notes that retaining the subsidy programme has some appeal in terms of its ability to generate relative macroeconomic stability, compared to the case under a no-subsidy regime.

In responding to a negative oil price shock, the central bank faces a dilemma of either stabilising output or prices. Following an oil price shock, the domestic inflation-based monetary reaction function represents a good strategy for stabilising output while its core-inflation-based counterpart is effective for stabilising prices. The export price-based Taylor rule (Frankel, 2003) generates a countercyclical effect on output, though at the expense of overall macroeconomic stability. Furthermore, monetary policy analysis conducted based on an ad-hoc central bank loss function reveals that the lowest loss function value is obtained under the core inflation-based monetary policy rule. This implies that, among its competitors, the core-inflation-based Taylor rule that features output and real exchange rate ranks best as a strategy for stabilising the economy. This is followed by the export-price based policy rule, the headline inflation-based rule, and finally the domestic inflation-based rule. We further demonstrate that the obtained policy ranking is robust to alternative assumptions relating to the presence/absence of fuel consumption subsidies in the economy. The policy trade-offs observed in this paper tend to suggest that no "across-the-board" monetary policy strategy exists for dealing with adverse terms of trade shocks in the resource-rich economy. It is therefore important that the CBN is cognisant of the trade-offs highlighted in this paper while designing monetary policy strategies for responding to emerging macroeconomic shocks.

The model developed in this paper is useful for the joint analysis of monetary and fiscal policies as well as the evaluation of the macroeconomic implications of energy pricing reforms in resource-rich countries. A more thorough analysis of the interactions between monetary and fiscal policy under our model set up is a viable area of research. Using our model for such an effort allows for an assessment of the revenue substitution phenomenon (Salti, 2008; Tijerina-Guajardo and Pagán, 2003), which potentially complicates the automatic stabilisers role of fiscal policy in resource-rich emerging economies. Also, examining monetary and fiscal policy behaviours before and after the 2008/09 global financial crisis (GFC) under our model set up is a useful exercise. Such analysis will contribute to the understanding of the evolution of macroeconomic policies in oil-producing emerging economies, especially in the post-GFC period. The model developed in this paper could be extended to accommodate a Sovereign Wealth Fund (SWF) as a mechanism for managing resource revenues in the resource-rich economy. Under such a setting, the macroeconomic and welfare benefits of the SWF can be explored.

Chapter 4

Monetary-Fiscal Interaction in an Oil-Producing Emerging Economy

4.1 Introduction

Monetary and fiscal policies play important roles in driving inflation dynamics and overall macroeconomic outcomes (Cebi, 2012; Davig and Leeper, 2009; Leeper, 1991; Leeper and Leith, 2016). However, given that these policies are usually implemented by separate independent institutions, their objectives may conflict at times. For instance, an unsustainable fiscal policy arising from the fiscal authority's desire to stabilise output may cause the central bank to embark on debt monetization; which in turn compromises the price stability objective of monetary policy (Ozatay, 1997). Also, since monetary policy decisions have implications for the evolution of fiscal variables, it follows that monetary policy effectiveness is dependent on how the fiscal authority responds to monetary shocks (Cao and Illing, 2019). This sort of policy interconnectedness and its macroeconomic implications explain why policy makers are generally interested in characterising the policy behaviours of monetary and fiscal authorities. There is consensus in literature that effective monetary-fiscal interaction facilitates the achievement of desired macroeconomic objectives, particularly with regards to price stability (Leeper and Leith, 2016).

From a theoretical perspective[1], Leeper (1991) formalised the categorisation of equilibrium policies into 'active' and 'passive' regions using a stochastic maximising model. Ex-

[1] The pioneering efforts at developing a theory to explain the interaction between monetary and fiscal policy were made by Sargent and Wallace (1981) and Leeper (1991).

ploring the model's stability characteristics in line with Blanchard and Kahn (1980)[2], Leeper (1991) showed that a combination of policy parameters from either of the two regions yields one stable and one unstable root, consistent with the notion of saddle-path equilibrium. This implies that either monetary or fiscal policy must be active and the other passive for a unique equilibrium to exist. Thus, an active behaviour uniquely determines the equilibrium pricing function while the passive policy prevents government debt from being explosive. The intuition behind Leeper's (1991) exposition is that the determinacy of the macroeconomic system is dependent not only on the response of monetary policy to inflation but also the fiscal response to public debt.

The foregoing analysis delineates possible policy combinations into four disjoint regions based on the policy parameter space. These are: region I - active monetary and passive fiscal policy; region II - passive monetary and active fiscal policy; region III - passive monetary and passive fiscal policy; and region IV - active monetary and active fiscal policy. Most traditional macroeconomic models designed for policy analysis are based on the idea of monetary dominance, which is consistent with region I in the sense of Leeper (1991). Under this framework, monetary policy actively responds to inflation according to the Taylor principle while fiscal policy adjusts to balance the government's inter-temporal budget (Ascari, Florio and Gobbi, 2017; Christiano et al., 2005; Smets and Wouters, 2007; Walsh, 2010). However, the monetary dominance view has been subjected to intense scrutiny following the 2008/09 global financial crisis (GFC)[3]. It is believed that the accumulation of fiscal debts in the wake of the crisis had non-trivial implications for inflation and the conduct of monetary policy (Debrun and Kinda, 2017; Leeper and Leith, 2016; Reinhart and Rogoff, 2010). This led to the emergence of a recent strand of the literature studying the evolution of monetary-fiscal interactions before and after the GFC (Libich and Nguyen, 2015).

Several studies have examined the interactions between monetary and fiscal policies, especially in the context of developed economies (see e.g. Afonso, Alves and Balhote 2019; Davig and Leeper 2009; Davig, Leeper, Galí and Sims 2006; Kliem, Kriwoluzky and Sarferaz 2016; Muscatelli, Tirelli and Trecroci 2004; Traum and Yang 2011). For instance, using data for the period 1955-2007, Traum and Yang (2011) confirmed the monetary dominance view for the United States during the pre-Volcker period, consistent with active monetary and

[2]According to Blanchard and Kahn (1980), a sufficient condition for the existence of saddle-path equilibrium requires that one root of the system lies inside the unit circle and one root lies outside.

[3]Leeper and Leith (2016) observed that quite a number of countries responded to the crisis by initiating joint policy actions involving drastic interest rate cuts and increased fiscal spendings

passive fiscal policy of Leeper (1991). On the other hand, Davig et al. (2006) and Davig and Leeper (2009) provided empirical evidence in support of passive monetary and active fiscal policy in the US during 1955Q1-1966Q4, a period preceding the great inflation. In the case of Turkey, Cebi (2012) observed a combination of active monetary policy and passive fiscal policy for the period 2002-2009 and argued that such a policy mix was instrumental to the country's impressive macroeconomic performance during the period.

In this paper, we argue that there are a number of reasons to believe that the nature of policy interactions may differ materially between resource-importing advanced economies and their resource-exporting emerging counterparts. First, the drivers of output and prices are potentially different across the two settings. For instance, compared to the outcomes observed in advanced oil importing economies, oil price shocks have been known to generate contrasting and more severe effects on real and nominal variables in oil-producing emerging economies (Berument et al., 2010; Cunado and De Gracia, 2005; Mork et al., 1990). The varied outcomes are often explained by differences in shock propagation mechanisms, degree of oil intensity, and policy responses (Berg et al., 2013; Bernanke et al., 1997; Kinda, 2013; Romero, 2008; Snudden, 2016). Second, small open resource-rich emerging economies (RREEs) exhibit certain characteristics that significantly increase their vulnerabilities to external shocks in general and resource-related shocks in particular. Such characteristics are often taken for granted in the analysis of policy interactions for commodity-importing advanced countries. For instance, in RREEs, fiscal and foreign exchange earnings are usually dominated by resource rents. This sort of dominance is usually associated with fiscal volatility (Barnett and Ossowski, 2002; Schmidt-Hebbel, 2012), policy pro-cyclicality (Abdih et al., 2010; Aregbeyen and Fasanyan, 2017; Schmidt-Hebbel, 2012), revenue substitution (Salti, 2008; Tijerina-Guajardo and Pagán, 2003), and resource curse (Mehlum et al., 2006; Sachs and Warner, 1995; Salti, 2008; Xavier, 1997)[4]. Another important feature, especially of most oil producing emerging economies relate to the use of fuel consumption subsidies for attenuating the impacts of oil price shocks on the domestic economy. In a number of cases, such subsidy arrangements have been shown to distort price signals, generate inefficient consumption, and create serious fiscal sustainability concerns (Clements et al., 2015; Murphy, Villafuerte and Ossowski, 2010; Soile and Mu, 2015). Barring other country-specific factors, these stylised facts may cause monetary and fiscal policies to interact differently in RREEs.

[4]Salti (2008) argue that a relatively higher share of resource rents in total fiscal revenue causes resource rent to corrupt institutions, thereby leading to lower economic growth.

In literature, the extent to which some of these unique characteristics matter for the interactions between monetary and fiscal policy in RREEs remains unclear and largely unexplored. To address this gap and contribute to the understanding of monetary-fiscal interactions in resource-rich economies whose policies are substantially driven by resource-related shocks, we pose a number of questions: (i) how do monetary and fiscal policies respond to resource-price shocks in a RREE with an energy subsidy regime? (ii) what is the characterisation of monetary-fiscal interactions in a RREE whose fiscal policy is largely driven by resource-related flows? (iii) did the 2008/09 GFC alter the dynamics of monetary and fiscal policy interaction in the RREE? (iv) does the nature of fiscal response to resource revenues matter for the interplay of monetary and fiscal policy in the RREE? (v) does monetary policy response to exchange rate matter for the characterisation of monetary-fiscal interactions in the RREE? We address these questions by developing a suitable DSGE model, which is estimated using Nigerian data for the period 2000:Q2 - 2018:Q2. Particularly, the estimated coefficients in the monetary and fiscal rules are explored to derive useful insights regarding the nature of policy interactions in Nigeria over the last two decades.

We report a number of interesting results. First, we show that a 1.0 per cent negative resource-price shock contracts output, depreciates the real exchange rate and increases headline inflation in the RREE. In response, the central bank embarks on contractionary monetary policy while primary deficit increases. We find evidence of active monetary policy and passive fiscal policy over the full sample. This is consistent with the policy mix characterised under region 1 of Leeper (1991) and in line with the monetary dominance view. Contrary to expectation, taxes respond negatively to debt under our benchmark model. Thus, government consumption plays a more significant role than taxes in stabilising debt. Second, the 2008/09 global financial crisis did not significantly alter the observed monetary-fiscal policy mix in the RREE. However, monetary policy became more active in the post-crisis period while government spending became more passive, implying better policy interaction. Furthermore, we find evidence of counter-cyclical government spending prior to the GFC and a pro-cyclical stance in the post-crisis period. Regardless of the nature of cyclicality of government spending, our results show that primary deficit decreases with increasing debt levels. Third, once resource-related flows are excluded from the fiscal rules, it turns out that taxes respond positively to debt. Fourth, a Taylor rule that excludes real exchange rate is also associated with a positive response of taxes to debt. Regardless of the type of monetary and fiscal policy rules considered in the paper, government spending responds negatively to increasing levels of debt; a behaviour that helps achieve the government's debt stabilisation objective. These results are useful for the design of appropriate monetary, fiscal and exchange rate policies in small open resource-rich economies.

This paper makes three key contributions. First, from a theoretical point of view, it extends the small open economy of (Gali and Monacelli, 2005) to allow for a resource sector, fuel subsidy regime, fiscal policy, and revenue substitution. These extensions reflect the economic characteristics of most RREEs and allow for the joint analysis of monetary and fiscal policies. Second, it documents empirical findings regarding monetary and fiscal policy interaction in RREEs whose fiscal policies are largely driven by resource flows, focusing on Nigeria. To our knowledge, this is the first attempt at characterising monetary-fiscal interactions under an economic setting that allows for fuel subsidies and revenue substitution in the fiscal rule. Third, it compares policy interactions before and after the GFC; contributing to the debate on the effects of the crisis on the behaviour of monetary and fiscal authorities in resource-rich emerging economies.

The rest of the chapter is organised as follows. Section 2 discusses the institutional framework for monetary and fiscal policy coordination in Nigeria and presents some stylised facts. In Section 3, we outline the DSGE model employed for our analysis, with special focus on monetary and fiscal policy rules and the implications of their behaviours for the characterisation of policy interaction in the RREE. Section 4 describes the estimation procedure and the data used. In Section 5, we characterise monetary-fiscal interactions in Nigeria and highlight how the observed interactions depend on policy responses to resource revenues and the exchange rate. The implications of the 2008 global financial crisis for the conduct of monetary and fiscal policies in the RREE are also discussed. Section 6 concludes.

4.2 Nigeria: Policy Framework and Selected Indicators

4.2.1 Institutional framework for policy coordination

The CBN Act of 2007 charges the Central Bank of Nigeria (CBN) with the responsibility of ensuring monetary and price stability, among other mandates. On the other hand, the Finance Act of 1958 empowers the Federal Ministry of Finance (FMF) to administer and control the finances of the Federal Government of Nigeria (FGN). These provisions imply that the FMF is responsible for fiscal policy while the CBN conducts monetary policy. Apart from empowering the FMF to formulate fiscal policies, the Finance Act also mandates the Ministry to collaborate with the CBN in formulating policies for curbing inflation in the economy. Thus, while these two agencies are independent of each other in the conduct of their policies, specific committees exist both at the CBN and the FMF for the purpose of facilitating collaboration between the two institutions towards the achievement of certain macroeconomic objectives. The composition and objectives of some of those committees are discussed next.

(i) Monetary Policy Committee

The Monetary Policy Committee (MPC) of the CBN is responsible for the formulation of monetary and credit policy. It determines the appropriate policy rate that is consistent with price stability as defined by the central bank. The committee comprises the Governor and four Deputy Governors of the CBN, two external board members, the Permanent Secretary of FMF, and a secretary, who is usually the Head of CBN's Monetary Policy Department. The CBN Act of 2007 provides for the representative of the fiscal authority (FMF) on the MPC. The MPC meets every other month and has a calendar of meetings. During the bimonthly meetings, the committee considers developments in the domestic and global economy and subsequently takes appropriate monetary policy decisions based on majority votes. The CBN has instrument independence, implying that the Banks' monetary policy decisions are not required to be approved by a higher authority.

(ii) Monetary and Fiscal Policy Coordinating Committee

The Monetary and Fiscal Policy Coordinating Committee (MFPCC) of the Debt Management Office (DMO) provides a forum for effective coordination and harmonization of monetary, fiscal and debt management policies and strategies of Nigeria. The MFPCC meets quarterly and is chaired by the Director-General of the DMO. Other institutional members of the Committee include DMO, CBN, FMF, Budget Office of the Federation (BOF), Office of the Accountant General of the Federation (OAGF), Securities and Exchange Commission (SEC), Nigerian Stock Exchange (NSE), Pension Commission (PENCOM), Federal Inland Revenue Service (FIRS), National Insurance Commission (NAICOM), National Bureau of Statistics (NBS), and the National Planning Commission (NPC). Amongst others, the MFPCC aims to harmonize the objectives of monetary, fiscal, and debt policies towards achieving overall macro-economic stability. It also ensures that the strategies for implementing these policies are properly synchronized so that they are complementary rather than conflicting. Thus, the Committee provides a platform for enhancing monetary-fiscal interactions, especially with regards to the financing of fiscal deficit and the management of public debt.

(iii) Fiscal Liquidity Assessment Committee

The Fiscal Liquidity Assessment Committee (FLAC) of the CBN meets weekly to share relevant data on fiscal operations that could impact on domestic liquidity. It conducts fiscal liquidity forecast and offers policy advice on fiscal issues to the Management of the CBN. Thus, the FLAC provides an avenue for monetary and fiscal authorities to interact for the purpose of articulating complementary macroeconomic policy decisions for the Nigerian economy. The FLAC is chaired by the Director of CBN's Monetary Policy Department. Other institutional members of the Committee include the DMO, BOF, FMF, FIRS, Nigerian National Petroleum Corporation (NNPC), Department of Petroleum Resources (DPR), Nigeria Customs Service, and the OAGF.

4.2.2 Stylised facts on selected macroeconomic indicators

Nigeria is sixth largest oil producing country in the world and Africa's biggest oil exporter. As shown in Figure 4.1*e*, the contribution of oil to the country's Gross Domestic Product (GDP) averaged about 18 per cent during 2000 and 2007. This implies that developments in the international oil market could have significant implications for the domestic economy. Figure 4.1*g* shows that the international price of oil increased steadily and substantially prior to the GFC of 2008/09, rising by 253.5 per cent from its level in 2000 to slightly above US$100/barrel in 2008. However, two major episodes of significant oil price declines have been recorded since the GFC. The first episodic decline occurred during the 2008/09 crisis (36.7 per cent decline from an average price of US$101 per barrel in 2008 to an average of US$64 in 2009) while the second one, which occurred during 2013-2016 was more significant and persistent (a decline of 60.5 per cent from an average price per barrel of US$111 in 2013 to an average of US$44 in 2016). Despite these declines, the average price of oil in the post-GFC period remain three times as high as its average for the period 2000-2003. It is believed that the size and persistence of the 2014-2016 oil price decline contributed substantially to the country's economic recession of 2016 - its first recession in 25 years (Marshal and Solomon, 2017).

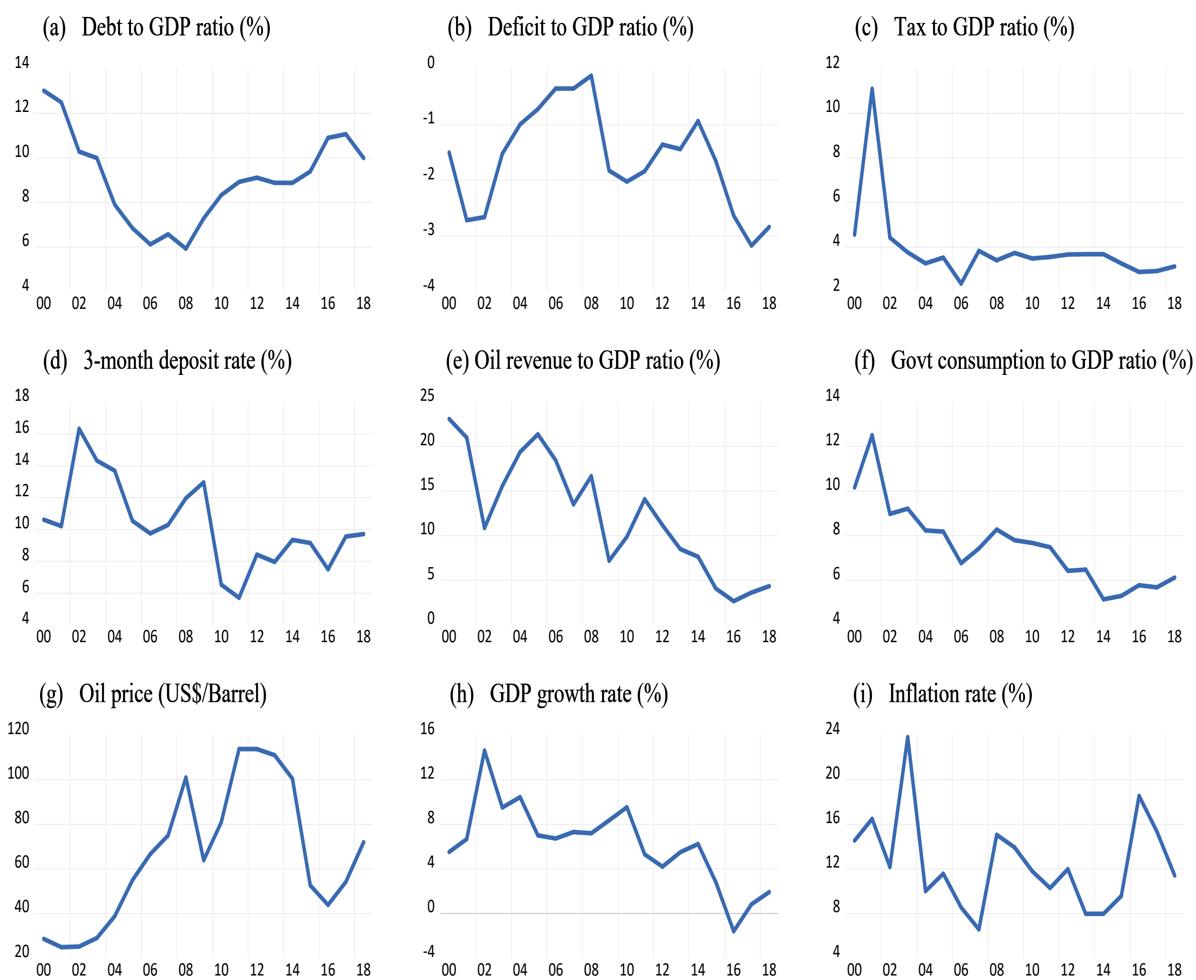

Figure 4.1: Time series pattern of selected macroeconomic and policy indicators

The country recorded a decline in GDP growth from 14.6 per cent in 2002 to 7.2 per cent in 2008, implying that the steady rise in international oil price during the pre-GFC period failed to drive output (Figures 4.1g and 4.1h). Inflation trended downwards during 2003-2007. However, a couple of spikes were recorded in the post-2008/09 crisis period, driven partly by the pass-through effects of exchange rate to domestic prices – as major exchange rate adjustments were implemented in the aftermath of the oil price declines of 2008-09 and

2014-2016 (Figure 4.1i). Notably, the oil price decline of 2014-2016 led to a decline in GDP and an increase in inflation (Figure 4.1g and Figure 4.1i). On the other hand, the less persistent oil price decline of 2008/09 produced an opposite effect as output increased while inflation declined.

How did monetary and fiscal authorities respond to the aforementioned developments in prices and output? Figure 4.1d shows a systematic decline in interest rate during 2003-2007 in response to the deflationary trend experienced during the period. On the other hand, monetary policy was accommodative during the 2016 economic recession as the interest rate was lowered (albeit with significant inertia) in response to the negative output growth despite the higher inflation rate recorded during the period. In terms of fiscal policy, government consumption as a ratio of GDP fell steadily in the face of the declining GDP growth during 2002-2006, suggestive of a pro-cyclical fiscal policy (Figure 4.1f). Similarly, non-oil revenue as a share of GDP fell significantly from about 11.1 per cent in 2001 to about 2.4 per cent in 2006 (Figure 4.1c). The tax to GDP ratio was quite low and below 4.0 per cent between 2008 and 2018.

The country built some fiscal space in the pre-GFC period by narrowing deficits and reducing debt (Figures 4.1a and 4.1b). The deficit to GDP ratio improved significantly from -2.7 per cent in 2001 to about -0.1 per cent in 2008 due to favourable oil prices (Figure 4.1g) and lower government expenditure (Figure 4.1f). However, the two oil price reversals recorded in the post-GFC period significantly worsened the ratio from its level in 2008 to about -3.2 per cent in 2017. In response to the behaviour of deficit-to-GDP ratio, the debt-to-GDP ratio exhibited a U-shape with a trough established during the GFC (Figure 4.1a). Intuitively, the oil price (Figure 4.1g) and the deficit to GDP ratio (Figure 4.1b) displayed an inverted U-shape during the sample period; implying that an increase in oil price was associated with lower fiscal deficit.

How did monetary and fiscal policies respond to oil price movements during the 2000-2018 period? The increases in oil price recorded in the 5-year period preceding the GFC was associated with declining trend in GDP growth, fall in prices, decreasing deficit-to-GDP ratio, falling debt-to-GDP ratio, and interest rate cuts. On the other hand, during the oil price recovery of 2009-2011, the GDP increased, inflation fell, deficit-to-GDP increased leading to a higher debt-to-GDP ratio, and interest rate fell. Thus, while the oil price increase of the pre-GFC period was associated with a contractionary fiscal policy, the oil price recovery of the post-GFC period was associated with expansionary fiscal policy. Under both episodes, monetary policy was expansionary.

The response of monetary and fiscal policies to episodes of declining oil prices was also mixed. During the oil price reversal of 2008-09, Nigeria's GDP grew, inflation declined, fiscal deficit widened (expansionary fiscal policy), debt-to-GDP ratio increased, and the interest rate rose (contractionary monetary policy). On the other hand, the oil price reversal of 2013-2016 was associated with a decline in GDP, increase in inflation, widening of fiscal deficit (expansionary fiscal policy), rise in debt to GDP ratio, and an initial increase in interest rate followed by a cut in 2016.

The analyses presented in this sub-section seem to suggest that, in response to domestic and external economic developments, monetary and fiscal policies behaved in a varied manner. Thus, a number of questions can be posed. First, what is the appropriate characterisation of the nature of monetary and fiscal policy interaction in Nigeria during the period 2000-2018? Second, did the GFC and the episodic declines in oil price in the post-GFC period alter the nature of monetary-fiscal interaction in the RREE? Third, how important are oil price instabilities and its implied fiscal volatility for the characterisation of monetary-fiscal interaction in the RREE? Fourth, in the face of rising debts and elevated fiscal deficits, what mechanism stabilises debt in the RREE? This paper seeks to address these questions using the structural model developed in the next section.

4.3 The Model

In this paper, we develop a New Keynesian model that is suitable for the joint analysis of monetary and fiscal policies in a resource-rich emerging economy. To this end, we extend Gali and Monacelli (2005) by incorporating: an oil sector as in Ferrero and Seneca (2019), oil in domestic consumption as in Medina and Soto (2005), oil in domestic production (Allegret and Benkhodja, 2015), a domestic fuel pricing rule that implies an implicit subsidy regime (Allegret and Benkhodja, 2015); and an inefficient financial sector as in Smets and Wouters (2007). In addition, we allow for fiscal rules that respond to oil-related flows (Algozhina, 2015). The model features nominal and real rigidities that impact on agents' decisions. The economy is inhabited by seven agents: households, non-oil goods producing firms, final goods producers, import goods retailers, oil producing firms, fiscal authority and the central bank. The economic environment within which each of the agents operates as well as their optimisation problems are presented next. The first order conditions and the log linearised version of the characterising equations are presented in Appendix C. The variables expressed in real terms are denoted by small letters.

4.3.1 Households

Household consumption, C_t, is a composite index comprising non-oil consumption bundle, $C_{no,t}$, and oil consumption, $C_{o,t}$:

$$C_t = \left[(1-\gamma_o)^{\frac{1}{\eta_o}} \left(C_{no,t}\right)^{\frac{\eta_o-1}{\eta_o}} + \gamma_o^{\frac{1}{\eta_o}} \left(C_{o,t}\right)^{\frac{\eta_o-1}{\eta_o}} \right]^{\frac{\eta_o}{\eta_o-1}}, \tag{4.1}$$

where parameter $\eta_o > 0$ measures the degree of substitution between core and fuel consumption and γ_o represents the share of domestic consumption devoted to fuel consumption, $C_{o,t}$. Expenditure minimization subject to equation (4.1) yields the demands for non-oil (core) consumption and fuel consumption as follows:

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

where $P_{ro,t}$ represents the subsidised price of imported fuel[5], $P_{no,t}$ is the price of core goods, and P_t is the aggregate consumer price index. Furthermore, core consumption bundle, $C_{no,t}$ is defined as a composite index given by a constant elasticity of substitution (CES) aggregator that combines imported bundle, $C_{f,t}$, and domestically produced goods, $C_{h,t}$, as follows:

$$C_{no,t} = \left[(1-\gamma_c)^{\frac{1}{\eta_c}} \left(C_{h,t}\right)^{\frac{\eta_c-1}{\eta_c}} + \gamma_c^{\frac{1}{\eta_c}} \left(C_{f,t}\right)^{\frac{\eta_c-1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c-1}}, \tag{4.2}$$

where $\eta_c > 0$ represents the elasticity of substitution between home and foreign goods in the core consumption basket and the parameter γ_c measures the share of domestic consumption sourced from the rest of the world by way of non-oil imports. Minimising the household's expenditure subject to equation (4.2) yields the demands for $C_{h,t}$ and $C_{f,t}$ as follows:

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

[5]The price of imported fuel is not simply the domestic currency price of fuel but rather a convex combination of the landing price of fuel and the domestic price of fuel in the previous period. Thus, following Allegret and Benkhodja (2015), $P_{ro,t}$ is determined based on a fuel pricing rule given as $P_{ro,t} = P_{ro,t-1}^{1-\nu} P_{lo,t}^{\nu}$ where the landing price of fuel, $P_{lo,t}$, is the current world price of fuel expressed in local currency.

where $P_{h,t}$ represents the price of domestically produced goods, $P_{f,t}$ is the price of imported goods (expressed in domestic currency) and $P_{no,t}$ is the core consumption price index. The corresponding equations for the aggregate consumer price index, P_t, and core consumption price index, $P_{no,t}$, are standard as follows:

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

Ricardian consumers

We consider two types of consumers in the model economy: Ricardian (R) and non-Ricardian (NR). The Ricardian consumers comprise a fraction (γ_R) who are optimisers and have unconstrained access to the financial markets. A representative household in this category is able to smooth its consumption over time by buying and selling financial assets without any form of constraints (Galí, 2018). On the other hand, the non-Ricardian consumers represent the remaining fraction ($1-\gamma_R$) who are non-optimisers and financially constrained. Thus, they completely consume their labour income within the period (Gabriel et al., 2010; Melina et al., 2016). However, both categories of households have identical preferences as each representative household derives utility from private consumption, C_t, and dis-utility from labour, N_t.

In order to make inter-temporal consumption and savings decisions, the representative optimising household maximises an expected discounted utility function given by

$$U_0^R = E_0 \sum_{s=0}^{\infty} \beta^s \left[\frac{\left(C_{t+s}^R - \phi_c C_{t+s-1} \right)^{1-\sigma}}{1-\sigma} - \frac{\left(N_{t+s}^R \right)^{1+\varphi}}{1+\varphi} \right], \tag{4.3}$$

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, N_t^R is the number of hours worked, $\beta \in (0,1)$ is a discount factor, σ is relative risk aversion coefficient, and $\varphi > 0$ is the inverse of the Frisch elasticity of labour supply. While equation (4.3) is separable in both consumption goods and labour effort, we assume that consumption is subject to external habit formation, implying that the habit stock is proportional to aggregate past consumption. The parameter $\phi_c \in (0,1)$ measures the degree of external habit formation in consumption.

The representative Ricardian household makes its inter-temporal decisions by maximising equation (4.3) subject to a per period budget constraint:

$$P_t C_t^R + P_{i,t} I_{no,t} + \frac{B_{t+1}}{R_t \mu_t} + \frac{\varepsilon_t B_{t+1}^*}{R_t^* \mu_t^*} = W_t N_t^R + R_{h,t} K_{h,t} + B_t + \varepsilon_t B_t^* + D_t - TX_t. \quad (4.4)$$

On the right hand side of equation (4.4), the Ricardian consumer earns labour income, $W_t N_t^R$, by supplying N_t^R hours of work at a nominal wage rate, W_t. The household also earns rental income, $R_{h,t} K_{h,t}$, by leasing an amount of non-oil capital, $K_{h,t}$, to the domestic (non-oil) firms at a rental rate, $R_{h,t}$. The household 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 $t+1$. B_{t+1} and B_{t+1}^* represent household's investments in domestic and foreign bonds at the end of period t, respectively; while the nominal exchange rate is denoted by ε_t. Each domestic bond pays a gross nominal rate of return, R_t, in domestic currency while its foreign counterpart pays an exchange rate adjusted nominal rate of return, R_t^*. We allow for domestic risk premium, μ_t, over the monetary policy rate when households hold domestic assets as well as a stochastic disturbance term that represents the risk premium faced by households when borrowing abroad, μ_t^* (Hollander et al., 2018; Smets and Wouters, 2007). It is assumed that both μ_t and μ_t^* evolve as first order autoregressive processes 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 non-oil investment goods, $I_{no,t}$, at the cost of $P_{i,t}$ per unit. Lastly, TX_t represents per-capita lump-sum net taxes from the government.

The non-oil investment goods, $I_{no,t}$, comprise home-produced, $I_{h,t}$, and foreign-produced, $I_{f,t}$, which are combined as follows:

$$I_{no,t} = \left[(1-\gamma_i)^{\frac{1}{\eta_i}} \left(I_{h,t}\right)^{\frac{\eta_i - 1}{\eta_i}} + \gamma_i^{\frac{1}{\eta_i}} \left(I_{f,t}\right)^{\frac{\eta_i - 1}{\eta_i}} \right]^{\frac{\eta_i}{\eta_i - 1}}, \quad (4.5)$$

where γ_i is the share of imports in aggregate non-investment goods and η_i is the elasticity of intra-temporal substitution between domestically produced and imported investment goods. Minimising the representative Ricardian household's cost subject to equation (4.5) yields the demand equations for home-produced and imported investment goods as follows:

$$I_{h,t} = (1-\gamma_i) \left[\frac{P_{h,t}}{P_{i,t}} \right]^{-\eta_i} I_{no,t}, \quad I_{f,t} = \gamma_i \left[\frac{P_{f,t}}{P_{i,t}} \right]^{-\eta_i} I_{no,t},$$

while the aggregate investment price deflator, $P_{i,t}$, is given by: $P_{i,t} = \left[(1-\gamma_i) P_{h,t}^{1-\eta_i} + \gamma_i P_{f,t}^{1-\eta_i} \right]^{\frac{1}{1-\eta_i}}$. Finally, the representative Ricardian household accumulates non-oil capital as follows:

$$K_{h,t+1} = (1-\delta_h) K_{h,t} + I_{no,t} \left[1 - S\left(\frac{I_{no,t}}{I_{no,t-1}} \right) \right], \tag{4.6}$$

where parameter $0 < \delta_h < 1$ represents the capital depreciation rate. The investment adjustment cost function, $S\left(\frac{I_{no,t}}{I_{no,t-1}}\right)$, is defined as:

$$S\left(\frac{I_{no,t}}{I_{no,t-1}} \right) = \frac{\chi}{2} \left(\frac{I_{no,t}}{I_{no,t-1}} - 1 \right)^2, \tag{4.7}$$

where $\chi \geq 0$ is the sensitivity parameter governing the size of adjustment cost. The details of the optimisation problem yielding the equations for consumption Euler, demand for foreign bonds, supply of capital, and demand for investment are presented in Appendix C.1.

Non-Ricardian consumers

In view of the fact that the non-Ricardian consumers are incapable of inter-temporal optimisation, we assume that the representative consumer in that category chooses its consumption, C_t^{NR}, by maximising:

$$U_0^{NR} = \frac{\left(C_{t+s}^{NR} - \phi_c C_{t+s-1} \right)^{1-\sigma}}{1-\sigma} - \frac{\left(N_{t+s}^{NR} \right)^{1+\varphi}}{1+\varphi}, \tag{4.8}$$

subject to the budget constraint:

$$P_t C_t^{NR} = W_t N_t^{NR} - TX_t. \tag{4.9}$$

Labour packer and wage setting

Each household, j, supplies its differentiated labour, $N_t(j)$, in a monopolistic market to a representative firm that aggregates the different labour types into a single labour input, N_t, using the following technology:

$$N_t = \left[\int_0^1 N_t(j)^{\frac{\eta_w - 1}{\eta_w}} dj \right]^{\frac{\eta_w}{\eta_w - 1}}, \tag{4.10}$$

where the elasticity of substitution between differentiated jobs is represented by parameter η_w. The labour-aggregating firm's profit is maximised subject to equation (4.10) in order to obtain the demand equation for differentiated labour, $N_t(j)$, and the aggregate wage level, W_t, which are given as:

$$N_t(j) = \left[\frac{W_t(j)}{W_t}\right]^{-\eta_w} N_t, \quad W_t = \left[\int_0^1 W_t(j)^{1-\eta_w}\, dj\right]^{\frac{1}{1-\eta_w}}, \tag{4.11}$$

We assume that a fraction of households, $1-\theta_w$, is chosen at random to optimally set their wages in each period while the remaining fraction, θ_w, keeps their wages at the previous period's level. Each household who is able to optimally reset its wage contract evaluates the disutility of labour relative to the utility arising from its labour income. Thus, the optimal wage setting problem involves maximising equation (4.3) subject to the household budget constraint as well as the demand for the differentiated labour. This yields the optimal reset wage equation given by:

$$W_t^{\bullet}(j) = \left(\frac{\eta_w}{\eta_w - 1}\right) E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\frac{(N_{t+s}(j))^{\varphi}}{\lambda_{c,t+s}}\right], \tag{4.12}$$

where $W_t^{\bullet}(j)$ is the optimal reset wage, and θ_w measures the degree of nominal wage rigidity. The aggregate nominal wage rule is therefore of the form:

$$W_t = \left[\theta_w W_{t-1}^{1-\eta_w} + (1-\theta_w) W_t^{\bullet 1-\eta_w}\right]^{\frac{1}{1-\eta_w}}. \tag{4.13}$$

Following Medina and Soto (2016), we make a simplifying assumption that the non-Ricardian households set wages equal to the average wage set by the Ricardian households. Finally, we aggregate consumption, C_t, and labour, N_t, for the Ricardian and non-Ricardian households as follows:

$$C_t = \gamma_R C_t^R + (1-\gamma_R) C_t^{NR}, \tag{4.14}$$

$$N_t = \gamma_R N_t^R + (1-\gamma_R) N_t^{NR}, \tag{4.15}$$

4.3.2 Firms

There are four categories of firms operating in the economy, namely: the final goods firm, the intermediate goods producing firms, the foreign goods importing firms and the oil-producing firm. The economic environments in which each of these firms operate are discussed next.

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

$$Y_{h,t} = \left[\int_0^1 Y_{h,t}(z_h)^{\frac{\epsilon_h - 1}{\epsilon_h}} \, dz_h \right]^{\frac{\epsilon_h}{\epsilon_h - 1}}, \tag{4.16}$$

where parameter $\epsilon_h > 1$ represents the elasticity of substitution among different intermediate goods. The first-order condition for the firm's optimization problem yields a standard downward sloping demand function for intermediate inputs, $Y_{h,t}(z_h)$, as well as the corresponding domestic price aggregator, $P_{h,t}$, as follows:

$$Y_{h,t}(z_h) = \left[\frac{P_{h,t}(z_h)}{P_{h,t}} \right]^{-\epsilon_h} Y_{h,t}, \quad P_{h,t} = \left[\int_0^1 P_{h,t}(z_h)^{1-\epsilon_h} \, dz_h \right]^{\frac{1}{1-\epsilon_h}}, \tag{4.17}$$

where $P_{h,t}(z_h)$ is the price charged on each intermediate good, z_h, produced by an intermediate goods producing firm. The demand for export-bound intermediate goods, $Y^*_{h,t}(z_h)$, as well as the corresponding price aggregator, $P^*_{h,t}$, can be derived in an analogous manner.

Intermediate goods firms: There is a continuum of intermediate goods firms, indexed by $z_h \in [0, 1]$ producing differentiated goods in a monopolistically competitive environment. Each representative intermediate-goods firm combines capital, refined oil (which is imported from abroad) and labour using a constant returns to scale technology as follows:

$$Y_{h,t}(z_h) = A_{h,t} K_{h,t}(z_h)^{\alpha_h^k} O_{h,t}(z_h)^{\alpha_h^o} N_t(z_h)^{\alpha_h^n}, \tag{4.18}$$

where $Y_{h,t}(z_h)$ is the output of the intermediate firm z_h; $K_{h,t}(z_h)$ represents capital input; $O_{h,t}(z_h)$ is refined fuel; and $N_t(z_h)$ denotes the labour input. The parameters $1 > \alpha_h^k > 0$, $1 > \alpha_h^o > 0$ and $1 > \alpha_h^n > 0$ are elasticities of the intermediate firm's output with respect to capital, refined oil and labour inputs, respectively. Under the assumption of constant returns to scale, $\alpha_h^k + \alpha_h^o + \alpha_h^n = 1$. The total factor productivity, $A_{h,t}$, follows a first order autoregressive process with an exogenous shock: $A_{h,t} = (A_{h,t-1})^{\rho_{a_h}} \exp\left(\xi_t^{A_h}\right)$. We solve the optimization problem of the intermediate goods producers in two stages. In the first stage, each firm chooses its input factors to minimize total cost

$$\min_{N_t(z_h), K_{h,t}(z_h), O_t(z_h)} W_t N_t(z_h) + R_{h,t} K_{h,t}(z_h) + P_{ro,t} O_{h,t}(z_h), \tag{4.19}$$

subject to equation (4.18). The first order conditions yield the optimal input combinations, which are then substituted into the production function to derive an expression for the real marginal cost as follows:

$$mc_t = \frac{1}{A_{h,t} p_{h,t}} \left(\frac{r_{h,t}}{\alpha_h^k}\right)^{\alpha_h^k} \left(\frac{p_{ro,t}}{\alpha_h^o}\right)^{\alpha_h^o} \left(\frac{w_t}{\alpha_h^n}\right)^{\alpha_h^n}, \tag{4.20}$$

where $mc_t = \frac{MC_t}{P_t}$ is the real marginal cost, $r_{h,t} = \frac{R_{h,t}}{P_t}$ is the real rental rate on capital, $p_{ro,t} = \frac{P_{ro,t}}{P_t}$ is the real domestic price of imported fuel (which is determined based on a pricing rule, $w_t = \frac{W_t}{P_t}$ is the real wage, and $p_{h,t} = \frac{P_{h,t}}{P_t}$ is the real price of domestically produced goods.

In the second stage, the intermediate goods producers maximize their expected discounted profits by choosing the price at which they sell their goods. Following Calvo's (1983) staggered pricing model, we allow a proportion of the intermediate goods producing firms, $(1-\theta_h)$, to reset their prices optimally in any given period while the other fraction, θ_h, who are unable to re-optimise their prices maintain the price at last fixing. Profit maximisation subject to the demand for intermediate goods (shown in equation 4.17) yields the optimal reset price given by

$$P_{h,t}^{\bullet} = \frac{\epsilon_h}{\epsilon_h - 1} \frac{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_h)^s P_{h,t+s} Y_{h,t+s} mc_{t+s}}{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_h)^s Y_{h,t+s}}, \tag{4.21}$$

where $\theta_h \in [0,1]$ is an index of price stickiness (Calvo, 1983) and $P_{h,t}^{\bullet}$ represents the optimal reset price. It then follows that the evolution of domestic price level is given by a law of motion:

$$P_{h,t} = \left[\theta_h P_{h,t-1}^{1-\epsilon_h} + (1-\theta_h)\left(P_{h,t}^{\bullet}\right)^{1-\epsilon_h}\right]^{\frac{1}{1-\epsilon_h}}. \tag{4.22}$$

We allow for some firms to also produce intermediate goods that can be bundled for the export market. Thus, in an analogous manner, profit maximisation subject to the demand for intermediate goods meant for the export market, $Y^{*}_{h,t}\left(z_h\right)$, yields an optimal reset price, $P^{*\bullet}_{h,t}$, for such a commodity while the associated Calvo parameter is denoted as θ_{hf}.

The import goods retailers: As in Medina and Soto (2007), we ameliorate the expenditure switching effect of exchange rate movements by allowing for incomplete exchange rate pass-through into import prices in the short-run through local-currency price stickiness. Thus, a group of perfectly competitive assemblers produce a final foreign good, $Y_{f,t}$, by combining a continuum of differentiated imported varieties, $Y_{f,t}\left(z_f\right)$, using a Dixit-Stiglitz aggregation technology given by

$$Y_{f,t} = \left[\int_0^1 Y_{f,t}\left(z_f\right)^{\frac{\epsilon_f - 1}{\epsilon_f}} dz_f\right]^{\frac{\epsilon_f}{\epsilon_f - 1}}, \tag{4.23}$$

where the parameter $\epsilon_f > 1$ represents the elasticity of substitution among different imported goods. The first-order condition for the firm's optimization problem, which entails maximising the import goods retailers' profit function subject to the aggregation technology in equation (4.23) yields a downward sloping demand function for imported intermediate goods, $Y_{f,t}\left(z_f\right)$, and a corresponding price index for imported goods, $P_{f,t}$, given as:

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

where $P_{f,t}\left(z_f\right)$ is the price charged on an imported intermediate product,z_f. In turn, each import goods retailer has monopoly power to determine the domestic price of their varieties, albeit infrequently as in Calvo (1983). The frequency at which prices can be optimally reset is guided by a price stickiness parameter, θ_f. Thus, an importing firm has a probability, θ_f, of keeping the price of its good fixed in the next period and a probability, $1-\theta_f$, of optimally resetting its price. For a firm that can reset its price, $P^{\bullet}_{f,t}\left(z_f\right)$, it does so by maximising the present value of its expected profits. Thus, by law of large numbers, the pricing rule for imported goods is given by

$$P_{f,t} = \left[\theta_f P_{f,t-1}^{1-\epsilon_f} + \left(1-\theta_f\right)\left(P^{\bullet}_{f,t}\right)^{1-\epsilon_f}\right]^{\frac{1}{1-\epsilon_f}}. \tag{4.24}$$

The oil firm: The representative oil firm combines materials sourced from the domestic economy, M_t, and oil-related capital, $K_{o,t}$, to produce oil output, $Y_{o,t}$. The oil output is sold in the international crude oil market at a price, $p^*_{o,t}$. The firm employs a constant return to scale Cobb-Douglas extraction technology to produce oil. This is given by

$$Y_{o,t} = A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m}, \tag{4.25}$$

where $A_{o,t}$ represents the oil technology and the parameters α_o^k and $\alpha_o^m \in (0,1)$ represent the elasticities of oil output with respect to oil-related capital and material inputs, respectively. We assume that the oil-related capital is accumulated by foreign direct investment, FDI^*_t, as follows:

$$K_{o,t} = (1-\delta_o) K_{o,t-1} + FDI^*_t, \tag{4.26}$$

where δ_o represents the rate at which oil-related capital depreciates. Foreign direct investment inflows to the oil sector responds to the real international price of oil as follows:

$$FDI^*_t = \left(FDI^*_{t-1}\right)^{\rho_{fdi}} \left(p^*_{o,t}\right)^{1-\rho_{fdi}}, \tag{4.27}$$

where parameter ρ_{fdi} measures the extent of inertia in the accumulation of foreign direct investment. We assume that the real international price of oil and the oil technology evolve according to the following $AR(1)$ processes with exogenous shocks:

$$p^*_{o,t} = \left(p^*_{o,t-1}\right)^{\rho_o} \exp\left(\xi_t^{p^*_o}\right), \quad A_{o,t} = \left(A_{o,t-1}\right)^{\rho_{a_o}} \exp\left(\xi_t^{A_o}\right). \tag{4.28}$$

As in Algozhina (2015), we assume that the oil firm (which is jointly owned by foreign direct investors and the government) receives its revenues net of royalties levied by government on production quantity at a rate τ as follows: $\Pi_{o,t} = (1-\tau)\,\varepsilon_t p^*_{o,t} Y_{o,t}$.

4.3.3 Open economy features

The domestic economy being modelled in this paper is a small open economy, implying that activities in the foreign economy are not impacted by developments in the domestic economy. The relationship between the small open economy and the rest of the world is described in this section.

Real exchange rate, terms of trade and incomplete pass-through: Following Monacelli (2005), we assume law of one price gap such that importing firms have some power in the determination of the prices of their goods. The law of one price gap, Ψ_t, is given by the ratio of foreign price index expressed in domestic currency to the domestic currency price of imports[6]:

$$\Psi_t = \frac{\varepsilon_t P_t^*}{P_{f,t}}, \tag{4.29}$$

where P_t^* is aggregate consumer price index of the foreign economy, $P_{f,t}$ is the average price of imported goods in terms of domestic currency and ε_t is the nominal exchange rate. We assume that law of one price holds for exports but not for imports. The real exchange rate, q_t, is defined as the ratio of foreign price index expressed in domestic currency to the aggregate domestic price index as follows:

$$q_t = \frac{\varepsilon_t P_t^*}{P_t}. \tag{4.30}$$

We can re-write the equation for the law of one price gap (equation 4.29) by making use of the definition of real exchange rate in equation (4.30) as follows:

$$\Psi_t = \frac{q_t}{p_{f,t}}, \tag{4.31}$$

where $p_{f,t} = \frac{P_{f,t}}{P_t}$ denotes the real price of imported goods[7]. Also, log-linearising equation (4.30) and taking the rate of change yields an equation for the evolution of the real exchange rate, q_t, presented in equation (C.89), Appendix C.2. Finally, we define the terms of trade, S_t, of the domestic economy as the domestic currency price of imports, $P_{f,t}$, relative to the export price (price of domestically produced tradable goods), $P_{h,t}$. This is given by:

$$S_t = \frac{P_{f,t}}{P_{h,t}}, \tag{4.32}$$

and log-linearised as in equation (C.90), Appendix C.2.

International risk sharing: The domestic consumption is linked with foreign consumption by assuming that agents in the rest of the world have access to the same set of bonds and

[6]The law of one price gap, Ψ_t, takes the value of one if the law of one price (LOP) holds.
[7]Variables in small letters are in real terms, deflated by the aggregate consumer price index, P_t

share the same preferences with their domestic counterparts. Thus, a condition analogous to equation (C.10) exists for the representative household in the rest of the world as follows:

$$1 = \beta E_t \left[\left(\frac{C_{t+1}^R - \phi_c C_t}{C_t^R - \phi_c C_{t-1}} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right] = \beta E_t \left[\left(\frac{C_{t+1}^* - \phi_c C_t^*}{C_t^* - \phi_c C_{t-1}^*} \right)^{-\sigma} \frac{\varepsilon_t}{\varepsilon_{t+1}} \frac{P_t^*}{P_{t+1}^*} \right]. \tag{4.33}$$

Simplifying equation (4.33) and making use of the definition of the real exchange rate, q_t, in equation (4.30) yields the international risk sharing equation as follows:

$$C_t^R - \phi_c C_{t-1} = \varrho q_t^{\frac{1}{\sigma}} \left(C_t^* - \phi_c C_{t-1}^* \right), \tag{4.34}$$

where ϱ represents a constant that depends on the relative initial conditions in asset holdings given by $\varrho \equiv E_t \left[\frac{C_{t+1}^R - \phi_c C_t}{\left(C_{t+1}^{R*} - \phi_c C_t^* \right) q_{t+1}^{\frac{1}{\sigma}}} \right]$ as in Gali and Monacelli (2005).

4.3.4 Policy rules

Fiscal policy

Each period, the government receives revenues from lump-sum tax, TX_t, issues one period bonds that results in a net debt position, B_t, and receives oil revenues in form of royalties from the oil firm, OR_t. The revenues are used to finance government expenditure on public goods, $G_{c,t}$, and service debt, $\frac{B_{t+1}}{R_t}$. Finally, when the need arises, the government makes subsidy payments, OS_t, within a framework that allows for the stabilisation of domestic fuel price. The government's budget constraint is given by

$$TX_t + OR_t + B_t = P_{g,t} G_{c,t} + OS_t + \frac{B_{t+1}}{R_t}. \tag{4.35}$$

Equation (4.35) shows that an increase in government spending, $G_{c,t}$, can be financed either by increasing taxes, generating more oil revenues or issuing more debt. As in Medina and Soto (2007), we assume that government consumption basket consists of imported goods, $G_{f,t}$, and domestically produced goods, $G_{h,t}$:

$$G_{c,t} = \left[(1 - \gamma_g)^{\frac{1}{\eta_g}} G_{h,t}^{\frac{\eta_g - 1}{\eta_g}} + \gamma_g^{\frac{1}{\eta_g}} G_{f,t}^{\frac{\eta_g - 1}{\eta_g}} \right]^{\frac{\eta_g}{\eta_g - 1}}, \tag{4.36}$$

where η_g is the elasticity of substitution between imported and domestically produced goods consumed by government and γ_g is the share of foreign goods in government's consumption basket. The demands for home and foreign goods are derived by minimising government's consumption cost subject to equation (4.36). This yields:

$$G_{h,t} = (1 - \gamma_g) \left(\frac{P_{h,t}}{P_{g,t}} \right)^{-\eta_g} G_{c,t}, \quad G_{f,t} = \gamma_g \left(\frac{P_{f,t}}{P_{g,t}} \right)^{-\eta_g} G_{c,t},$$

while the government consumption price index is given by:

$$P_{g,t} = \left[(1 - \gamma_g) P_{h,t}^{1-\eta_g} + \gamma_g P_{f,t}^{1-\eta_g} \right]^{\frac{1}{1-\eta_g}}, \tag{4.37}$$

where $P_{g,t}$ is the deflator of government expenditure. In order to allow for fuel consumption subsidy in the small open economy, we follow Allegret and Benkhodja (2015). We assume that aggregate refined oil, O_t, is produced abroad and imported into the small open economy at a landing price, $P_{lo,t}$, (i.e. the cost of importing a litre of fuel into the domestic economy, expressed in domestic currency) by the government. In turn, the government sells the imported fuel at a regulated price, $P_{ro,t}$ based on a fuel pricing regime given by:

$$P_{ro,t} = P_{ro,t-1}^{1-\nu} P_{lo,t}^{\nu}, \tag{4.38}$$

where the landing price of imported fuel (expressed in domestic currency), $P_{lo,t}$, is given by[8]:

$$P_{lo,t} = \varepsilon_t \frac{P_{o,t}^*}{P_t^*} \Psi_t^o. \tag{4.39}$$

The variable $P_{o,t}^*$ is the foreign currency price of oil abroad, ε_t is the nominal exchange rate and Ψ_t^o is the law of one price gap associated with the import price of fuel. The parameter $0 < \nu < 1$ governs the extent to which government subsidises fuel consumption. When $\nu = 1$, the implicit subsidy regime seizes to exist while $\nu = 0$ implies complete price regulation. Thus, the implicit fuel subsidy payment by government is given by the difference between the value of fuel imports expressed in domestic currency and the amount realised from fuel sales in the domestic economy as follows:

$$OS_t = (P_{lo,t} - P_{ro,t}) O_t, \tag{4.40}$$

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

where total imported fuel (O_t) comprises fuel consumption by households, $C_{o,t}$, and consumption by domestic firms, $O_{h,t}$. On the revenue side of the budget constraint (Equation 4.35), the government collects lump-sum taxes and oil revenues. The amount of oil revenue, OR_t, accruing to government is given by:

$$OR_t = \tau\varepsilon_t p^*_{o,t} Y_{o,t}, \tag{4.41}$$

where τ is the royalty rate on oil production quantity, $Y_{o,t}$ denotes oil output, and ε_t is the nominal exchange rate. Following Algozhina (2015), we consider backward looking fiscal policy reaction functions that allow government consumption and tax level to respond to lagged debt and output. In addition, we allow taxes and government consumption to respond to oil revenue and oil subsidy payments. Thus, our linearised benchmark fiscal policy rules are specified as follows:

$$\widetilde{g}_{c,t} = \rho_g \widetilde{g}_{c,t-1} + (1-\rho_g)\left[\omega_b \widetilde{b}_{t-1} + \omega_{gy}\widetilde{y}_{t-1} + \omega_{os}\widetilde{os}_t + \omega_{or}\widetilde{or}_t\right] + \xi_t^{G_c}, \tag{4.42}$$

$$\widetilde{tx}_t = \rho_{tx}\widetilde{tx}_{t-1} + (1-\rho_{tx})\left[\varphi_b \widetilde{b}_{t-1} + \varphi_y \widetilde{y}_{t-1} + \varphi_{os}\widetilde{os}_t + \varphi_{or}\widetilde{or}_t\right] + \xi_t^{tx}, \tag{4.43}$$

where the parameters ρ_g and ρ_{tx} represent the degree of smoothing in government spending and tax rules, respectively. The parameters $\omega_b, \omega_{gy}, \omega_{os}$ and ω_{or} are government consumption feedback coefficients with respect to lagged domestic debt, lagged output, oil subsidy payments and oil revenues, respectively. In equation (4.43), 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, and given by an exogenous process.

A negative value for φ_{or} implies revenue substitution between tax and oil revenues. The notion of Ricardian equivalence requires that increasing debt levels are associated with higher taxes and lower government consumption (i.e. $\varphi_b > 0, \omega_b < 0$). This parameter combination implies passive fiscal policy where deficit shocks are financed with future taxes (Leeper, 1991). A combination of active monetary policy and passive fiscal policy espouses the monetary dominance view under which monetary shocks drive prices and fiscal shocks are immaterial. According to Leeper (2005), such a policy equilibrium is appropriate for the implementation of an interest rate-based inflation targeting regime. On the other hand, a parameter combination of the form $\varphi_b < 0, \omega_b > 0$ connotes active fiscal policy; a situation where the fiscal authority fails to adjust taxes strongly enough in response to deficit shocks and government expenditure does not adjust in a manner that stabilises debt. A combination of passive monetary policy and active fiscal policy represents a unique equilibrium that is consistent with the Fiscal Theory of Price Level (FTPL) proposed by Woodford (1995). Under such an equilibrium, inflation is seen as both a fiscal and monetary phenomenon.

In order to explore the idiosyncrasies of monetary-fiscal interactions in small open resource-rich economies, we exclude resource-related flows from the fiscal rules specified above and compare our results. Thus, in addition to equations (4.42) and (4.43), we consider the following alternative fiscal policy rules:

$$\widetilde{g}_{c,t} = \rho_g \widetilde{g}_{c,t-1} + (1-\rho_g)\left[\omega_b \widetilde{b}_{t-1} + \omega_{gy}\widetilde{y}_{t-1}\right] + \xi_t^{G_c}, \tag{4.44}$$

$$\widetilde{tx}_t = \rho_{tx}\widetilde{tx}_{t-1} + (1-\rho_{tx})\left[\varphi_b \widetilde{b}_{t-1} + \varphi_y \widetilde{y}_{t-1}\right] + \xi_t^{tx}. \tag{4.45}$$

Equations (4.44) and (4.45) are similar to the rules specified in Leeper (1991) and Traum and Yang (2011).

Monetary policy

The central bank follows a simple Taylor rule in setting the short term nominal interest rate, R_t. Thus, the linearised monetary policy rule is specified as follows:

$$\widetilde{R}_t = \rho_r \widetilde{R}_{t-1} + (1-\rho_r)\left[\omega_\pi \widetilde{\pi}_t + \omega_y \widetilde{y}_{h,t} + \omega_q \widetilde{q}_t\right] + \xi_t^r, \tag{4.46}$$

where the central bank responds to aggregate inflation, $\pi_t = \frac{P_t}{P_{t-1}}$; domestic output, $y_{h,t}$; and real exchange rate, q_t. The parameter ρ_r is the interest rate smoothing parameter capturing monetary policy inertia. The parameters ω_π, ω_y and ω_q are the policy coefficients chosen by the central bank with respect to inflation, domestic output and real exchange rate, respectively. The monetary policy shock, ξ_t^r, is assumed independent and identically distributed (*iid*). Equation (4.46) is consistent with a managed floating exchange rate regime (Sangare, 2016).

In line with the Taylor principle, the feedback coefficient on inflation is expected to be greater than unity, i.e. $\omega_\pi > 1$. Under such circumstance, the monetary authority is unconstrained and can thus respond strongly to inflation in order to achieve price stability. This is consistent with the notion of active monetary policy in the categorisation of equilibrium policies by Leeper (1991). On the other hand, monetary policy is passive if it is constrained by private and fiscal policy behaviour in such a way that money stock is allowed to respond to deficit shocks, $\omega_\pi < 1$, (Leeper, 1991). In this case, the fiscal authority independently determines its budget while the monetary authority is required to adjust monetary policy in order to satisfy the government budget constraint. This is usually the case when the central bank pursues macroeconomic objectives other than price stability, such as output growth.

4.3.5 Market clearing and aggregation

Domestic output, $Y_{h,t}$, is absorbed by household's consumption of domestically produced goods, $C_{h,t}$; materials input used up by oil producing firms, M_t; government consumption of domestically produced goods, $G_{h,t}$; non-oil exports, $C^*_{h,t}$; and domestic investment[9], $I_{h,t}$. Consequently, the domestic resource constraint is given by $P_{h,t}Y_{h,t} = P_{h,t}C_{h,t} + \varepsilon_t P^*_{h,t}C^*_{h,t} + P_{h,t}M_t + P_{h,t}I_{h,t} + P_{h,t}G_{h,t}$. On the other hand, the aggregate GDP, Y_t, which combines both oil ($Y_{o,t}$) and non-oil output ($Y_{h,t}$) is given by $P_tY_t = P_{h,t}Y_{h,t} + \varepsilon_t P^*_{o,t}Y_{o,t} + IM_t = P_{h,t}C_{h,t} + P_{h,t}M_t + P_{h,t}I_{h,t} + P_{h,t}G_{h,t} + NX_t$. Net exports ($NX_t$) is given by $NX_t = EX_t - IM_t$, where EX_t is aggregate exports and IM_t represents aggregate imports. Aggregate exports, EX_t, comprises oil exports ($EX_{o,t}$ measured as $\varepsilon_t P^*_{o,t}Y_{o,t}$) and non-oil exports ($EX_{no,t}$ measured as $\varepsilon_t P^*_{h,t}C^*_{h,t}$). Similarly, aggregate imports, IM_t, comprises 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 import into the economy is given by: $Y_{f,t} = C_{f,t} + I_{f,t} + G_{f,t}$. Setting the current account equal to the financial account, we obtain the following expression for the Balance of Payments (BOP):

$$\frac{q_t b^*_t}{R^*_t \mu^*_t} = q_t b^*_{t-1} + nx_t - (1-\tau)\, q_t p^*_{o,t} y_{o,t} + q_t f di^*_t, \tag{4.47}$$

The labour and capital markets clear as follows:

$$N_t = \int_0^1 N_t^R(j)\,dj + \int_0^1 N_t^{NR}(j)\,dj \qquad \text{and} \qquad K_{h,t} = \int_0^1 K_{h,t}(j)\,dj.$$

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 in oil price ($\xi_t^{\psi^o}$), domestic total factor productivity ($\xi_t^{a_h}$), domestic monetary policy (ξ_t^{r}), government

[9] Which is used to augment the stock of physical capital available for use in the production process in period $t+1$

consumption ($\xi_t^{G_c}$), tax (ξ_t^{tx}), domestic risk premium (ξ_t^{μ}), domestic supply ($\xi_t^{\pi_h}$), foreign monetary policy ($\xi_t^{r^*}$), foreign inflation ($\xi_t^{\pi^*}$), and foreign risk premium ($\xi_t^{\mu^*}$).

4.3.6 Rest of the world

The demand for domestic goods by the foreign economy, $C_{h,t}^*$, is given by:

$$C_{h,t}^* = \gamma^* \left(\frac{P_{h,t}^*}{P_t^*} \right)^{-\eta^*} C_t^*, \tag{4.48}$$

where $P_{h,t}^*$ is the price of domestically produced goods in foreign currency, P_t^* is the aggregate consumer price index in the foreign economy, and C_t^* is aggregate foreign consumption. The parameter, η^*, represents the foreign price elasticity of demand for domestic goods while the share of domestic goods in foreign consumption is captured by γ^*. The IS curve for the foreign economy is specified as:

$$\frac{1}{R_t^* \mu_t^*} = \beta E_t \left[\left(\frac{C_{t+1}^{R*} - \phi_c^* C_t^*}{C_t^{R*} - \phi_c^* C_{t-1}^*} \right)^{-\sigma^*} \frac{1}{\pi_{t+1}^*} \right], \tag{4.49}$$

where ϕ_c^* is the habit formation parameter in the foreign economy and σ^* is the relative risk aversion coefficient. The variables C_t^*, R_t^* and π_t^* represent consumption, interest rate and inflation rate in the foreign economy. The central bank in the foreign economy sets interest rate in a similar fashion as the domestic economy by following a Taylor rule. The linearised monetary policy rule for the foreign economy is specified as follows:

$$\tilde{R}_t^* = \rho_{r^*} \tilde{R}_{t-1}^* + (1 - \rho_{r^*}) \left[\omega_{\pi^*} \tilde{\pi}_t^* + \omega_{y^*} \tilde{y}_{h,t}^* \right] + \xi_t^{r^*}, \tag{4.50}$$

where ρ_{r^*} represents the interest rate smoothing parameter in the foreign economy while ω_{π^*} and ω_{y^*} are the feedback coefficients for inflation and output, respectively. Bars denote the steady state levels of the variables and $\xi_t^{r^*}$ represents monetary policy shock in the foreign economy. Finally, inflation rate in the foreign economy is assumed to follow an $AR(1)$ process as follows: $\pi_t^* = \left(\pi_{t-1}^* \right)^{\rho_{\pi^*}} \exp \left(\xi_t^{\pi^*} \right)$.

4.4 Model Estimation

4.4.1 Estimation methodology

The Bayesian methodology outlined in Schorfheide (2000) is used to estimate a log-linearised version of our model. This modelling approach is useful for combining the robust micro foundations of the model with an intuitive probabilistic distribution of the observables (Smets and Wouters, 2007). Also, Bayesian estimation facilitates the estimation of the key structural parameters of the model by allowing for the incorporation of additional information on the model parameters in the form of prior distributions.

In the first step towards estimating our model, we solve the system of linear rational expectations equations by casting our log-linearized set of equations presented in Appendix C.2 into a canonical form that conforms with the solution method proposed by Sims (2002). After the solution is obtained, measurement equations are added in order to link the observable variables to the vector of state variables in a state-space representation. We use data on fifteen variables: $y_t, c_t, i_{no,t}, q_t, \pi_t, \pi_{no,t}, r_t, y^*_t, \pi^*_t, r^*_t, p^*_{o,t}, b_t, tx_t, g_{c,t}, y_{o,t}$, while the remaining variables are assumed to be unobserved. The choice of observable variables are 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 measurement equations are used to construct the likelihood function (i.e. the probability of observing the data given the model parameters) for the structural parameters via Kalman filter[10]. The likelihood function is then combined with the prior distribution of the parameters in order to obtain the posterior density function. Finally, we numerically derive the posterior distribution of the parameters from the posterior density by running two parallel chains and generating 150,000 draws in each chain based on the Metropolis-Hastings Monte Carlo Markov Chain (MCMC) algorithm. We discard 30 per cent of the first draws as burn-in.

4.4.2 Data

The model developed in the previous section is estimated for the Nigerian economy using 73 quarterly observations on 15 selected macroeconomic variables over the sample period of

[10]This is computed under the assumption of normally distributed disturbances.

2000Q2 - 2018Q2 [11]. Nigeria represents the small open economy in our model set up while the rest of the world consists of Nigeria's major trading partners of the Euro area, the United States, and India[12].

The domestic variables, which relate to the Nigerian economy are: per capita real domestic GDP ($y_{h,t}$), per capita real consumption (c_t), per capita real investment ($i_{no,t}$), real effective exchange rate (q_t), headline consumer price index (p_t), core consumer price index ($p_{no,t}$), nominal interest rate (R_t), oil output ($y_{o,t}$), government debt (b_t), tax revenue (tx_t) and government consumption ($g_{c,t}$). We use data on the three fiscal variables (i.e. $b_t, tx_t, g_{c,t}$) as well as two oil sector variables ($p^*_{o,t}, y_{o,t}$) for the model estimation in order to properly identify the parameters in the fiscal policy rule and generate plausible characterisation of the macroeconomic policy mix. Data set on the domestic variables are sourced from the National Bureau of Statistics (NBS) and the Central Bank of Nigeria (CBN) Statistics database.

The foreign economy variables include trade-weighted foreign real GDP per capita (y^*_t), trade-weighted foreign aggregate CPI (P^*_t), trade-weighted foreign interest rate (R^*_t), and the real international price of oil ($P^*_{o,t}$). The data set used for the computation of the trade-weighted foreign variables as well as the international price of oil are retrieved from the Federal Reserve Bank of St. Louis (FRED) and the International Financial Statistics (IFS) of the International Monetary Fund (IMF).

We carry out necessary transformations on the data set in order to make them model consistent. First, we demean and deseasonalise relevant variables. Since the variables implied by our model are stationary, we remove trend from the data by taking first difference in the logarithm of the variables with the exception of the domestic and foreign interest rates. In order to avoid the problem of stochastic singularity when evaluating the likelihood function (and also to account for possible inaccuracies in national accounts data for the domestic economy), we balance the number of observables with the number of stochastic disturbances in our model by incorporating four measurement errors relating to domestic output (ξ^{yobs}_t), consumption (ξ^{cobs}_t), investment (ξ^{iobs}_t), and oil output (ξ^{yoobs}_t).

[11] The choice of the estimation sample is largely influenced by data availability for the domestic economy.

[12] These three regions account for about 65 per cent of Nigeria's total external trade over the last two decades. In the normalised weights for the computation of the foreign variables, the Euro area is predominant with a trade weight of 0.39 while the weights for the United States and India are 0.36 and 0.25, respectively.

4.4.3 Model parameters

Parametrization

The values of the calibrated parameters are presented in Table 4.1. The parametrization is done to fit quarterly data with values borrowed from standard values assumed by Gali and Monacelli (2005) for small open economies. We also took values from studies on resource-rich emerging economies, such as Romero (2008), Wolden-Bache et al. (2008), Hove et al. (2015), Ferrero and Seneca (2019), and Iklaga (2017). We set the discount factor, β, equal to 0.99 (Allegret and Benkhodja, 2015; Iklaga, 2017); the depreciation rate, δ, equal to 0.025 (Algozhina, 2015; Allegret and Benkhodja, 2015; Iklaga, 2017); the share of imports in household's investment, γ_i, equal to 0.2; and the share of imports in household's consumption, γ_c, equal to 0.35 in line with sample data and close to 0.4 assumed by Gali and Monacelli (2005).

Table 4.1: Calibrated parameters

Parameter Definition	Symbol	Value
Discount factor	β	0.990
Depreciation rate in both the oil and non-oil sectors	$\delta_h = \delta_o$	0.025
Share of imports in household's consumption	γ_c	0.400
Share of fuel in household's consumption	γ_o	0.085
Share of imports in household's investment	γ_i	0.200
Calvo - wages	θ_w	0.750
Elasticity of domestic output with respect to capital	α_h^k	0.330
Elasticity of domestic output with respect to oil	α_h^o	0.120
Elasticity of domestic output with respect to labour	α_h^n	0.550
Elasticity of oil output with respect to capital	α_o^k	0.700
Elasticity of oil output with respect to materials	α_o^m	0.300
Share of imports in government's consumption	γ_g	0.120
Elasticity of substitution between foreign & domestic goods - Govt.	η_g	0.600
Share of household fuel consumption in total fuel imports	γ_{co}	0.750
Persistence in oil sector foreign direct investment process	ρ_{fdi}	0.300
Calvo - exports goods	θ_{hf}	0.700
Foreign relative risk aversion	σ^*	1.000
Foreign habit formation	ϕ_c^*	0.000
Intra-temporal elasticity in foreign demand	$\eta_{c_h^*}$	0.790
Coefficient of inflation in Taylor Rule - foreign economy	ω_{π^*}	1.500
Coefficient of output in Taylor Rule - foreign economy	ω_{y^*}	0.500

Furthermore, we set the elasticity of domestic output with respect to capital, α_h^k, equal to 0.33 (Algozhina, 2015; Rasaki and Malikane, 2015); elasticity of domestic output with respect to labour, α_h^n, equal to 0.55 (Ncube and Balma, 2017); elasticity of oil output with respect to capital, α_o^k, equal to 0.7 (Algozhina, 2015); elasticity of oil output with respect to materials, α_o^m, equal to 0.3 (Algozhina, 2015; Ferrero and Seneca, 2019), elasticity of substitution between foreign and domestic goods consumed by government, η_g, equal to 0.6 (Hollander et al., 2018).

Table 4.2: Steady state ratios

Ratio	**Symbol**	**Value**
Domestic consumption to domestic output	$\bar{C_h}/\bar{Y_h}$	0.690
Investment to domestic output	$\bar{I}_{no}/\bar{Y_h}$	0.150
Domestic materials to domestic output	$\bar{M}/\bar{Y_h}$	0.010
Government consumption to domestic output	$\bar{G_c}/\bar{Y_h}$	0.070
Non-oil export to output	$\bar{C_h^*}/\bar{Y_h}$	0.070
Import to domestic output	$\bar{IM}/\bar{Y_h}$	0.150
Share of non-oil export in aggregate export	$1-\bar{Y_o}/\bar{EX}$	0.050
Share of oil in GDP	$\bar{Y_O}/\bar{Y}$	0.260
Fiscal debt to oil revenue	$\bar{B}/\bar{OR}$	0.700
Taxes to oil revenue	$\bar{TX}/\bar{OR}$	0.050
Government consumption to oil revenue	$p_g\bar{G_c}/\bar{OR}$	0.700
Non-oil imports to total import	$\bar{C_f}/\bar{IM}$	0.400
Fuel import to total import	$\bar{O}/\bar{IM}$	0.300
Oil sector foreign direct investment to net exports	$q\bar{FDI}/\bar{NX}$	0.300
Exports to net exports	$\bar{EX}/\bar{NX}$	0.600
Imports to net exports	$1-\bar{EX}/\bar{NX}$	0.400
Foreign debt service payments to net exports	$q\bar{B^*R^*}/\bar{NX}$	0.020
Foreign debt to net exports	$q\bar{B}^*/\bar{NX}$	0.3112
Oil profit repatriation to net exports	$(1-\tau)q\bar{P_o^*}Y_o/\bar{NX}$	0.600
Public goods imports to total import	$\bar{G_f}/\bar{IM}$	0.050
Fuel subsidy payments to oil revenue	$\bar{OS}/\bar{OR}$	0.200
Fuel sales value to fuel subsidy payments	$\bar{P_{ro}O}/\bar{OS}$	0.300
Domestic debt service payments to oil revenue	$\bar{B/R}/\bar{OR}$	0.020
Fuel import value to fuel subsidy payments	$q\bar{P_o^*}O/\bar{OS}$	0.300

The foreign economy's monetary policy reaction to inflation, ω_{π^*}, is set equal to 1.50 (Hollander et al., 2018) while the response to output, ω_{y^*}, is set to 0.50 (Hollander et al., 2018). The second category of parameters were calibrated so as to match the corresponding data sample mean while the last set of parameters correspond to the implied steady state values from the model setup. The steady state ratios reported in Table 4.2 are derived using data for the Nigerian economy spanning the last three decades.

Prior moments

Table 4.3 presents the prior distributions for the parameters to be estimated. The priors relating to parameters for the small open economy were formed partly based on the data and Iklaga (2017) while those for the foreign economy are based on Smets and Wouters (2007). In cases where limited information is available to form credible priors, we allow such priors to have a more diffuse distribution than those typically found in related literature.

Of particular interest to our study are the parameters in the monetary and fiscal policy rules. The reaction coefficients in the monetary policy function are assumed to follow gamma distributions with the coefficient for inflation (ω_π) centered at 1.5 while the coefficients for output (ω_y) and real exchange rate (ω_q) are each set to 0.125 (Iklaga, 2017; Smets and Wouters, 2007). Most of the parameters relating to the fiscal rules are based on Algozhina (2015) as follows: response of lump-sum taxes to fiscal debt, φ_b, (0.40), response of lump-sum taxes to fuel subsidy payments, φ_{os}, (0.10), and response of lump-sum taxes to oil revenue, φ_{or}, (0.30). The assumed priors for the response of government consumption to debt, oil revenue, and fuel subsidies are set to -0.30, 0.00, and 0.8, respectively. Following Cebi (2012), we assume zero priors for the responses of the fiscal rules to output in a bid to allow the data reveal the nature of fiscal cyclicality in the resource-rich economy.

4.5 Results

4.5.1 Parameter estimates

Table 4.3 reports the prior and posterior distributions for the estimated structural and policy parameters. The estimates for the shock persistence parameters and the standard deviation of shocks are presented in Table C.1 of Appendix C.3. The parameter for labour supply elasticity, φ, which controls the response of hours to structural shocks is estimated at 1.47. This is is slightly higher than the assumed prior of 1.45. At 1.35, the estimated relative risk aversion parameter (σ) implies that the response of savings/investment decision of households to structural shocks is not as high as 2.0 initially assumed. It is, however, higher than the

1.31 obtained by Iklaga (2017) for the Nigerian economy and lower that the value of 1.38 estimated by Smets and Wouters (2007) for the US economy. At $\phi_c = 0.41$, the estimated consumption habit parameter is lower than the assumed 0.70 and the value of 0.71 estimated by Iklaga (2017).

Table 4.3: Prior and posterior estimates for the full sample, 2000Q2-2018Q2

Parameter	**Prior distribution**			**Posterior distribution**		
	Density	Mean	Std Dev	Mean	90% HPD Int.	
Structural parameters						
Ricardian consumers: γ_R	Beta	0.60	0.10	0.438	0.310	0.574
Labour supply elasticity: φ	Gamma	1.45	0.10	1.473	1.312	1.631
Relative risk aversion: σ	Inv. Gamma	2.00	0.40	1.347	1.077	1.596
External habit: ϕ_c	Beta	0.70	0.10	0.413	0.285	0.538
Investment adj. cost: χ	Gamma	4.00	3.00	2.995	1.076	4.800
Fuel pricing parameter: ν	Beta	0.30	0.10	0.338	0.113	0.553
Oil - core cons. elast.: η_o	Gamma	0.20	0.10	0.158	0.038	0.272
For. - dom. cons. elast.: η_c	Gamma	0.60	0.20	0.631	0.295	0.945
For. - dom. inv. elast.: η_i	Gamma	0.60	0.20	0.613	0.297	0.919
Calvo - domestic prices: θ_h	Beta	0.70	0.10	0.592	0.463	0.732
Calvo - import prices: θ_f	Beta	0.70	0.10	0.594	0.432	0.758
Monetary policy parameters						
Taylor, π: ω_π	Gamma	1.500	0.20	2.866	2.588	3.141
Taylor, y: ω_y	Gamma	0.125	0.05	0.086	0.033	0.137
Taylor, q: ω_q	Gamma	0.125	0.05	0.127	0.040	0.209
Taylor, smoothing: ρ_r	Beta	0.500	0.25	0.279	0.082	0.478
Fiscal policy rules parameters						
Tax, b: φ_b	Normal	0.40	1.00	-0.053	-1.158	1.114
Tax, or: φ_{or}	Normal	0.30	1.00	-0.051	-0.333	0.235
Tax, os: φ_{os}	Normal	0.10	1.00	0.836	0.343	1.283
Tax, y: φ_y	Normal	0.00	0.50	0.107	-0.650	0.885
Tax, smoothing: ρ_{tx}	Beta	0.50	0.25	0.539	0.370	0.718
Govt. Cons., b: ω_b	Normal	-0.30	0.20	-0.171	-0.453	0.130
Govt. Cons., or: ω_{or}	Normal	0.00	0.20	1.207	1.156	1.265
Govt. Cons., os: ω_{os}	Normal	0.80	1.00	-0.047	-0.215	0.093
Govt. Cons., y: ω_{gy}	Normal	0.00	0.50	1.188	0.673	1.704
Govt. cons., smoothing: ρ_{g_c}	Beta	0.50	0.25	0.139	0.041	0.233

The elasticity of substitution between oil and non-oil goods, η_o, is estimated at 0.16, which is slightly lower than the assumed prior value of 0.2. The elasticity of intra-temporal substitution between domestically produced and imported investment goods consumed by the household, η_i, is estimated at 0.61, which is about the same value as the assumed prior of 0.60.

The estimated Calvo price parameters for domestically produced goods and imported goods are estimated at about 0.59, compared to their respective priors of 0.7. The fuel pricing rule parameter, ν, which governs the extent to which government subsidises the consumption of fuel in the domestic economy is estimated at about 0.34; implying a pass-through of about 34.0 per cent from international oil price changes to domestic petrol price. The estimated fuel pricing rule has implications for the evolution of domestic prices and the response of monetary policy to an oil price shock.

Turning to the estimated monetary policy reaction function, equation (4.51) shows that the feedback coefficient on inflation is about 2.07, implying that the CBN was quite aggressive in responding to price inflation during the sample period. The estimated feedback coefficient for inflation is higher than unity, which is consistent with the Taylor principle and the active monetary policy argument of Leeper (1991). In addition to inflation, the monetary authority responds to output and the exchange rate as their feedback coefficients in the estimated Taylor rule are 0.06 and 0.09, respectively. At $\rho_r = 0.28$, the estimated interest rate smoothing parameter is quite low, compared to the assumed prior of 0.5. It is, however, slightly higher than 0.26 obtained by Medina and Soto (2005) for the Chilean economy, 0.27 obtained by Romero (2008) for the Mexican economy, and 0.20 estimated by Olayeni (2009) for Nigeria over the 1986-2004 period.

$$\begin{aligned}
\widetilde{R}_t &= 0.279\widetilde{R}_{t-1} + 2.066\widetilde{\pi}_t + 0.062\widetilde{y}_{h,t} + 0.092\widetilde{q}_t && (4.51)\\
\widetilde{tx}_t &= 0.539\widetilde{tx}_{t-1} - 0.024\widetilde{b}_{t-1} + 0.049\widetilde{y}_{t-1} + 0.385\widetilde{os}_t - 0.023\widetilde{or}_t && (4.52)\\
\widetilde{g}_{c,t} &= 0.139\widetilde{g}_{c,t-1} - 0.147\widetilde{b}_{t-1} + 1.023\widetilde{y}_{t-1} - 0.041\widetilde{os}_t + 1.039\widetilde{or}_t && (4.53)
\end{aligned}$$

The estimated tax rule for the oil-producing emerging economy is shown in equation (4.52). It reveals that the feedback parameter with respect to lagged debt, φ_b, is -0.02. Though statistically insignificant (Table 4.3), the estimated negative response of taxes to debt is contrary to expectation. This unexpected response reflects the weak domestic tax systems in most resource rich emerging economies and highlights the revenue substitution phenomenon discussed in Berg et al. (2013) and Tijerina-Guajardo and Pagán (2003). The responses of taxes to output, oil subsidy payments and oil revenues are estimated at 0.05, 0.39 and -0.02, respectively. These imply that taxes rise in response to increased fuel subsidy payments but falls with increased oil revenues. The estimated negative response of taxes to oil revenues in equation (4.52) provides evidence of revenue substitution in the resource-rich emerging economy, similar to the finding by Tijerina-Guajardo and Pagán (2003) for the Mexican economy. As shown in Table 4.3, only fuel subsidies turned out statistically significant in the tax rule.

The estimated government spending rule presented in equation (4.53) indicates that the response of government consumption to debt is -0.15. This implies that government consumption declines with increased debt levels. This is consistent with the tenets of Ricardian fiscal policy and in line with the passive fiscal policy characterisation of Leeper (1991). Also, government spending responds positively to output (1.02), negatively to fuel subsidy payments (-0.04), and positively to oil revenues (1.04). It is important to note that the estimated negative response of government spending to fuel subsidy payments implies that the subsidy regime constrains the ability of fiscal policy to effectively drive aggregate demand in the oil-producing emerging economy. Our results indicate that only oil revenue and output are statistically significant in the estimated government spending rule (Table 4.3).

Since both taxes and government spending decrease with increasing debt levels, our results suggest that government spending (which, as shown in equation (4.53) has a higher fiscal feedback coefficient on debt) plays a non-trivial role in stabilising debt. Also, equations (4.52) and (4.53) provide evidence of pro-cyclical fiscal policy as both taxes and government spending rise with increased output. The degree of fiscal smoothing is higher in the tax rule than in the government spending rule, contrary to the findings of Cebi (2012) for the developed economy of Turkey. This further buttresses our view regarding the weak tax systems in the resource-rich emerging economy and the active role of government spending as a tool for debt stabilisation.

4.5.2 The effects of a negative oil price shock

In this section, we discuss the implications of a negative real international oil price shock for selected real and nominal variables. We pay particular attention to how monetary and fiscal policies respond to the shock. As shown in Figure 4.2, a 1.0 per cent negative shock to the real international price of oil leads to a contraction of about 2 basis points in total GDP upon impact. Since oil is included in the production technology of firms, real marginal cost declines following a negative shock to real international oil price, causing domestic inflation to fall. However, the pass-through effects of the depreciated real exchange rate to domestic prices causes imported goods inflation to rise. Thus, following a 1.0 per cent negative real oil price shock, the combined effects of higher imported inflation and lower domestic prices generates an increase of 0.5 basis points in core inflation. Similarly, the headline inflation rises, albeit by a smaller magnitude than the core inflation.

In response to increased headline inflation, the CBN embarks on a contractionary monetary policy with an initial interest rate hike of about 0.4 basis points. This is followed by an interest rate cut that helps to boost output and consumption. The initial increase in interest rate by the CBN exacerbates the contractionary impact of the oil price shock on output. This highlights Ferrero and Seneca (2019)'s argument regarding the policy trade-off confronting the monetary authority of small open resource-rich economies facing a negative resource-price shock. In other words, the CBN faces the dilemma of stabilising either prices or output in the aftermath of a negative real international oil price shock.

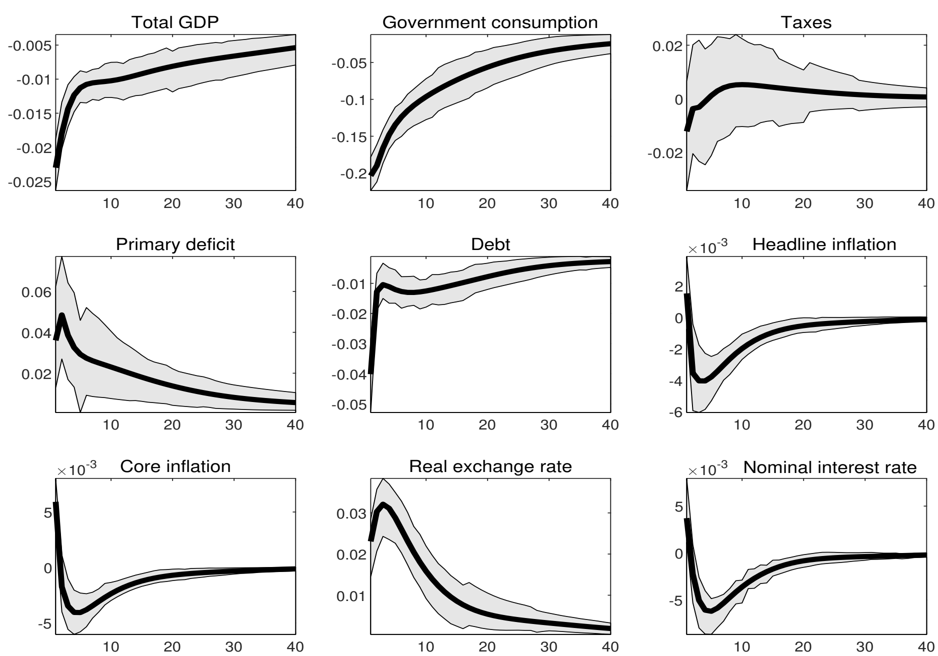

Figure 4.2: Macroeconomic and policy responses to a negative real international oil price shock

In terms of the responses of the fiscal variables, both government spending and taxes decline following a negative real oil price shock. The reduction in government spending in response to lower oil revenues and aggregate output signifies fiscal pro-cyclicality, which is consistent with the estimated equation (4.53) and the findings of Romero (2008) in a similar study for the oil-exporting economy of Mexico. The observed weak response of taxes reflects our earlier findings regarding the statistical insignificance of oil revenues in equation (4.52) and the poor domestic tax mobilisation systems prevalent in most resource rich emerging economies (Salti, 2008).

Following a negative oil price shock, the nominal interest rate rises initially but falls subsequently, remaining below its steady state level for more than 20 quarters. This has implications for the fiscal variables as a lower interest rate causes a reduction in debt. The lower debt as well as the reduction in fiscal revenues arising from the negative oil price shock provide impetus for the government to increase primary deficit. Thus, in rational expectations equilibrium, primary deficit acts in a manner that stabilises debt. Whereas the response of taxes is weak, government consumption falls strongly in response to the increased primary deficit to ameliorate the deficit shock and stabilise debt.

4.5.3 Policy interactions before and after the 2008 GFC

This section examines whether the 2008/09 global financial crisis has implications for monetary-fiscal interactions in the resource-rich economy. We partition the data sample into two as follows: (i) pre-GFC sample, covering the period 2000Q2-2008Q4; and (ii) post-GFC sample, covering the period 2009Q1-2018Q2. The model is fitted to the two data samples and we compare our results, especially with regards to the estimated monetary and fiscal policy rules. Table C.2 under Appendix C.3 reports the estimated structural and policy parameters for the two models while the estimated monetary and fiscal policy reaction functions are summarised in equations (4.54) - (4.59).

The estimated monetary policy rules provide empirical evidence of an active monetary policy in both the pre- and post-GFC periods, implying that the estimated monetary policy reaction function obey the Taylor principle regardless of the occurrence of the GFC. However, the pre-crisis period was associated with higher interest rate smoothing while the post-crisis period was characterised by higher monetary policy responses to inflation, domestic output and the real exchange rate. As shown in equations (4.54) and (4.57), the responses of interest rate to inflation in the pre- and post-crisis periods were estimated at 1.33 and 1.63, respectively. Thus, the CBN was more aggressive in containing inflation in the post-GFC period. This finding is further buttressed by the impulse responses of nominal interest rate to an oil price shock presented in Figure 4.3.

Estimated policy rules for the pre-GFC period:

$$\begin{aligned}
\widetilde{R}_t &= 0.350\widetilde{R}_{t-1} + 1.331\widetilde{\pi}_t + 0.092\widetilde{y}_{h,t} + 0.079\widetilde{q}_t && (4.54)\\
\widetilde{tx}_t &= 0.698\widetilde{tx}_{t-1} - 0.014\widetilde{b}_{t-1} + 0.032\widetilde{y}_{t-1} + 0.074\widetilde{os}_t + 0.079\widetilde{or}_t && (4.55)\\
\widetilde{g}_{c,t} &= 0.844\widetilde{g}_{c,t-1} - 0.045\widetilde{b}_{t-1} - 0.011\widetilde{y}_{t-1} + 0.148\widetilde{os}_t + 0.029\widetilde{or}_t && (4.56)
\end{aligned}$$

Estimated policy rules for the post-GFC period:

$$\begin{aligned}
\widetilde{R}_t &= 0.267\widetilde{R}_{t-1} + 1.625\widetilde{\pi}_t + 0.103\widetilde{y}_{h,t} + 0.098\widetilde{q}_t && (4.57)\\
\widetilde{tx}_t &= 0.281\widetilde{tx}_{t-1} - 1.225\widetilde{b}_{t-1} + 0.109\widetilde{y}_{t-1} + 1.300\widetilde{os}_t + 0.106\widetilde{or}_t && (4.58)\\
\widetilde{g}_{c,t} &= 0.064\widetilde{g}_{c,t-1} - 0.140\widetilde{b}_{t-1} + 0.371\widetilde{y}_{t-1} - 0.067\widetilde{os}_t + 0.867\widetilde{or}_t && (4.59)
\end{aligned}$$

In terms of the tax rule, the estimated fiscal feedback coefficients on debt shown in equations (4.55) and (4.58) indicate that taxes respond negatively to debt before and after the GFC. This is contrary to theoretical expectation, but in line with our finding for the full sample (equation (4.52)). This implies that the disturbances associated with the 2008 GFC did not cause any significant change to tax policy in the resource-rich emerging economy. However, the degree of tax smoothing is estimated to be higher in the pre-crisis sample, a period of increasing oil prices. At an estimated value of about -1.23, the negative response of taxes to debt was more elevated during the post-crisis period. In all, taxes were more responsive to debt, output, fuel subsidies and oil revenues in the post-crisis period. As shown in Figure 4.3, taxes appear to respond more to real international oil price shock in the post-GFC period.

Turning to the government spending rule, equations (4.56) and (4.59) indicate that government spending falls in response to increasing debt levels. This is consistent with our finding for the full sample (equation (4.53)) and in line with expectations. In other words, government consumption acts to stabilise debt in both the pre- and post-GFC periods. However, we note that government spending responds more to debt levels in the post-GFC period; implying a more passive fiscal policy in the sense of Leeper (1991). As shown in Figure 4.3, following a negative shock to real international oil price, both debt and government consumption fall. However, as the negative effects of the oil price shock continues to taper off both in the pre- and post-GFC periods, government consumption falls further in the post-GFC period as against the situation in the pre-GFC period.

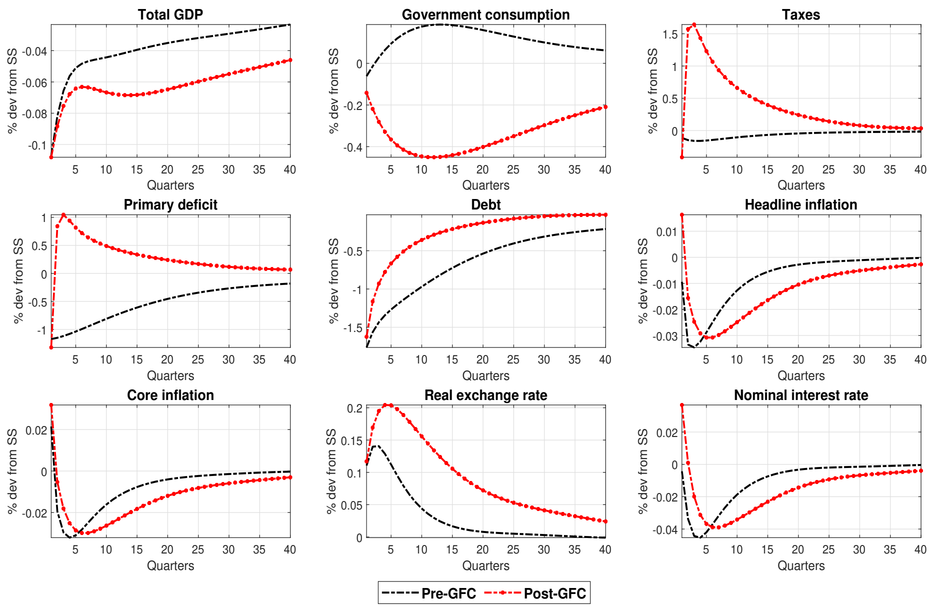

Figure 4.3: Impulse responses to a negative real international oil price shock, pre- and post-global financial crisis periods

Also, government spending was substantially more persistent in the pre-GFC period; a development that may not be unconnected with the favourable and stable oil prices recorded during the period. Interestingly, while government spending was counter-cyclical during the pre-GFC period (equation (4.56)), the positive feedback coefficient on output in the post-GFC period imply a pro-cyclical fiscal policy regime (equation (4.59)). This is in line with the impulse responses presented in Figure 4.3. Notably, the response of government spending to fuel subsidy payments was positive in the pre-GFC period and negative in the post-GFC period. While the positive response observed in the pre-GFC period is supported by the steady rise in oil prices during the period, the negative feedback coefficient on fuel subsidies in the post-GFC period is associated with episodic declines in global oil prices as well as higher oil price volatility.

4.5.4 Policy interactions under alternative fiscal rules

In this section, we investigate whether the nature of the fiscal rules considered in our benchmark model matters for monetary-fiscal interaction in the resource-rich economy. To this end, we re-estimated our model under alternative fiscal rules that ignore oil-related flows (i.e. oil revenues and fuel subsidy payments) as shown in equations (4.44) and (4.45). The estimated parameters for the benchmark and alternative models are shown in Table C.3 under Appendix C.3 while the estimated monetary and fiscal reaction functions are reported in equations (4.60) - (4.65).

Notably, the response of taxes to debt is sensitive to our alternative specifications regarding the conduct of fiscal policy. Whereas taxes respond negatively to increasing debt under the benchmark specification in equation (4.61), we report a positive response under the alternative model in equation (4.64). This result tends to suggest that the pursuit of conservative fiscal rules may help resource-rich economies develop a more robust tax mobilisation systems. Overall, results under the alternative model show that monetary policy responds more actively to inflation while taxes respond positively to debt and government consumption responds negatively to debt. The findings under the alternative model are consistent with the results reported by Cebi (2012) for Turkey; and in line with the idea of active monetary and passive fiscal policy of Leeper (1991).

Estimated policy rules under the model that includes oil related flows in the fiscal rules:

$$\widetilde{R}_t = 0.279\widetilde{R}_{t-1} + 2.066\widetilde{\pi}_t + 0.062\widetilde{y}_{h,t} + 0.092\widetilde{q}_t \tag{4.60}$$

$$\widetilde{tx}_t = 0.539\widetilde{tx}_{t-1} - 0.024\widetilde{b}_{t-1} + 0.049\widetilde{y}_{t-1} + 0.385\widetilde{os}_t - 0.023\widetilde{or}_t \tag{4.61}$$

$$\widetilde{g}_{c,t} = 0.139\widetilde{g}_{c,t-1} - 0.147\widetilde{b}_{t-1} + 1.023\widetilde{y}_{t-1} - 0.041\widetilde{os}_t + 1.039\widetilde{or}_t \tag{4.62}$$

Estimated policy rules under the model that excludes oil related flows from the fiscal rules:

$$\widetilde{R}_t = 0.243\widetilde{R}_{t-1} + 2.126\widetilde{\pi}_t + 0.105\widetilde{y}_{h,t} + 0.086\widetilde{q}_t \tag{4.63}$$

$$\widetilde{tx}_t = 0.643\widetilde{tx}_{t-1} + 0.009\widetilde{b}_{t-1} + 0.049\widetilde{y}_{t-1} \tag{4.64}$$

$$\widetilde{g}_{c,t} = 0.936\widetilde{g}_{c,t-1} - 0.020\widetilde{b}_{t-1} + 0.002\widetilde{y}_{t-1} \tag{4.65}$$

The monetary policy rule displays lower inertia and higher responses to inflation and output under the alternative model. However, the response of monetary policy to the real exchange rate is higher when resource-related flows are included in the fiscal rule. In other words, the response of fiscal policy to oil related flows imposes additional pressure on the central bank to respond to exchange rate developments in the resource-rich emerging economy.

The degree of fiscal smoothing in the tax rule is higher under the alternative model while the response of taxes to output is the same under the two models. This provides empirical evidence in support of the view that fiscal rules that ignore resource-relates flows are associated with lower fiscal volatility. This also tend to suggest that the implementation of a functional sovereign wealth fund in the resource-rich economy could engender better macroeconomic stability. Similarly, government spending exhibit higher inertia once resource-related flows are excluded from the fiscal rules. The implications of the alternative fiscal rules for the response of the economy to an oil price shock are discussed next.

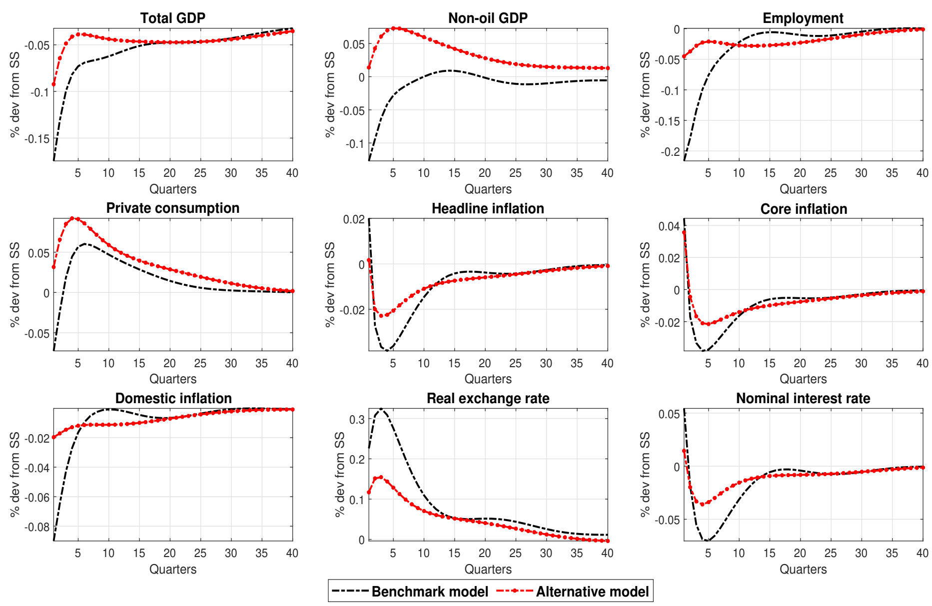

Figure 4.4: Impulse responses to a negative real international oil price shock under alternative fiscal rules

As shown in Figure 4.4, the contractionary impact of a negative oil price shock on aggregate output is ameliorated under the mode that excludes oil-related flows from the fiscal rules (alternative model). Furthermore, the fiscal rules that ignore oil-related flows yield lower lower exchange rate depreciation and headline inflation. Monetary policy responds to the lower headline inflation with an interest rate cut, which in turn attenuates the reduction in employment and boosts private consumption and non-oil GDP. These findings are in line with the results reported by Medina and Soto (2016), which show that better macroeconomic outcomes are achieved in the resource-rich economy of Chile once fiscal policy is muted to commodity prices.

4.5.5 Policy interactions under alternative monetary policy rules

In view of the roles played by the exchange rate in the transmission of oil price shocks to the resource-rich economy (Figure 4.2), we consider monetary-fiscal interactions under two alternative assumptions regarding the central bank's monetary policy reaction function. These are: (i) a monetary policy rule that responds to real exchange rate as in our benchmark model - managed floating exchange rate regime, and (ii) a monetary policy rule that does not respond to real exchange rate depicted as the alternative model - floating exchange rate regime (Sangare, 2016). The parameter estimates for the two models are reported in Table C.4 under Appendix C.3 while the estimated monetary and fiscal policy reaction functions are summarised in equations (4.66) - (4.71).

Estimated policy rules under the model that includes exchange rate in the Taylor rule:

$$\widetilde{R}_t = 0.279\widetilde{R}_{t-1} + 2.066\widetilde{\pi}_t + 0.062\widetilde{y}_{h,t} + 0.092\widetilde{q}_t \tag{4.66}$$

$$\widetilde{tx}_t = 0.539\widetilde{tx}_{t-1} - 0.024\widetilde{b}_{t-1} + 0.049\widetilde{y}_{t-1} + 0.385\widetilde{os}_t - 0.023\widetilde{or}_t \tag{4.67}$$

$$\widetilde{g}_{c,t} = 0.139\widetilde{g}_{c,t-1} - 0.147\widetilde{b}_{t-1} + 1.023\widetilde{y}_{t-1} - 0.041\widetilde{os}_t + 1.039\widetilde{or}_t \tag{4.68}$$

Estimated policy rules under the model that excludes exchange rate from the Taylor rule:

$$\widetilde{R}_t = 0.319\widetilde{R}_{t-1} + 1.952\widetilde{\pi}_t + 0.061\widetilde{y}_{h,t} \tag{4.69}$$

$$\widetilde{tx}_t = 0.543\widetilde{tx}_{t-1} + 0.020\widetilde{b}_{t-1} + 0.055\widetilde{y}_{t-1} + 0.363\widetilde{os}_t - 0.034\widetilde{or}_t \tag{4.70}$$

$$\widetilde{g}_{c,t} = 0.125\widetilde{g}_{c,t-1} - 0.146\widetilde{b}_{t-1} + 1.039\widetilde{y}_{t-1} - 0.066\widetilde{os}_t + 1.060\widetilde{or}_t \tag{4.71}$$

It is quite revealing that under a floating exchange rate regime (a Taylor rule that excludes real exchange rate), taxes respond positively to debt while government consumption responds negatively to debt. These responses are in line with theoretical expectations, such that both taxes and government spending act in a manner that stabilise debt. Thus, the alternative model upholds the monetary dominance view for Nigeria, where fiscal policy is

Ricardian and monetary policy obeys the Taylor principle. The estimated monetary policy rules presented in equations (4.66) and (4.69) provide evidence of higher degree of interest rate smoothing under the floating exchange rate regime (i.e. the alternative model), implying lower interest rate volatility. The interest rate feedback coefficient on inflation is lower under the alternative model while the responses of monetary policy to output under the two models are about the same. Under both models, the size of the fiscal responses to debt and output are similar. Similar to the findings under the benchmark model, equation (4.70) shows that taxes decline with increasing oil revenues. This finding is in line with the revenue substitution phenomenon highlighted by Tijerina-Guajardo and Pagán (2003) for the Mexican economy. Also, government consumption declines with increasing fuel subsidy payments under the two models. This implies that increased subsidy payments constrains fiscal space and limits the capacity of fiscal policy to drive desired macroeconomic objectives, such as output stabilisation.

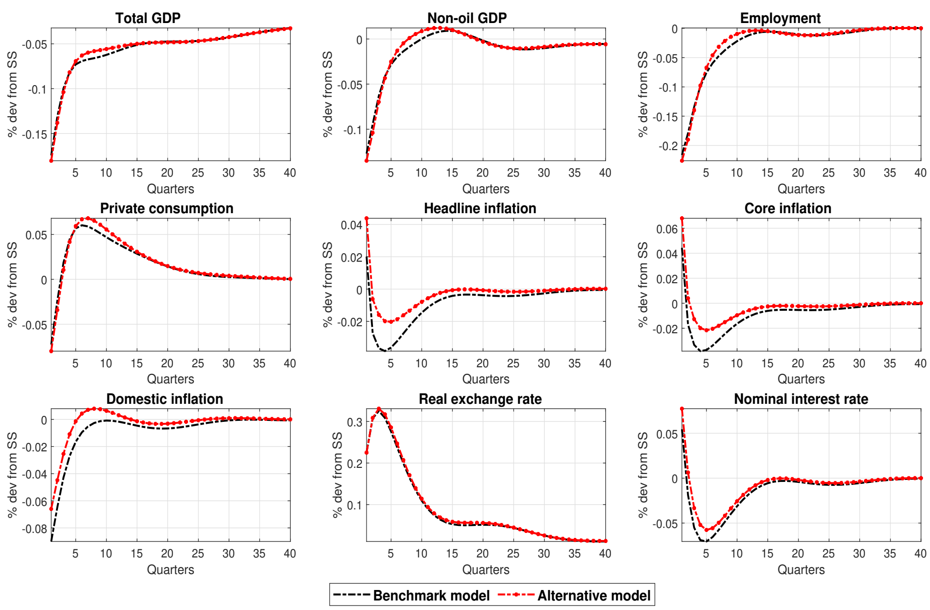

Figure 4.5: Impulse responses to a negative real international oil price shock under alternative Taylor rules

As shown in Figure 4.5, the impulse responses to a real international oil price shock under the two models are qualitatively and quantitatively similar. Following a negative oil price shock, the the floating exchange rate regime yields a slightly more depreciated exchange rate, causing higher increases in the core and headline measures of inflation. Thus, a higher headline inflation is observed under the alternative model. The central bank responds with a relatively higher interest rate hike, which generates lower domestic inflation but comes at a cost of lower employment, non-oil output and total GDP. Overall, while the alternative model yields the desired response of taxes to debt, our results did not provide evidence of substantial gains in terms of the overall response of the economy to a negative real international oil price shock. In other words, regardless of whether monetary policy responds to real exchange rate or not, an oil price shock has similar macroeconomic implications for the economy.

4.6 Conclusion

In this paper, we study monetary-fiscal interactions under a new-Keynesian DSGE model of an oil exporting economy that accounts for three key characteristics. First, the domestic economy is highly dependent on oil. Thus, we include fuel in the consumption basket of households and the production technology of firms. Second, we allow for a fuel subsidy regime that distorts domestic price signals and puts additional fiscal burden on the government. Third, we specify fiscal rules that allows for the vulnerability of fiscal policy to resource-related flows. The model is estimated for Nigeria using data on fifteen macroeconomic variables for the period 2000Q2-2018Q2.

We document a number of useful results. First, we show that a negative shock to the real price of oil contracts the aggregate GDP, depreciates the real exchange rate, and increases headline inflation in the resource-rich emerging economy. The central bank responds with an initial interest rate hike, while primary deficit increases. We report active monetary policy and passive fiscal policy over the full sample. This implies a Ricardian fiscal policy and a monetary policy reaction function that obeys the Taylor principle. To our knowledge, this represents the first attempt at estimating the fiscal reaction function for Nigeria. Second, the 2008/09 global financial crisis did not significantly alter the structure of monetary-fiscal interaction in the RREE. However, both the monetary and fiscal policy rules are less persistent in the post-crisis period while government spending was counter-cyclical in the pre-crisis period.

Third, both taxes and government consumption fall in response to growing debt levels under our benchmark model. Thus, government consumption causes primary deficit to decline and acts to stabilise debt. However, once resource-related flows (oil revenues and fuel subsidy payments) are excluded from the fiscal rules, taxes respond positively to debt while government spending responds negatively. These imply that fiscal rules that do not respond to resource-related flows generate beneficial outcomes in terms of neutralising the revenue substitution problem, activating the "automatic stabiliser" role of fiscal policy, reducing fiscal pro-cyclicality, and enhancing overall macroeconomic stability in the small open oil-producing economy. In other words, both taxes and government spending stabilise debt under the alternative model consistent with the dictates of Ricardian fiscal policy. Fourth, an alternative monetary policy rule under which the central bank does not respond to exchange rate causes taxes to respond positively to increasing debt levels.

Future research efforts could benefit from a number of methodological and model extensions. In terms of the methodology, the model could be adapted to study the interaction between monetary and fiscal policy in resource rich economies using a Markov switching DSGE model (Goncalves, Portugal and Aragon, 2016). This approach enables the study of policy interactions under a setting that allows the parameters of the policy rules to switch between active and passive regimes over time. Second, even though the tasks of monetary and macro-prudential policies are conducted by the same institution in most economies, the objectives of the two policies have been found to contradict at times, especially since the occurrence of the 2008 global financial crisis. Therefore, extending the model developed in this paper to allow for the joint analysis of monetary, fiscal, and macro-prudential policy has a lot of appeal.

Chapter 5

Key Findings and Directions for Future Research

The dynamic effects of oil price shocks on oil-importing advanced economies have been thoroughly investigated from both theoretical and empirical perspectives. In contrast, the literature on oil-producing emerging economies is relatively scanty and still evolving. In this thesis, we argue that resource-rich emerging economies exhibit unique features that either exacerbate their response to adverse terms of trade shocks or increase their vulnerabilities. These include high dependence on oil as a source of energy, foreign exchange and fiscal revenues; dependence on fuel importation due to low domestic refining capacity; inefficient fuel consumption subsidy regimes; fiscal volatility and pro-cyclicality; revenue substitution; presence of hand-to-mouth consumers; financial market inefficiencies; and high import dependence. Ignoring some of these features in theoretical models of oil-producing emerging economies has implications for the understanding of business cycle dynamics and macroeconomic policies in those economies. This thesis, which comprises three related papers, contributes to the debate on the oil-macroeconomy nexus in small open oil-producing emerging economies. It pays attention to some of the features mentioned above. The key issues emanating from the papers as well as suggestions for future research are discussed in this section.

5.1 Key findings

Paper 1: In the first paper, we study the macroeconomic implications of ignoring two key features in DSGE models often used to analyse business cycle dynamics and monetary policy in resource-rich economies: (i) capital accumulation and (ii) oil intensity of domestic output. We argue that while it is common practice to abstract from these features for the reasons of tractability (see e.g. Ferrero and Seneca, 2019; Galí, 2015; Gali and Monacelli, 2005; Romero, 2008; amongst others), the implications of such model simplification for the response of oil-producing economies to an oil price shock has not been explored till date. To fill this gap, we extend the model developed by Ferrero and Seneca (2019) accordingly and compare our results with those generated from the original model. The main results are as follows:

1. Abstracting from physical capital in DSGE models of an oil-producing economy leads to the under-estimation of the economy's response to an oil price shock (Vásconez et al., 2015). Following a negative international oil price shock, the reduction in demand for materials input by the oil firms is substantially larger under the model with capital, leading to a more severe contractionary effects on domestic output when compared to the case under the model without capital. Under a CPI inflation-based Taylor rule, the higher exchange rate pass-through to prices recorded under the model with capital causes the central bank to be relatively more hawkish in response to an oil price shock; thus exacerbating the contractionary response of output (Bernanke et al., 1997). However, under the model with capital, the economy rebounds faster due to firm's investment dynamics in response to interest rate adjustments implemented by the central bank.

2. Including oil as a factor input in domestic production attenuates the contractionary effects of a negative oil price shock on non-oil GDP as firms respond to the lower marginal cost arising from the reduction in input prices. In terms of inflation, the lower marginal cost recorded under the model that features oil intensity generates lower domestic inflation; which further reduces the influence of imported inflation on headline inflation. Thus, accounting for oil intensity moderates the contractionary impact of a negative oil price shock on output and limits the pass-through effects of exchange rate into CPI inflation.

3. Once capital is included, the central bank is able to achieve greater macroeconomic stability by responding not only to inflation and output, but also exchange rate. In addition, contrary to the results reported by Ferrero and Seneca (2019), allowing for interest rate inertia in the central bank's reaction function reduces policy loss under our benchmark model that includes capital. Thus, of the competing alternative monetary policy rules considered under our benchmark model, a Taylor rule that features inflation rate, output, real exchange rate and interest rate inertia *(IFDITRyq)* emerges as the optimal monetary response to an oil price shock.

4. These findings highlight the need for a cautious interpretation of quantitative results emanating from DSGE models of small open oil-producing economies that abstract from capital and oil intensity. Monetary policy exercises conducted on the basis of such restricted models should also be interpreted with caution.

Paper 2: We study business cycle dynamics in an oil producing emerging economy with an inefficient fuel subsidy regime. In line with the overarching objective of the thesis, we account for a number of emerging economy features, including: presence of hand-to-mouth consumers, inefficient financial market, fuel importation, oil in household consumption, resource-driven fiscal policy, fiscal pro-cyclicality, and revenue substitution. The model, which is estimated for the Nigerian economy, is used to address a number of questions that have been ignored in literature. We report a number of interesting results as follows:

1. Output fluctuations are driven mainly by oil and monetary policy shocks in the short run and domestic supply shocks in the medium term. Specifically, oil shocks account for about 23 per cent of variations in output up to the fifth year, while fiscal policy appears muted. Impulse response analyses show that a negative oil price shock generates persistent negative impact on the aggregate GDP and a short-lived positive effect on headline inflation consistent with the findings of Ferrero and Seneca (2019). Non-oil GDP is however boosted due to lower input prices and the transfer of productive resources from the oil sector to the non-oil sector. On the other hand, monetary and domestic supply shocks jointly account for around 72 per cent of short run variations in headline inflation while oil-price shocks play a less prominent role due to the low pass-through effect arising from the fuel subsidy regime.

2. We estimate that about 43 per cent of changes to international oil prices is transmitted into domestic fuel price in Nigeria. The implied fuel consumption subsidy adds

additional rigidity to domestic prices which in turn alters the dynamics of aggregate inflation and indeed, the response of monetary policy to an oil price shock. Following a negative oil price shock, a zero-subsidy regime generates lower output contraction, lower headline inflation, but higher real exchange rate depreciation in the short run. This implies that the fuel subsidy regime accentuates the contractionary effects of a negative oil price shock while also constraining the capacity of fiscal policy to drive output growth in the long run. However, retaining the subsidy programme has some appeal in terms of its ability to generate relative macroeconomic stability, compared to the situation under a no-subsidy regime. We argue that subsidy reforms potentially has fiscal, growth, and welfare implications for the economy and caution that a successful reform must necessarily accommodate the deployment of well-targeted safety nets as well as the evolution of sustainable adjustment mechanisms.

3. Given an oil price shock, the core inflation-based monetary policy reaction function that features output and real exchange rate represents an optimal strategy for stabilising the Nigerian economy in the aftermath of an oil price shock. This finding is robust to alternative assumptions regarding the inclusion/exclusion of fuel subsidy regime in our model. Core inflation-based Taylor rule outperforms its competitors in stabilising prices and exchange rate but leads to output instability in the short run. However, a domestic inflation-based monetary policy rule yields superior outcomes in stabilising output. While an export price targeting rule reverses the contractionary effects of a negative oil price shock on aggregate GDP, it comes at the expense of overall domestic stability (Vogel et al., 2015). These results imply that monetary policy faces a trade-off between inflation and output stabilisation objectives (Ferrero and Seneca, 2019). Therefore, we argue that no “across-the-board” and “all-seasons” monetary strategy exists for dealing with adverse terms of trade shocks in the resource-rich economy. It is important that the CBN is aware of these trade-offs while designing monetary policy response to an oil price shock.

4. Following an oil price shock, a counter-cyclical fiscal policy regime aids the effectiveness of monetary policy in stabilising both real and nominal variables. This highlights the need for effective interaction between monetary and fiscal policy in Nigeria. The presence of hand-to-mouth consumers amplifies the contractionary effects of lower oil prices on output and consumption while the inflationary pressures resulting from exchange

rate depreciation are ameliorated in the absence of hand-to-mouth consumers.

Paper 3: The paper studies the interaction between monetary and fiscal policy in a resource-rich emerging economy whose fiscal policy is driven strongly by resource-related flows. Following Leeper (1991), we classify policy into active and passive regions by examining the behaviour of monetary and fiscal authorities. Our DSGE model features nominal and real rigidities, including an additional price stickiness that arises from a domestic fuel pricing rule. The fuel pricing rule gives rise to an implicit fuel subsidy regime with significant fiscal implications. Thus, we specify backward-looking fiscal rules that respond to debt, output, and oil related flows - i.e. receipts from resource rent and payments for fuel subsidy. On the other hand, monetary policy responds to inflation, domestic output and the real exchange rate. The model is fitted to Nigerian data in order to analyse the country's experience over the last two decades. Specifically, we characterise monetary-fiscal interaction in Nigeria over the period 2000:Q2 - 2018:Q2 and examine the sensitivity of our results to (i) the 2008/09 global financial crisis (ii) alternative fiscal policy rules and (iii) alternative monetary policy reaction functions. Our key findings are as follows:

1. Over the full sample, 2000:Q2 - 2018:Q2, we find evidence of active monetary and passive fiscal policy. This policy mix corresponds to the monetary dominance view where fiscal policy respects the government budget constraint and monetary policy responds sufficiently to inflation. In rational expectations equilibrium, primary deficit decreases with increasing debt levels. Contrary to expectations, the response of taxes to debt is negative and statistically insignificant due to low domestic revenue mobilisation in the resource-rich small open economy. However, government spending responds negatively to debt in line with expectation. These results highlight the weak domestic revenue mobilisation systems in the resource-rich emerging economy and the role of government expenditure as a tool for debt stabilisation. In addition, the estimated tax rule confirms the presence of revenue substitution in the resource-rich economy. We recommend that, in addition to strengthening the institutional arrangements for enhancing monetary-fiscal coordination, the design and implementation of dynamic tax policies that are less sensitive to resource-related flows are crucial for ensuring debt sustainability and macroeconomic stability in the country. It is expected that the recently passed 2020 Finance Act, if effectively enforced, will help the country improve its revenue mobilisation drive and reduce the incidence of deficit bias in Nigeria.

2. The findings reported above are robust to the occurrence of the 2008/09 global financial crisis. In other words, although the estimated monetary and fiscal policy rules exhibit less inertia in the post-crisis period; our results indicate active monetary and passive fiscal policy both in the pre- and post-crisis periods. The less persistent policy rules estimated for the post-crisis period could be partly explained by the higher volatility in oil prices during the period. In order to reduce policy and macroeconomic volatilities, it is recommended that the country embraces a fiscal rule that is based on cyclically adjusted balances while also strengthening existing fiscal institutions.

3. Once the responses of the fiscal rules to oil-related flows are muted, the fiscal feedback parameter in the tax rule turns positive; implying that taxes become positively responsive to debt in line with expectation. A comparison of impulse responses under the alternative fiscal rules further showed that macroeconomic gains accrue to the resource-rich economy when policies do not respond to resource-related flows. Rule-based fiscal policies supported by an appropriate institutional framework are capable of helping emerging economies to attain fiscal solvency, achieve macroeconomic stability, and ensure intergenerational equity (Schmidt-Hebbel, 2012). Thus, this paper calls for the strengthening of fiscal institutions and existing rules for managing oil earnings as a useful strategy for achieving greater policy harmony, long-term growth, and overall macroeconomic stability in the country.

4. Excluding real exchange rate from the Taylor rule causes taxes to adjust positively to debt while interest rate exhibits greater inertia. These suggest that a policy that allows for a more market determined exchange rate facilitates smoother domestic adjustments that enhances the capacity of taxes to respond positively to deficit shocks and activates the "automatic stabiliser" role of fiscal policy.

5. Over the full sample, we find evidence of pro-cyclical government spending driven by the fiscal authority's behaviour in the post-GFC period. In most emerging economies, fiscal policy pro-cyclicality are often partly caused by political economy pressures (Huidrom, Kose and Ohnsorge, 2016). Therefore, the implementation of proper institutional mechanisms (comprising fiscal rules, stabilisation funds, and medium-term expenditure frameworks) can help the country avoid pro-cyclical bias, achieve fiscal discipline and build fiscal space. Sufficient political will must also be demonstrated in support of the country's sovereign wealth fund.

5.2 Study limitations and directions for future research

In this section, we highlight some limitations of our study and indicate potential areas of future research. In paper 1, the extent to which oil producing economies are dependent on oil as a source of energy may not have been adequately captured. Thus, including oil in the consumption basket of households represents a useful extension for analysing the direct effects of oil price shocks on households consumption as well as the appropriateness of core inflation-based monetary policy rule (Medina and Soto, 2005). Second, determining the extent to which our findings regarding the roles of capital accumulation and oil intensity may differ under a model that allows for a fuel subsidy regime as well as alternative fiscal rules represents an avenue for future work (Di Bella et al., 2015; Estache and Leipziger, 2009).

The second paper can be extended in a number of ways. First, the model could be extended to accommodate a Sovereign Wealth Fund (SWF) as a mechanism for managing resource revenues in the resource-rich economy. Under such a setting, the macroeconomic and welfare benefits of the SWF can be explored. Second, we made a simplifying assumption that the central bank does not accumulate foreign reserves and the small open economy is not foreign exchange constrained. This assumption could be relaxed as in Senbeta (2011). In an economy characterised by fuel imports, the full impacts of an inefficient fuel consumption subsidy as well as the macroeconomic implications of its removal can be better explored by allowing for external reserves accumulation and foreign exchange constraints in the domestic economy.

In paper 3, we assume parameter constancy in the estimation of the monetary and fiscal policy rules. Future research efforts could benefit from a number of extensions. From a methodological point of view, the model could be adapted to study the interaction between monetary and fiscal policy within the framework of a Markov switching DSGE model. This approach enables the study of policy interactions under a setting that allows for regime shifts in the estimation of the parameters in the policy rules (Goncalves et al., 2016). Second, the 2008/09 global financial crisis led to increased recognition of macro-prudential policies as an important tool for preserving financial stability (Zhang and Zoli, 2016). Therefore, extending the model to include a financial sector is appealing as it allows for the study of macro-prudential policy, in addition to monetary and fiscal policies.

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Appendix A

Appendix for Chapter 1

A.1 Model variants

A.1.1 Benchmark model ($mod1$)

In this Appendix, we provide detailed derivations of the relevant first-order conditions of our benchmark model ($mod1$) described in the text. The relevant equations are summarised in A.1.1.2 while the log-linearized model is presented in A.1.1.3. The shock processes are presented in A.1.1.4. Variables in expressed in real terms are denoted by small letters. Also, variables with tildes represent log-deviations of such variables from their steady state values while the steady state variables are represented with bars. Thus, for any variable say Y_t,the following notations apply: $y_t = \frac{Y_t}{P_t}$, and $\tilde{Y}_t \equiv \log\left(\frac{Y_t}{\overline{Y}}\right)$.

first-order conditions

- **Household optimization problem:** The representative household maximise utility by choosing $\{C_t, N_t, B_{t+1}, K_{h,t+1}, I_t\}_{s=0}^{\infty}$. Thus, it maximizes:

$$E_0 \sum_{s=0}^{\infty} \beta^s \left(\ln C_{t+s} - \frac{N_{t+s}^{1+\varphi}}{1+\varphi} \right), \tag{A.1}$$

subject to the nominal budget constraint:

$$P_t C_t + P_t I_t + Q_t B_{t+1} + Q_t^* B_{t+1}^* \varepsilon_t = W_t N_t + R_{r,t} K_t + B_t + \varepsilon_t B_t^* + D_t - T_t, \tag{A.2}$$

and the process of capital accumulation:

$$K_{t+1} = (1-\delta) K_t + I_t \left[1 - \frac{\chi}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right], \tag{A.3}$$

The Lagrangian for this problem can be written as:

$$\begin{aligned}\mathcal{L} = E_0 \sum_{s=0}^{\infty} \beta^s \Bigg\{ & \ln C_{t+s} - \frac{N_{t+s}^{1+\varphi}}{1+\varphi} \\ & - \lambda_t^c \left[P_t C_t + P_t I_t + Q_t B_{t+1} + Q_t^* B_{t+1}^* \varepsilon_t - W_t N_t - R_{r,t} K_t - B_t - \varepsilon_t B_t^* - D_t + T_t . \right] \\ & - \lambda_t^k \left[K_{h,t+1} - (1-\delta) K_{h,t} - I_t \left(1 - \frac{\chi}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right) \right] \Bigg\}, \end{aligned} \tag{A.4}$$

where the λ_t^c and λ_t^k are the Lagrange multipliers associated with household budget constraint and the law of motion for capital, respectively. In order to derive the first-order conditions, we set the partial derivatives of $\mathcal{L}$ with respect to $C_t, N_t, B_{t+1}, K_{t+1}, I_t, \lambda_t^c$ and λ_t^k equal to zero. Thus, the first-order conditions for $C_t, N_t, B_{t+1}, K_{t+1}$, and I_t are respectively:

$$\frac{1}{C_t} = \lambda_t^c P_t, \tag{A.5}$$

$$N_t^{\varphi} = \lambda_t^c W_t, \tag{A.6}$$

$$\lambda_t^c Q_t = \beta E_t \lambda_{t+1}^c, \tag{A.7}$$

$$\lambda_t^k = \beta E_t \left[\lambda_{t+1}^c R_{k,t+1} + \lambda_{t+1}^k (1-\delta) \right], \tag{A.8}$$

$$\lambda_t^c P_t - \lambda_t^k \left[1 - \frac{\chi}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \chi \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] = \chi \beta E_t \left[\lambda_{t+1}^k \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right]. \tag{A.9}$$

Combining equations (A.5) and (A.6), we derive the expression for real wage, which is equation (2.7) in the text as:

$$\frac{W_t}{P_t} = N_t^{\varphi} C_t. \tag{A.10}$$

The consumption Euler equation shown as equation (2.7) in the text is derived by combining equations (A.5) and (A.7) to yield:

$$Q_{t,} \;=\; \beta \left(\frac{C_{t+1}}{C_t} \right)^{-1} \frac{1}{\pi_{t+1}}, \tag{A.11}$$

where $Q_t \;=\; (1+R_t)^{-1}$ and $\pi_t \;=\; \frac{P_t}{P_{t-1}}$.

Substituting for $\lambda_t^c = \frac{1}{P_t C_t}$ from equation (A.5) into equation (A.8) and defining real rental rate as $r_{h,t} = \frac{R_{h,t}}{P_t}$, we derive the expression for capital (equation (2.9) in the text) as follows:

$$\lambda_t^k \;=\; \beta E_t \left[\frac{1}{C_{t+1}} r_{h,t+1} + \lambda_{t+1}^k (1-\delta) \right], \tag{A.12}$$

where the real rental rate is derived from the non-oil producing firm's optimization problem. Lastly, we apply equation (A.5) to (A.9) to derive the expression for investment in equation (2.10) of the text as:

$$\frac{1}{C_t} - \lambda_t^k \left[1 - \frac{\chi}{2} - \frac{3}{2}\chi \left(\frac{I_t}{I_{t-1}} \right)^2 + 2\chi \left(\frac{I_t}{I_{t-1}} \right) \right] = \chi \beta E_t \lambda_{t+1}^k \left[\left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right]. \tag{A.13}$$

- **Final goods producers:** The representative final goods producer seeks to maximize its profit:

$$\mathit{\Pi}_t = P_{h,t} Y_{h,t} - \int_0^1 P_{h,t}(j)\, Y_{h,t}(j)\, dj, \tag{A.14}$$

subject to the constant returns to scale bundling technology:

$$Y_{h,t} = \left[\int_0^1 Y_{h,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}. \tag{A.15}$$

To describe the firm's optimization problem, we put equation (A.15) into (A.14) as follows:

$$\max_{Y_{h,t}(j)} \mathit{\Pi}_t = P_{h,t} \left[\int_0^1 Y_{h,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}} - \int_0^1 P_{h,t}(j)\, Y_{h,t}(j)\, dj. \tag{A.16}$$

Taking the partial derivative of equation (A.16) with respect to $Y_{H,t}(j)$ yields:

$$\frac{\partial \mathit{\Pi}_t}{\partial Y_{h,t}(j)} = (Y_{h,t})^{-1} Y_{h,t}(j) - \left[\frac{P_{h,t}(j)}{P_{h,t}} \right]^{-\epsilon} = 0, \tag{A.17}$$

and the firm's demand for intermediate goods, $Y_{h,t}(j)$ displayed in equation (2.17) of the text is derived from (A.17). The final goods pricing rule shown in equation (2.18) of the text is derived by substituting equation (A.17) into the bundling technology to yield:

$$P_{h,t} = \left[\int_0^1 P_{h,t}\left(j\right)^{1-\epsilon} dj \right]^{\frac{1}{1-\epsilon}}. \tag{A.18}$$

- **Intermediate goods producers:** The intermediate goods producer chooses optimal quantities of factor inputs to employ by minimizing cost:

$$\min_{N_t(j),K_{h,t}(j),O_t(j)} W_t N_t\left(j\right) + R_{h,t} K_{h,t}\left(j\right) + P_{o,t} O_t\left(j\right), \tag{A.19}$$

subject to a constant returns to scale Cobb-Douglas technology:

$$Y_{h,t}\left(j\right) = A_{h,t} K_{h,t}\left(j\right)^{\alpha_h^k} O_t\left(j\right)^{\alpha_h^o} N_t\left(j\right)^{\alpha_h^n}. \tag{A.20}$$

The Lagrangian for the firm's optimization problem can be written as:

$$\begin{aligned} \mathcal{L} = &- \left[W_t N_t\left(j\right) + R_{h,t} K_{h,t}\left(j\right) + P_{o,t} O_t\left(j\right)\right] \\ &+ \lambda_t^g\left(j\right) P_{h,t} \left[A_{h,t} K_{h,t}\left(j\right)^{\alpha_h^k} O_t\left(j\right)^{\alpha_h^o} N_t\left(j\right)^{\alpha_h^n} - Y_{h,t}\left(j\right)\right]. \end{aligned} \tag{A.21}$$

The first-order condition with respect to $N_t\left(j\right)$ is:

$$\frac{\partial \mathcal{L}_t\left(j\right)}{\partial N_t\left(j\right)} = -W_t + \lambda_t^g\left(j\right) \alpha_h^n P_{h,t} \frac{Y_{h,t}\left(j\right)}{N_t\left(j\right)} = 0, \tag{A.22}$$

$$\frac{W_t}{P_t} = mc_t \alpha_h^n s_t^{-\lambda} \frac{Y_{h,t}\left(j\right)}{N_t\left(j\right)} = w_t, \tag{A.23}$$

$$N_t\left(j\right) = \frac{mc_t \alpha_H^n s_t^{-\lambda} Y_{h,t}\left(j\right)}{w_t}, \tag{A.24}$$

From equation (A.22), the real wage is derived as equation (A.23) and the intermediate firm's demand for labour is given by equation (A.24). Similarly, the first-order condition with respect to $K_{H,t}(j)$ is:

$$
\begin{aligned}
\frac{\partial \mathcal{L}_t(j)}{\partial K_{h,t}(j)} &= - R_{h,t} + \lambda_t^g(j)\,\alpha_h^k P_{h,t}\frac{Y_{h,t}(j)}{K_{h,t}(j)} \;=\; 0, && \text{(A.25)}\\
\frac{R_{h,t}}{P_t} &= mc_t\alpha_h^k s_t^{-\lambda}\frac{Y_{h,t}(j)}{K_{h,t}(j)} \;=\; r_{h,t}, && \text{(A.26)}\\
K_{h,t}(j) &= \frac{mc_t\alpha_h^k s_t^{-\lambda} Y_{h,t}(j)}{r_{h,t}}. && \text{(A.27)}
\end{aligned}
$$

From equation (A.25), the real rental rate is derived as equation (A.26) and the intermediate firm's demand for capital is given by equation (A.27). Finally, the first-order condition with respect to $O_t(j)$ is:

$$
\begin{aligned}
\frac{\partial \mathcal{L}_t(j)}{\partial O_t(j)} &= - P_{o,t} + \lambda_t^g(j)\,\alpha_h^o P_{h,t}\frac{Y_{h,t}(j)}{O_t(j)} \;=\; 0, && \text{(A.28)}\\
\frac{P_{o,t}}{P_t} &= mc_t\alpha_h^o s_t^{-\lambda}\frac{Y_{h,t}(j)}{O_t(j)} \;=\; p_{o,t}, && \text{(A.29)}\\
O_t(j) &= \frac{mc_t\alpha_h^o s_t^{-\lambda} Y_{h,t}(j)}{p_{o,t}}, && \text{(A.30)}
\end{aligned}
$$

From equation (A.28), the real price of oil in domestic currency is derived as equation (A.29) and the intermediate firm's demand for oil input is given by equation (A.30). Based on equations (A.24), (A.27) and (A.30), we obtain the intermediate firm's input combinations as follows:

$$
\begin{aligned}
\frac{K_{h,t}(j)}{N_t(j)} &= \frac{\alpha_h^k w_t}{\alpha_h^n r_{h,t}}, && \text{(A.31)}\\
\frac{O_t(j)}{N_t(j)} &= \frac{\alpha_h^o w_t}{\alpha_h^n p_{o,t}}, && \text{(A.32)}
\end{aligned}
$$

which are shown in the text as equations (2.22) and (2.23). By putting equations (A.24), (A.27) and (A.30) into the production function (equation A.20), we obtain the firm's marginal cost displayed as equation (2.24) in the text as:

$$mc_t = \frac{1}{A_{h,t}s_t^{-\gamma}}\left(\frac{r_{h,t}}{\alpha_h^k}\right)^{\alpha_h^k}\left(\frac{p_{o,t}}{\alpha_h^o}\right)^{\alpha_h^o}\left(\frac{w_t}{\alpha_h^n}\right)^{\alpha_h^n}, \tag{A.33}$$

Price setting: An intermediate firm that qualifies to optimally reset its price, $P_{H,t}^{\bullet}(j)$ does so by maximising profit:

$$\max_{P_{h,t}^{\bullet}(j)} E_t \sum_{s=0}^{\infty} (\beta\theta)^s Y_{h,t}(j)\left[(1+\zeta)P_{h,t}^{\bullet}(j) - P_{h,t+s}mc_{t+s}\right], \tag{A.34}$$

subject to the demand for its product:

$$Y_{h,t+s}(j) = \left(\frac{P_{h,t}(j)}{P_{h,t}}\right)^{-\epsilon} Y_{h,t+s}, \tag{A.35}$$

The optimal reset price is obtained by taking the partial derivative of:

$$\max_{P_{h,t}^{\bullet}(j)} E_t \sum_{s=0}^{\infty} (\beta\theta)^s Y_{h,t+s}\left(\frac{P_{h,t}(j)}{P_{h,t+s}}\right)^{-\epsilon}\left[(1+\zeta)P_{h,t}^{\bullet}(j) - P_{h,t+s}mc_{t+s}\right], \tag{A.36}$$

with respect to $P_{H,t}^{\bullet}(j)$. We suppress the index (j) since the firms face the same marginal cost, and write the first-order condition as:

$$(1+\zeta)(1-\epsilon)\left(P_{h,t}^{\bullet}\right)^{-\epsilon} E_t \sum_{s=0}^{\infty} (\beta\theta)^s P_{h,t+s}^{\epsilon} Y_{h,t+s}$$
$$+ \epsilon\left(P_{h,t}^{\bullet}\right)^{-\epsilon-1} E_t \sum_{s=0}^{\infty} (\beta\theta)^s P_{h,t+s}^{1+\epsilon} mc_{t+s} Y_{h,t+s} = 0, \tag{A.37}$$

Solving equation (A.37) for $P_{h,t}^{\bullet}$, we obtain the optimal reset price shown in equation (2.28) of the text as:

$$P_{h,t}^{\bullet} = \frac{1}{1+\zeta}\frac{\epsilon}{\epsilon-1}\frac{E_t \sum_{s=0}^{\infty} (\beta\theta)^s P_{h,t+s} Y_{h,t+s} mc_{t+s}}{E_t \sum_{s=0}^{\infty} (\beta\theta)^s Y_{h,t+s}}, \tag{A.38}$$

- **Oil producing firms:** Each oil firm maximizes its profit:

$$\Pi_{o,t} = P_{o,t}Y_{o,t} - R_{h,t}K_{o,t} - P_{h,t}M_t, \tag{A.39}$$

subject to a decreasing return to scale extraction technology:

$$Y_{o,t} = A_{o,t}K_{o,t}^{\alpha_o^k}M_t^{\alpha_o^m}, \tag{A.40}$$

Using equation (A.40), we can rewrite (A.39) as:

$$\Pi_{o,t} = P_{o,t}A_{o,t}K_{o,t}^{\alpha_o^k}M_t^{\alpha_o^m} - R_{h,t}K_{o,t} - P_{h,t}M_t, \tag{A.41}$$

and take the partial derivative of equation (A.41) with respect to $K_{o,t}$ and M_t in order to derive the firm's demand for capital and material input. The first-order condition for capital is:

$$\frac{\partial \Pi_{o,t}}{\partial K_{o,t}} = \alpha_o^k P_{o,t}\frac{Y_{o,t}}{K_{o,t}} - R_{h,t} = 0, \tag{A.42}$$

$$K_{o,t} = \frac{\alpha_o^k p_{o,t}^* s_t^{1-\gamma} Y_{o,t}}{r_{h,t}}. \tag{A.43}$$

The definition of real price of oil, which is given as $p_{o,t} = \frac{P_{o,t}}{P_t} = \frac{P_{o,t}^*}{P_t^*}s_t^{1-\gamma}$ in equation (2.32) of the text has been imposed on equation (A.42) to obtain the demand for capital in equation (A.43), which is as shown in equation (2.34) of the text. Also, the first-order condition for material is:

$$\frac{\partial \Pi_{o,t}}{\partial M_t} = \alpha_o^m P_{o,t}\frac{Y_{o,t}}{M_t} - P_{h,t} = 0. \tag{A.44}$$

Similarly, substituting for $p_{o,t} = \frac{P_{o,t}}{P_t} = \frac{P_{o,t}^*}{P_t^*}s_t^{1-\gamma}$ in equation (A.44) yields the oil firm's demand for material input (shown in equation (2.35) of the text) as:

$$M_t = \frac{\alpha_o^m p_{o,t}^* s_t^{1-\gamma} Y_{o,t}}{p_{h,t}}. \tag{A.45}$$

The non-linear system

The set of non-linear equations characterizing the model is presented as follows:

$$\frac{W_t}{P_t} = N_t^{\varphi} C_t, \tag{A.46}$$

$$Q_{t,t+1} = \beta \left(\frac{C_{t+1}}{C_t}\right)^{-1} \frac{1}{\pi_{t+1}}, \tag{A.47}$$

$$\lambda_t^k = \beta E_t \left[\frac{1}{C_{t+1}} r_{h,t+1} + \lambda_{t+1}^k (1-\delta)\right], \tag{A.48}$$

$$\frac{1}{C_t} - \lambda_t^k \left[1 - \frac{\chi}{2} - \frac{3}{2}\chi \left(\frac{I_t}{I_{t-1}}\right)^2 + 2\chi \left(\frac{I_t}{I_{t-1}}\right)\right] = \chi \beta E_t \lambda_{t+1}^k \left[\left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right], \tag{A.49}$$

$$K_{t+1} = (1-\delta) K_t + I_t \left[1 - \frac{\chi}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right], \tag{A.50}$$

$$C_{h,t} = (1-\gamma) s_t^{\gamma} C_t, \tag{A.51}$$

$$C_{f,t} = \gamma s_t^{\gamma-1} C_t, \tag{A.52}$$

$$\pi_{f,t} = \left(\frac{s_t}{s_{t-1}}\right)^{1-\gamma} \pi_t, \tag{A.53}$$

$$C_t = \varrho Y_t^* \tau_t^{1-\gamma}, \tag{A.54}$$

$$q_t = s_t^{1-\gamma}, \tag{A.55}$$

$$P_t = P_{h,t}^{1-\gamma} P_{f,t}^{\gamma}, \tag{A.56}$$

$$Y_{h,t} = A_{h,t} K_{h,t}^{\alpha_h^k} O_t^{\alpha_h^o} N_t^{\alpha_h^n}, \tag{A.57}$$

$$\frac{K_{h,t}}{N_t} = \frac{\alpha_h^k w_t}{\alpha_h^n r_{h,t}}, \tag{A.58}$$

$$\frac{O_t}{N_t} = \frac{\alpha_h^o w_t}{\alpha_h^n p_{o,t}}, \tag{A.59}$$

$$mc_t = \frac{1}{A_{h,t} s_t^{-\gamma}} \left(\frac{r_{h,t}}{\alpha_h^k}\right)^{\alpha_h^k} \left(\frac{p_{o,t}}{\alpha_h^o}\right)^{\alpha_h^o} \left(\frac{w_t}{\alpha_h^n}\right)^{\alpha_h^n}, \tag{A.60}$$

$$P_{h,t}^{\bullet} = \frac{1}{1+\zeta} \frac{\epsilon}{\epsilon-1} \frac{E_t \sum_{s=0}^{\infty} (\beta\theta)^s P_{h,t+s} Y_{h,t+s} mc_{t+s}}{E_t \sum_{s=0}^{\infty} (\beta\theta)^s Y_{h,t+s}}, \tag{A.61}$$

$$Y_{o,t} = A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m}, \tag{A.62}$$

$$K_{o,t} = \frac{\alpha_o^k p_{o,t}^* s_t^{1-\gamma} Y_{o,t}}{r_{h,t}}, \tag{A.63}$$

$$M_t = \frac{\alpha_o^m p_{o,t}^* s_t^{1-\gamma} Y_{o,t}}{p_{h,t}}, \tag{A.64}$$

$$p_{o,t} = q_t p_{o,t}^*, \tag{A.65}$$

$$K_t = K_{h,t}^{1-\eta} + K_{o,t}^{\eta}, \tag{A.66}$$

$$Y_{h,t} = C_{h,t} + M_t + I_t + G_{c,t}. \tag{A.67}$$

Log-linearized equations

In this section, we summarize the set of first-order Taylor approximation of equations (A.46) - (A.67). This leads to 23 characterizing equations of the benchmark model, *mod1*. Variables with tildes represent log deviations from their respective steady state values while the steady state values are denoted in bars without the subscript t.

$$\widetilde{mc}_t - \gamma \widetilde{s}_t + \widetilde{y}_{h,t} = (1+\varphi)\,\widetilde{n}_t + \widetilde{c}_t, \tag{A.68}$$

where the definition of the real wage shown in equation (A.23) has been used in (A.68).

$$\widetilde{c}_t = E_t \widetilde{c}_{t+1} - \left(\widetilde{R}_t - E_t \widetilde{\pi}_{t+1}\right), \tag{A.69}$$

$$\widetilde{\lambda}_t^k = \beta E_t \left[\overline{r}_h \left(\widetilde{r}_{h,t+1} - \widetilde{c}_{t+1}\right) + (1-\delta)\,\widetilde{\lambda}_{t+1}^k\right], \tag{A.70}$$

where $r_h = \frac{1}{\beta} - (1-\delta)$ is the steady state real interest rate.

$$\begin{aligned}
\widetilde{\lambda}_t^k &= \chi \left[\left(\widetilde{i}_t - \widetilde{i}_{t-1} \right) - \beta E_t \left(\widetilde{i}_{t+1} - \widetilde{i}_t \right) \right] - \widetilde{c}_t, && \text{(A.71)} \\
\widetilde{k}_{t+1} &= (1-\delta)\widetilde{k}_t + \delta \widetilde{i}_t, && \text{(A.72)} \\
\widetilde{c}_{h,t} &= \gamma \widetilde{s}_t + \widetilde{c}_t, && \text{(A.73)} \\
\widetilde{c}_{f,t} &= -(1-\gamma)\widetilde{s}_t + \widetilde{c}_t, && \text{(A.74)} \\
\widetilde{\pi}_{f,t} &= (1-\gamma)(\widetilde{s}_t - \widetilde{s}_{t-1}) + \widetilde{\pi}_t, && \text{(A.75)} \\
\widetilde{c}_t &= \widetilde{c}_t^* + (1-\gamma)\widetilde{s}_t, && \text{(A.76)} \\
\widetilde{q}_t &= (1-\gamma) + \widetilde{s}_t, && \text{(A.77)} \\
\widetilde{\pi}_t &= (1-\gamma)\widetilde{\pi}_{h,t} + \gamma \widetilde{\pi}_{f,t}, && \text{(A.78)} \\
\widetilde{y}_{h,t} &= \widetilde{A}_{h,t} + \alpha_h^k \widetilde{k}_{h,t} + \alpha_h^o \widetilde{o}_t + \alpha_h^n \widetilde{n}_t, && \text{(A.79)} \\
\widetilde{k}_{h,t} &= \widetilde{w}_t + \widetilde{n}_t - \widetilde{r}_{h,t}, && \text{(A.80)} \\
\widetilde{o}_t &= \widetilde{w}_t + \widetilde{n}_t - \widetilde{p}_{o,t}, && \text{(A.81)} \\
\widetilde{mc}_t &= \alpha_h^k \widetilde{r}_{h,t} + \alpha_h^o \widetilde{p}_{o,t} + \alpha_h^n \widetilde{w}_t - \widetilde{A}_{h,t} + \gamma \widetilde{s}_t, && \text{(A.82)} \\
\widetilde{\pi}_{h,t} &= \beta E_t \widetilde{\pi}_{h,t+1} + \kappa \widetilde{mc}_t, && \text{(A.83)}
\end{aligned}$$

where, $\kappa = \frac{(1-\beta\theta)(1-\theta)}{\theta}$ in equation (A.83) and the expression for real marginal cost, mc_t, is shown in equation (A.82). The remaining log-linearized equations are as follows:

$$\begin{aligned}
\widetilde{y}_{o,t} &= \widetilde{A}_{o,t} + \alpha_o^k \widetilde{k}_{o,t} + \alpha_o^m \widetilde{m}_t, && \text{(A.84)} \\
\widetilde{k}_{o,t} &= \widetilde{p}_{o,t}^* + (1-\gamma)\widetilde{s}_t + \widetilde{y}_{o,t} - \widetilde{r}_{h,t}, && \text{(A.85)} \\
\widetilde{m}_t &= \widetilde{p}_{o,t}^* + \widetilde{q}_t + \widetilde{y}_{o,t} - \tilde{p}_{h,t}, && \text{(A.86)} \\
\widetilde{p}_{o,t} &= \widetilde{q}_t + \widetilde{p}_{o,t}^*, && \text{(A.87)} \\
\widetilde{k}_t &= (1-\eta)\widetilde{k}_{h,t} + \eta \widetilde{k}_{o,t}, && \text{(A.88)} \\
\widetilde{y}_{h,t} &= \frac{\overline{C}_H}{\overline{Y}_H}\widetilde{c}_{h,t} + \frac{\overline{M}}{\overline{Y}_H}\widetilde{m}_t + \frac{\overline{I}}{\overline{Y}_H}\widetilde{i}_t + \frac{\overline{G}}{\overline{Y}_H}\widetilde{g}_{c,t}, && \text{(A.89)} \\
\widetilde{R}_t &= \rho_r \widetilde{R}_{t-1} + (1-\rho_r)(\omega_\pi \widetilde{\pi}_t + \omega_y \widetilde{y}_{h,t}) + \xi_t^r. && \text{(A.90)}
\end{aligned}$$

Exogenous processes

In the model, we accommodate 6 exogenous shocks (including the monetary policy shock) and their processes are expressed as follows:

$$\widetilde{p}^*_{o,t} = \rho_o \widetilde{p}^*_{o,t-1} + \xi_t^{p^*_o}, \tag{A.91}$$

$$\widetilde{A}_{h,t} = \rho_{a_h} \widetilde{A}_{h,t-1} + \xi_t^{a_h}, \tag{A.92}$$

$$\widetilde{A}_{o,t} = \rho_{a_0} \widetilde{A}_{o,t-1} + \xi_t^{a_o}, \tag{A.93}$$

$$\widetilde{c}^*_t = \rho_{c^*} \widetilde{c}^*_{t-1} + \xi_t^{c^*}, \tag{A.94}$$

$$\widetilde{g}_{c,t} = \rho_g \widetilde{g}_{c,t-1} + \xi_t^{g_c}, \tag{A.95}$$

A.1.2 Intermediate model ($mod2$)

In this Appendix, we present a variant of the model with a non-oil sector which excludes oil as a factor input. The model is quite similar to the one described in Appendix A.1.1 as the behaviours of households, final goods producers, oil producers, government and central bank remain unchanged while the open economy features are similarly valid. However, the optimization problem of the intermediate goods producers is altered due to the exclusion of oil in the production technology of the representative firm. This is shown below:

- **Intermediate goods producers:** The intermediate goods producer of this model variant chooses capital and labour, minimizing cost:

$$\min_{N_t(j), K_{h,t}(j)} W_t N_t(j) + R_{h,t} K_{h,t}(j), \tag{A.96}$$

subject to a constant returns to scale Cobb-Douglas technology:

$$Y_{h,t}(j) = A_{h,t} K_{h,t}(j)^{\alpha_h^k} N_t(j)^{\alpha_h^n}. \tag{A.97}$$

The constant returns to scale assumption implies that $\alpha_h^k + \alpha_h^n = 1$. The Lagrangian for the firm's optimization problem is:

$$L_t(j) = -\left[W_t N_t(j) + R_{h,t} K_{h,t}(j)\right] + \lambda_t^g(j) P_{h,t} \left[A_{h,t} K_{h,t}(j)^{\alpha_h^k} N_t(j)^{\alpha_h^n} - Y_{h,t}(j)\right]. \tag{A.98}$$

The optimization problem above yields expressions for factor inputs and marginal cost which are different from those obtained under $mod1$ presented in Appendix A.1.1. The first-order conditions for labour is:

$$\begin{aligned} \frac{\partial L_t(j)}{\partial N_t(j)} &= -W_t + \lambda_t^g(j)\,\alpha_h^n N(j)^{\alpha_h^n - 1} P_{h,t} A_{h,t} K_{h,t}(j)^{\alpha_h^k} = 0, && \text{(A.99)} \\ \frac{W_t}{P_t} &= mc_t \alpha_h^n s_t^{-\gamma} A_{h,t} K_{h,t}(j)^{\alpha_h^k} N_t(j)^{\alpha_h^n - 1} = w_t. && \text{(A.100)} \end{aligned}$$

Equation (A.99) and the definition $\frac{P_{h,t}}{P_t} = s_t^{-\gamma}$ have been used to to derive the real wage given as equation (A.100). Similarly, the partial derivative of equation (A.98) with respect to capital is:

$$\begin{aligned} \frac{\partial L_t(j)}{\partial K_{h,t}(j)} &= -R_{h,t} + \lambda_t^g(j)\,\alpha_h^k N(j)^{\alpha_h^n} P_{h,t} A_{h,t} K_{h,t}(j)^{\alpha_h^k - 1} = 0, && \text{(A.101)} \\ \frac{R_{h,t}}{P_t} &= mc_t \alpha_h^k s_t^{-\gamma} A_{h,t} K_{h,t}(j)^{\alpha_h^k - 1} N_t(j)^{\alpha_h^n} = r_{h,t}. && \text{(A.102)} \end{aligned}$$

As in the case of labour, equation (A.101) and the definition $\frac{P_{h,t}}{P_t} = s_t^{-\gamma}$ have been used to to derive the real rental rate shown in equation (A.102). Equations (A.99) and (A.102) are combined to obtain optimal combination of factor inputs as follows:

$$\frac{K_{h,t}(j)}{N_t(j)} = \frac{\alpha_h^k}{\alpha_h^n}\frac{w_t}{r_{h,t}}, \qquad \text{(A.103)}$$

where the real wage, w_t, is as derived in equation (A.100) and the real rental rate, $r_{h,t}$, is as derived in equation (A.102). Finally, the firm's marginal cost is obtained by substituting the demand for factor inputs given by (A.100) and (A.102) into the firm's production function, equation (A.97), yielding:

$$mc_t = \frac{1}{A_{h,t} s_t^{-\gamma}} \left(\frac{r_{h,t}}{\alpha_h^k}\right)^{\alpha_h^k} \left(\frac{w_t}{\alpha_h^n}\right)^{\alpha_h^n}. \qquad \text{(A.104)}$$

Equation (A.104) differs from (A.60) in the sense that the firm's marginal cost under $mod2$ is not affected by the price of oil. This implies oil price dynamics do not generate inflationary effects via the firm's cost of production $mod2$. Apart from the other relevant equations presented in Appendix A.1.1, the relevant characterizing equations for $mod2$ are (A.97), (A.103) and (A.104). These are log-linearized, respectively as follows:

$$\widetilde{y}_{h,t} = \widetilde{A}_{h,t} + \alpha_h^k \widetilde{k}_{h,t} + \alpha_h^n \widetilde{n}_t, \tag{A.105}$$

$$\widetilde{k}_{h,t} = \widetilde{w}_t + \widetilde{n}_t - \widetilde{r}_{h,t}, \tag{A.106}$$

$$\widetilde{mc}_t = \alpha_h^k \widetilde{r}_{h,t} + \alpha_h^n \widetilde{w}_t - \widetilde{A}_{h,t} + \gamma \widetilde{s}_t, \tag{A.107}$$

Equation (A.107) implies that oil price dynamics do not directly feature in the Philips curve for *mod*2. In addition to equations (A.105) - (A.107), the other relevant log-linearized equations from the model presented in Appendix A.1.1 are equations (A.68) - (A.78), (A.83) - (A.86) and (A.88) - (A.90). This makes a total of 21 equations characterizing the dynamics of the model. We close the model by assuming an appropriate monetary policy rule similar to those discussed in the text.

A.1.3 Baseline model (*mod*3)

The model considered here follows Gali and Monacelli (2005), which was extended by Ferrero and Seneca (2019) to include an oil sector. Unlike the model variants considered in Appendices A.1 and A.2, the baseline model, *mod*3, completely abstracts from capital and also excludes oil in the production technology of the intermediate goods producers. However, the open economy features remain valid. Quite a number of changes are made to the model presented in Appendix A.1.1. First, the exclusion of capital from the model implies that the optimization problem of the representative household is altered. Second, the intermediate goods producers use a linear technology that feature only labour. Third, the oil firm's production technology features a single factor input (materials) produced by the final goods firms. These modifications require that the optimization problems of the respective agents be altered as follows:

- **Households:** The Lagrangian for the representative household's optimization problem becomes:

$$\mathcal{L} = E_o \sum_{s=0}^{\infty} \beta^s \Bigg\{ \ln C_{t+s} - \frac{N_{t+s}^{1+\varphi}}{1+\varphi} - \lambda_t^c \left[P_t C_t + Q_t B_{t+1} + Q_t^* \varepsilon_t B_{t+1} - W_t N_t - B_t - \varepsilon_t B_t^* - D_t + T_t \right] \Bigg\}. \tag{A.108}$$

The partial derivatives of equation (A.108) with respect to C_t, N_t and B_{t+1} produce the relevant equilibrium conditions for the household, same as those shown in equations (A.10) and (A.11). The other relevant equations relating to the household and open economy features are equations (2.14), (2.40) - (2.43), and (2.48).

- **Intermediate goods producers:** The intermediate goods producer in this model variant minimizes its cost:

$$\min_{N_t(j)} W_t N_t(j), \tag{A.109}$$

subject to a linear technology:

$$Y_{h,t}(j) = A_{h,t} N_t(j). \tag{A.110}$$

The optimization problem yields an expression for real wage and marginal cost as follows:

$$w_t = mc_t s_t^{-\gamma} A_{h,t}, \tag{A.111}$$

$$mc_t = \frac{w_t}{A_{h,t} s_t^{-\gamma}}. \tag{A.112}$$

Equation (A.111) replaces equation (A.23) in $mod1$ while equation (A.112) replaces equation (A.33). Subject to the modification with regards to the expression for real marginal cost in equation (A.112), the expression for Phillips curve shown in equation (A.83) remains valid.

- **Oil sector firms:** The representative oil firm seeks to maximize its profit:

$$P_{o,t} Y_{o,t} - P_{h,t} M_t, \tag{A.113}$$

subject to the diminishing returns to scale technology given as:

$$Y_{o,t} = A_{o,t} M_t^{\alpha_o^m}. \tag{A.114}$$

The firm's optimization problem is written as:

$$\max_{M_t} \mathit{\Pi}_{o,t} = P_{o,t} A_{o,t} M_t^{\alpha_o^m} - P_{h,t} M_t, \tag{A.115}$$

which yields an expression for the oil firm's demand for material input as follows:

$$M_t = \frac{\alpha_o^m p_{o,t}^* q_t Y_{o,t}}{p_{h,t}}. \tag{A.116}$$

- **Market clearing:** The economy's resource constraint becomes:

$$Y_{h,t} = C_{h,t} + M_t + G_t. \tag{A.117}$$

which differs from equation (A.67) as it excludes investment goods. Overall, the model is characterized by a system of 15 equations, which are equations (A.10), (A.11),(2.14), (2.40) - (2.43), (2.48), (A.116), (A.110), (A.112), (A.114), and (A.117). Subject to the modification to the real marginal cost equation shown in equation (A.112), the Phillips curve derived in equation (A.83) remains valid for the baseline model, *mod*3. Finally, the model is closed with an appropriate monetary policy rule similar to those discussed in the text.

A.2 Results

A.2.1 Figures

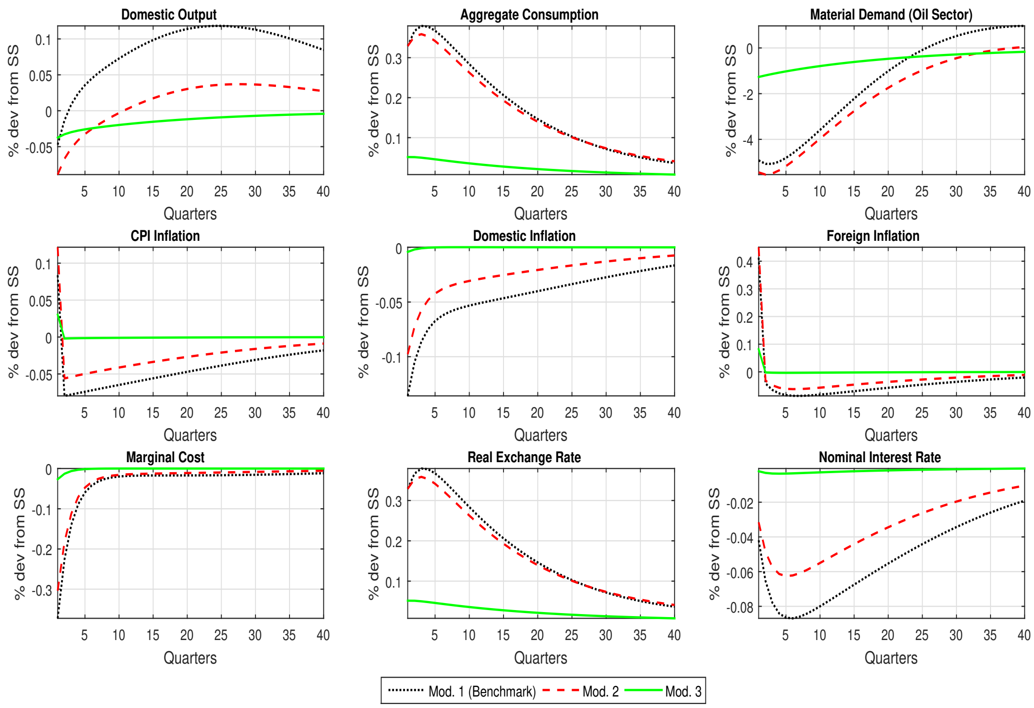

Figure A.1: Impulse responses to a negative international oil price shock for the three models under a domestic inflation-based Taylor rule. $mod1$ is the benchmark model, which adds capital and includes oil in the production technology of non-oil producing domestic firms. $mod2$ is the intermediate model, which includes capital, but excludes oil from the production technology of non-oil producing domestic firms. $mod3$ is the baseline model, which abstracts from capital and excludes oil from the production technology of non-oil producing domestic firms.

Figures A.1 and A.2 highlight the implications of our assumptions regarding capital and oil intensity of domestic production.

Overall, it is shown that adding capital into the model amplifies the response of the economy to an oil price shock, irrespective of the monetary policy rule in place. The inclusion of oil as a factor input in domestic production initially dampens the contractionary effect of a negative oil price shock upon impact. On the other hand, the responses of different measures of inflation to an international oil price shock are amplified once capital is added into our model while the inclusion of oil input in domestic production further amplifies the responses.

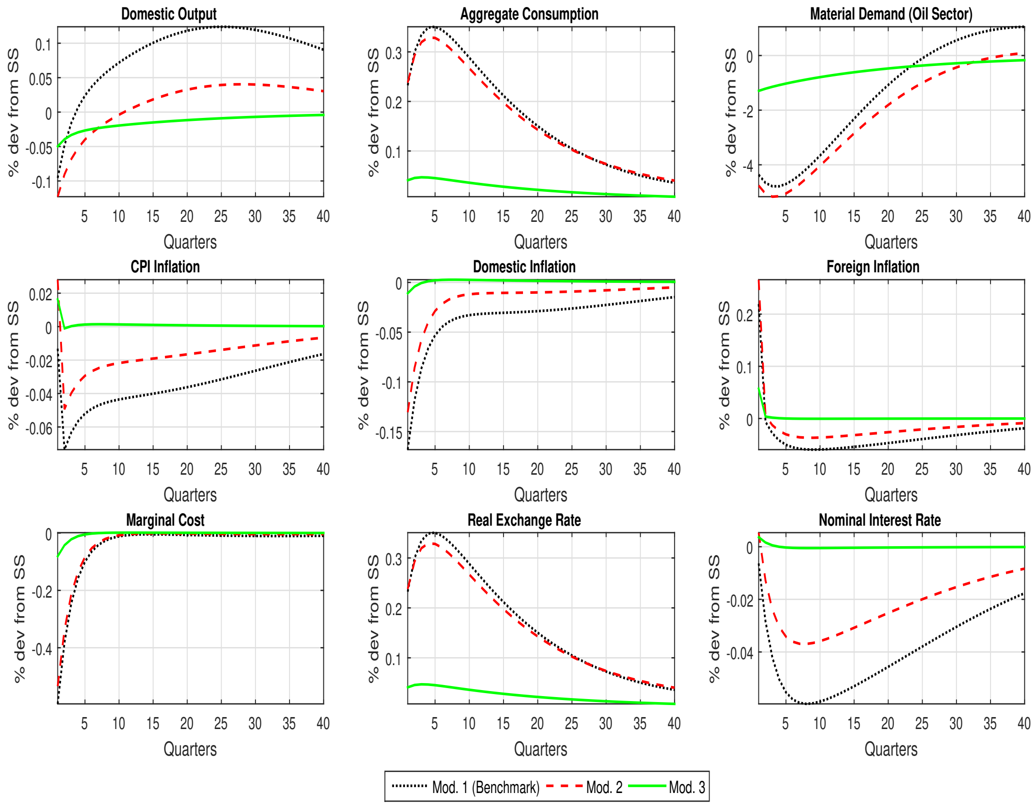

Figure A.2: Impulse responses to a negative international oil price shock for the three models under a CPI inflation-based Taylor rule. *mod*1 is the benchmark model, which adds capital and includes oil in the production technology of non-oil producing domestic firms. *mod*2 is the intermediate model, which includes capital, but excludes oil from the production technology of non-oil producing domestic firms. *mod*3 is the baseline model, which abstracts from capital and excludes oil from the production technology of non-oil producing domestic firms.

A.2.2 Tables

Table A.1 shows macroeconomic fluctuations and policy losses associated with alternative monetary policy rules under the intermediate model, *mod*2 (i.e. the model that incorporates capital but excludes oil in the production technology of domestic non-oil producing firms). Of the competing options, *IFDITRys* emerges as the best policy rule as it records the lowest policy loss of 0.0332. This is followed by *IFDITRy* and *FDITRy* implying that the central bank is able to accrue some policy benefits by keeping an eye on domestic inflation, rather than CPI inflation. This is in addition to paying attention to output, exchange rate and allowing for interest rate inertia. Table A.4 presents the optimised Taylor rule parameters used for calculating the policy loss calculations shown in Table A.1.

Table A.1: Macroeconomic fluctuations and policy loss under *mod*2

Regime	Standard Deviations (%)						Loss
	$\widetilde{y}_{h,t}$	$\widetilde{c}_{h,t}$	$\widetilde{\pi}_t$	$\widetilde{\pi}_{h,t}$	$\widetilde{q}_t$	$\widetilde{R}_t$	
CITR	0.2793	2.0421	0.0717	0.1120	1.2253	0.1575	0.3025
DITR	0.2474	2.2290	0.3037	0.0002	1.3374	0.1298	0.0359
FCITRy	0.2819	2.0579	0.0894	0.1032	1.2347	0.1755	0.2814
FDITRy	0.2474	2.2295	0.3041	0.0014	1.3377	0.1305	0.0359
IFCITRy	0.2800	2.0666	0.1281	0.1045	1.2399	0.1244	0.2186
IFCITRyq	0.2645	2.1806	0.2469	0.0446	1.3084	0.1008	0.0671
IFDITRy	0.2485	2.2185	0.2899	0.0047	1.3311	0.1240	0.0337
IFDITRyq	0.2469	2.2214	0.2896	0.0077	1.3328	0.1233	0.0332
SCITR	0.3051	1.9901	0.0000	0.1433	1.1940	0.1188	0.4143
SDITR	0.2475	2.2291	0.3038	0.0000	1.3374	0.1296	0.0359
SNGDPGT	0.2362	2.2887	0.3705	0.0282	1.3732	0.1794	0.0692
Commitment	0.2471	2.2244	0.2906	0.0051	1.3347	0.1246	0.0324
Discretion	0.2478	2.2175	0.2872	0.0130	1.3305	0.1297	0.0354

Table A.2 shows the macroeconomic fluctuations and losses associated with alternative monetary policy rules under the baseline model, *mod*3 (i.e. the model that abstracts from capital and excludes oil from the production technology of domestic non-oil producing firms). The optimised Taylor rule parameters used for generating the policy loss calculations presented in Table A.2 are shown in Table A.5. As can be seen, *DITR* and *FDITRy* yield the lowest policy losses emerging as the optimal policy rules. These are followed by the variants of domestic inflation-based Taylor rules that feature output, exchange rate and interest rate inertia.

Table A.2: Macroeconomic fluctuations and policy loss under *mod*3

Regime	Standard Deviations (%)						Loss
	$\widetilde{y}_{h,t}$	$\widetilde{c}_{h,t}$	$\widetilde{\pi}_t$	$\widetilde{\pi}_{h,t}$	$\widetilde{q}_t$	$\widetilde{R}_t$	
$CITR$	0.1168	0.2854	0.0091	0.0183	0.1713	0.0187	0.0130
$DITR$	0.1007	0.3021	0.0382	0.0000	0.1813	0.0151	0.0051
$FCITRy$	0.1128	0.2898	0.0140	0.0126	0.1739	0.0171	0.0101
$FDITRy$	0.1006	0.3023	0.0384	0.0007	0.1814	0.0144	0.0051
$IFCITRy$	0.1117	0.2897	0.0189	0.0156	0.1738	0.0046	0.0102
$IFCITRyq$	0.1028	0.2995	0.0323	0.0024	0.1797	0.0140	0.0056
$IFDITRy$	0.1029	0.2992	0.0332	0.0039	0.1795	0.0105	0.0055
$IFDITRyq$	0.1030	0.2991	0.0331	0.0038	0.1795	0.0106	0.0055
$SCITR$	0.1213	0.2819	0.0000	0.0220	0.1692	0.0146	0.0158
$SDITR$	0.1007	0.3021	0.0382	0.0000	0.1813	0.0151	0.0051
$SNGDPGT$	0.0914	0.3192	0.0622	0.0158	0.1915	0.0227	0.0085
$Commitment$	0.0994	0.3040	0.0405	0.0020	0.1824	0.0156	0.0051
$Discretion$	0.1003	0.3028	0.0387	0.0059	0.1817	0.0091	0.0056

The optimised simple rules parameters for the policy loss computations under our three model variants are presented in Tables A.3 - A.5.

Table A.3: Optimised simple rule parameters, *mod*1

Parameters	ρ_r	ω_π	ω_y	ω_q
$CITR$	0.0000	2.1250	0.0000	0.0000
$DITR$	0.0000	12.6269	0.0000	0.0000
$FCITRy$	0.0000	2.0332	-0.0154	0.0000
$FDITRy$	0.0000	9.0878	-0.0858	0.0000
$IFCITRy$	0.2277	2.1229	-0.0098	0.0000
$IFCITRyq$	0.9980	0.6872	4.2795	-3.3446
$IFDITRy$	0.7249	9.3891	-0.0676	0.0000
$IFDITRyq$	0.5720	1.5825	-0.0059	-0.0889
$SCITR$	0.0000	∞	0.0000	0.0000
$SDITR$	0.0000	∞	0.0000	0.0000
$SNGDPGT$	0.0000	0.0000	∞	0.0000

Table A.4: Optimised simple rule parameters, $mod2$

Parameters	ρ_r	ω_π	ω_y	ω_q
$CITR$	0.0000	2.1948	0.0000	0.0000
$DITR$	0.0000	754.9020	0.0000	0.0000
$FCITRy$	0.0000	2.5896	0.2455	0.0000
$FDITRy$	0.0000	270.5070	1.3787	0.0000
$IFCITRy$	0.9950	85.3257	28.0334	0.0000
$IFCITRyq$	0.9895	0.9076	2.3267	-0.5069
$IFDITRy$	0.9542	125.7870	0.2662	0.0000
$IFDITRyq$	0.5582	1.5714	0.0122	-0.0960
$SCITR$	0.0000	∞	0.0000	0.0000
$SDITR$	0.0000	∞	0.0000	0.0000
$SNGDPGT$	0.0000	0.0000	∞	0.0000

Table A.5: Optimised simple rule parameters, $mod3$

Parameters	ρ_r	ω_π	ω_y	ω_q
$CITR$	0.0000	2.0522	0.0000	0.0000
$DITR$	0.0000	2328.8900	0.0000	0.0000
$FCITRy$	0.0000	1.5004	0.0901	0.0000
$FDITRy$	0.0000	1.5013	0.1542	0.0000
$IFCITRy$	0.7974	1.4986	0.1364	0.0000
$IFCITRyq$	-0.2386	0.9620	2.6251	1.4050
$IFDITRy$	0.7950	1.5005	0.1501	0.0000
$IFDITRyq$	0.8015	1.5184	0.1896	0.0227
$SCITR$	0.0000	∞	0.0000	0.0000
$SDITR$	0.0000	∞	0.0000	0.0000
$SNGDPGT$	0.0000	0.0000	∞	0.0000

Appendix B

Appendix for Chapter 2

B.1 First order conditions

Households

Ricardian consumers

The representative Ricardian household maximizes a utility function given by:

$$U_0^R = E_0 \sum_{s=0}^{\infty} \beta^s \left[\frac{\left(C_{t+s}^R(j) - \phi_c C_{t+s-1}\right)^{1-\sigma}}{1-\sigma} - \frac{N_{t+s}^R(j)^{1+\varphi}}{1+\varphi} + h(G_{c,t+s}) \right], \tag{B.1}$$

subject to the nominal budget constraint:

$$\begin{aligned} P_t C_t^R(j) + P_{i,t} I_{no,t}(j) + \frac{B_{t+1}(j)}{R_t \mu_t} + \frac{\varepsilon_t B_{t+1}^*(j)}{R_t^* \mu_t^*} \\ = W_t N_t^R(j) + R_{h,t} K_{h,t}(j) + B_t(j) + \varepsilon_t B_t^*(j) + D_t - TX_t, \end{aligned} \tag{B.2}$$

and the process of capital accumulation:

$$K_{h,t+1}(j) = (1-\delta_h) K_{h,t}(j) + I_{no,t}(j) \left[1 - \frac{\chi}{2} \left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)} - 1 \right)^2 \right]. \tag{B.3}$$

The Lagrangian for this problem can be written as:

$$
\begin{aligned}
\mathcal{L} = E_0 \sum_{s=0}^{\infty} \beta^s \Bigg\{ & \frac{\left(C_{t+s}^R(j) - \phi_c C_{t+s-1}\right)^{1-\sigma}}{1-\sigma} - \frac{N_{t+s}^R(j)^{1+\varphi}}{1+\varphi} + h(G_{c,t+s}) \\
& - \lambda_{C,t}^R \Bigg[P_t C_t^R(j) + P_{i,t} I_{no,t}(j) + \frac{B_{t+1}(j)}{R_t \mu_t} + \frac{\varepsilon_t B_{t+1}^*(j)}{R_t^* \mu_t^*} \\
& - W_t N_t^R(j) - R_{h,t} K_{h,t}(j) - B_t(j) - \varepsilon_t B_t^*(j) - D_t + TX_t \Bigg] \\
& - \lambda_{K,t}^R \left[K_{h,t+1}(j) - (1-\delta_h) K_{h,t}(j) - I_{no,t} \left(1 - \frac{\chi}{2} \left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)} \right)^2 \right) \right] \Bigg\}
\end{aligned} \tag{B.4}
$$

where $\lambda_{C,t}^R$ and $\lambda_{K,t}^R$ are the Lagrange multipliers associated with household budget constraint and the law of motion for capital, respectively. In order to derive the first-order conditions, we set the partial derivatives of $\mathcal{L}$ with respect to $C_t^R(j), B_{t+1}(j), B_{t+1}^*(j), K_{h,t+1}(j), I_{no,t}(j)$, $\lambda_{C,t}^R$ and $\lambda_{K,t}^R$ equal to zero. Thus, the first-order conditions for $C_t^R(j), B_{t+1}(j), B_{t+1}^*(j)$, $K_{h,t+1}(j)$, and $I_{no,t}(j)$ are respectively given by:

$$
\frac{\partial L}{\partial C_t^R(j)} = \left(C_t^R(j) - \phi_c C_{t-1}\right)^{-\sigma} - \lambda_{C,t}^R P_t = 0, \tag{B.5}
$$

$$
\frac{\partial L}{\partial B_{t+1}(j)} = - \frac{\lambda_{C,t}^R}{R_t \mu_t} + \beta E_t \lambda_{C,t+1}^R = 0, \tag{B.6}
$$

$$
\frac{\partial L}{\partial B_{t+1}^*(j)} = - \frac{\lambda_{C,t}^R \varepsilon_t}{R_t^* \mu_t^*} + \beta E_t \lambda_{C,t+1}^R = 0, \tag{B.7}
$$

$$
\frac{\partial L}{\partial K_{h,t+1}(j)} = \beta E_t \lambda_{C,t+1}^R R_{h,t+1} - \lambda_{K,t}^R + \beta E_t \lambda_{K,t+1}^R (1-\delta_h) = 0, \tag{B.8}
$$

$$
\begin{aligned}
\frac{\partial L}{\partial I_{no,t+1}(j)} = & - \lambda_{C,t}^R P_{i,t} + \lambda_{K,t}^R - \frac{\chi}{2} \lambda_{K,t}^R \left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)} - 1 \right)^2 \\
& - \chi \lambda_{K,t}^R I_{no,t}(j) \left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)} - 1 \right) \frac{1}{I_{no,t-1}(j)} \\
& + \chi \beta E_t \lambda_{K,t+1}^R I_{no,t+1}(j) \left(\frac{I_{no,t+1}(j)}{I_{no,t}(j)} - 1 \right) \frac{I_{no,t+1}(j)}{I_{no,t}(j)^2} = 0.
\end{aligned} \tag{B.9}
$$

Combining equations (B.5) and (B.6), we derive the consumption Euler equation shown as equation (**??**) in the text as:

$$\frac{1}{R_t \mu_t} = \beta E_t \left[\left(\frac{C_{t+1}^R(j) - \phi_c C_t}{C_t^R(j) - \phi_c C_{t-1}} \right)^{-\sigma} \frac{1}{\pi_{t+1}} \right]. \tag{B.10}$$

The demand for foreign bonds shown as equation (3.19) in the text is derived by combining equations (B.5) and (B.7) to yield:

$$\frac{1}{R_t^* \mu_t^*} = \beta E_t \left[\frac{\varepsilon_{t+1}}{\varepsilon_t} \left(\frac{C_{t+1}^R(j) - \phi_c C_t}{C_t^R(j) - \phi_c C_{t-1}} \right)^{-\sigma} \frac{1}{\pi_{t+1}} \right], \tag{B.11}$$

where$\pi_t = \frac{P_t}{P_{t-1}}$. Substituting for $\lambda_{C,t}^R = \frac{1}{P_t \left(C_t^R(j) - \phi_c C_{t-1} \right)^\sigma}$ from equation (B.5) into equation (B.8) and defining real rental rate as $r_{h,t} = \frac{R_{h,t}}{P_t}$, we derive the expression for capital (equation (3.20) in the text) as follows:

$$\lambda_{K,t}^R = \beta E_t \left[\frac{1}{\left(C_{t+1}^R(j) - \phi_c C_t \right)^\sigma} r_{h,t+1} + \lambda_{K,t+1}^R (1 - \delta_h) \right], \tag{B.12}$$

where the real rental rate is derived from the non-oil producing firm's optimization problem. Lastly, we apply equation (B.5) to (B.9) to derive the expression for non-oil investment in equation (3.22) of the text as:

$$\begin{aligned} \left(C_t^R(j) - \phi_c C_{t-1} \right)^{-\sigma} - \lambda_{K,t}^R \left[1 - \frac{\chi}{2} - \frac{3}{2}\chi \left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)} \right)^2 + 2\chi \left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)} \right) \right] \\ = \chi \beta E_t \lambda_{K,t+1}^R \left[\left(\frac{I_{no,t+1}(j)}{I_{no,t}(j)} - 1 \right) \left(\frac{I_{no,t+1}(j)}{I_{no,t}(j)} \right)^2 \right]. \end{aligned} \tag{B.13}$$

Non-Ricardian consumers

The representative non-Ricardian household maximize a utility function given by:

$$U_0^{NR} = \frac{\left(C_{t+s}^{NR}\left(j\right) - \phi_c C_{t+s-1}\right)^{1-\sigma}}{1-\sigma} - \frac{N_{t+s}^{NR}\left(j\right)^{1+\varphi}}{1+\varphi} + h(G_{c,t+s}), \tag{B.14}$$

subject to the nominal budget constraint:

$$P_t C_t^{NR}\left(j\right) = W_t N_t^{NR}\left(j\right) - TX_t. \tag{B.15}$$

As earlier assumed, this group of households neither invest in bonds nor accumulate capital. Since they are non-optimizers, their entire disposable income is used to purchase consumption goods. The Lagrangian for this problem can be written as:

$$\begin{aligned}\mathcal{L} = &\frac{\left(C_{t+s}^{NR}\left(j\right) - \phi_c C_{t+s-1}\right)^{1-\sigma}}{1-\sigma} - \frac{N_{t+s}^{NR}\left(j\right)^{1+\varphi}}{1+\varphi} \\ &+ h(G_{c,t+s}) - \lambda_{C,t}^{NR}\left(P_t C_t^{NR}\left(j\right) - W_t N_t^{NR}\left(j\right) - TX_t\right),\end{aligned} \tag{B.16}$$

where $\lambda_{C,t}^{R}$ is the Lagrange multiplier associated with household budget constraint of the non-Ricardian household. Since the representative household chooses $\left\{C_t^R\left(j\right)\right\}_{s=0}^{\infty}$, we set the partial derivatives of $\mathcal{L}$ in equation (B.16) with respect to $C_t^R\left(j\right)$ and $\lambda_{C,t}^{NR}$ equal to zero. As shown in equation (3.25) of the text, the first-order conditions for $C_t^R\left(j\right)$ is:

$$\begin{aligned}\frac{\partial L}{\partial C_t^{NR}\left(j\right)} &= \left(C_t^{NR}\left(j\right) - \phi_c C_{t-1}\right)^{-\sigma} - \lambda_{C,t}^{R} P_t = 0, \\ \lambda_{C,t}^{NR} &= \frac{1}{\left(C_t^{NR}\left(j\right) - \phi_c C_{t-1}\right)^{\sigma} P_t}.\end{aligned} \tag{B.17}$$

The equilibrium conditions of the representative non-Ricardian household are described by the optimal consumption level (equation B.17) and the budget constraint (equation B.15).

Labour supply and wage setting

The labour-aggregating firm uses the following technology:

$$N_t = \left[\int_0^1 N_t\left(j\right)^{\frac{\eta_w - 1}{\eta_w}} dj\right]^{\frac{\eta_w}{\eta_w - 1}}, \tag{B.18}$$

and seeks to maximise a profit function given by:

$$\max_{N_t(j)} \mathit{\Pi}_{w,t} = W_t N_t - \int_0^1 W_t(j) N_t(j) \, dj. \tag{B.19}$$

Putting equation (B.18) into (B.19) yields:

$$\max_{N_t(j)} \mathit{\Pi}_{W,t} = W_t \left[\int_0^1 N_t(j)^{\frac{\eta_w - 1}{\eta_w}} dj \right]^{\frac{\eta_w}{\eta_w - 1}} - W_t(j) \int_0^1 N_t(j) \, dj. \tag{B.20}$$

The first order condition of the above problem with respect to $N_t(j)$ yields the labour-aggregating firm's demand for differentiated labour, which is shown in equation (2.46) of the text as:

$$N_t(j) = \left[\frac{W_t(j)}{W_t} \right]^{-\eta_w} N_t. \tag{B.21}$$

Substituting equation (2.43) into (2.40), we can derive the aggregate wage level as:

$$W_t = \left[\int_0^1 W_t(j)^{1-\eta_w} dj \right]^{\frac{1}{1-\eta_w}}, \tag{B.22}$$

which is shown in equation (2.47) of the text. In line with Calvo (1983), we assume that $1 - \theta_w$ fraction of households optimally define their wages while the remaining fraction, θ_w, follows a rule that enables them to retain the wage level in the previous period as follows:

$$W_t(j) = W_{t-1}(j). \tag{B.23}$$

A representative household that is able to reset wage level in period t does so by maximizing its utility subject to its budget constraint, the capital accumulation process and the demand for its differentiated labour shown in equation (B.21). Thus, the maximization problem can be written as:

$$\max_{W_t^\bullet(j)} E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left\{ \frac{(C_{t+s}(j) - \phi_c C_{t+s-1})^{1-\sigma}}{1-\sigma} - \frac{1}{1+\varphi}\left(N_{t+s}\left(\frac{W_{t+s}}{W_t^\bullet(j)}\right)^{\eta_w}\right)^{1+\varphi} + h(G_{c,t+s}) \right.$$
$$- \lambda_{C,t+s}^R \left[P_t C_t(j) + P_{i,t} I_{no,t}(j) + \frac{B_{t+1}(j)}{R_t \mu_t} + \frac{\varepsilon_t B_{t+1}^*(j)}{R_t^* \mu_t^*} \right.$$
$$\left. - W_t^\bullet(j)\left(N_{t+s}(j)\left(\frac{W_{t+s}}{W_t^\bullet(j)}\right)^{\eta_w}\right) - R_{h,t}K_{h,t}(j) - B_t(j) - \varepsilon_t B_t^*(j) - D_t + TX_t \right]$$
$$\left. - \lambda_{K,t}^R \left[K_{h,t+1}(j) - (1-\delta_h) K_{h,t}(j) - I_{no,t}\left(1 - \frac{\chi}{2}\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)}\right)^2\right)\right]\right\}. \quad \text{(B.24)}$$

Taking the first order condition of equation (B.24) with respect to $W_t^\bullet(j)$ yields:

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

and substituting the demand for differentiated labour, $N_t(j)$, in (equation B.21) into the above expression yields:

$$E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left\{ \eta_w [N_{t+s}(j)]^{\varphi} \frac{1}{W_t^\bullet(j)} + (1-\eta_w)\lambda_{C,t+s} \right\} = 0. \quad \text{(B.25)}$$

Finally, as shown in equation (2.48) of the text, the optimal reset wage can be written as:

$$W_t^\bullet(j) = \left(\frac{\eta_w}{\eta_w - 1}\right) E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\frac{(N_{t+s}(j))^{\varphi}}{\lambda_{C,t+s}}\right]. \quad \text{(B.26)}$$

Equation (B.26) can be re-written specifically for each category, $i = R, NR$, of household as follows:

$$W_t^{\bullet}(j) = \left(\frac{\eta_w}{\eta_w - 1}\right) E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\frac{\left(N_{t+s}^R(j)\right)^{\varphi}}{\lambda_{C,t+s}^R}\right], \tag{B.27}$$

$$W_t^{\bullet}(j) = \left(\frac{\eta_w}{\eta_w - 1}\right) E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\frac{\left(N_{t+s}^{NR}(j)\right)^{\varphi}}{\lambda_{C,t+s}^{NR}}\right]. \tag{B.28}$$

Equations (B.27) and (B.28) define the labour supply by Ricardian and non-Ricardian households, respectively. By law of large numbers, the aggregate wage level (equation B.22) is:

$$W_t = \left[\theta_w W_{t-1}^{1-\eta_w} + (1-\theta_w) W_t^{\bullet 1-\eta_w}\right]^{\frac{1}{1-\eta_w}}, \tag{B.29}$$

as shown in equation (3.30) of the text. Finally, consumption demand and hours of Ricardian and non-Ricardian households can be aggregated as follows:

$$C_t = \gamma_R C_t^R + (1-\gamma_R) C_t^{NR}, \tag{B.30}$$

$$N_t = \gamma_R N_t^R + (1-\gamma_R) N_t^{NR}, \tag{B.31}$$

where for Ricardian households, $C_t^R = \int_0^1 C_t^R(j)\,dj$ and $N_t^R = \int_0^1 N_t^R(j)\,dj$. And for non-Ricardian households, $C_t^{NR} = \int_0^1 C_t^{NR}(j)\,dj$ while $N_t^{NR} = \int_0^1 N_t^{NR}(j)\,dj$.

Final goods producers

The representative final goods producer seeks to maximize its profit given by:

$$\Pi_{h,t}(z_h) = P_{h,t} Y_{h,t} - \int_0^1 P_{h,t}(z_h) Y_{h,t}(z_h)\,dz_h, \tag{B.32}$$

subject to the constant returns to scale bundling technology:

$$Y_{h,t} = \left[\int_0^1 Y_{h,t}(z_h)^{\frac{\epsilon_h - 1}{\epsilon_h}}\,dz_h\right]^{\frac{\epsilon_h}{\epsilon_h - 1}}. \tag{B.33}$$

To describe the firm's optimization problem, we put equation (B.33) into (B.32) as follows:

$$\max_{Y_{h,t}(z_h)} \mathit{\Pi}_{h,t}(z_h) = P_{h,t}\left[\int_0^1 Y_{h,t}(z_h)^{\frac{\epsilon_h-1}{\epsilon_h}}\, dz_h\right]^{\frac{\epsilon_h}{\epsilon_h-1}} - \int_0^1 P_{h,t}(z_h)\, Y_{h,t}(z_h)\, dz_h. \tag{B.34}$$

Taking the partial derivative of equation (B.34) with respect to $Y_{h,t}(z_h)$ yields:

$$\frac{\partial \mathit{\Pi}_{h,t}}{\partial Y_{h,t}(z_h)} = (Y_{h,t})^{-1}\, Y_{h,t}(z_h) - \left[\frac{P_{h,t}(z_h)}{P_{h,t}}\right]^{-\epsilon_h} = 0,$$

$$Y_{h,t}(z_h) = \left[\frac{P_{h,t}(z_h)}{P_{h,t}}\right]^{-\epsilon_h} Y_{h,t}, \tag{B.35}$$

where equation (B.35) is the firm's demand for intermediate goods, $Y_{h,t}(z_h)$ as claimed in equation (3.35) of the text. The final goods pricing rule shown in equation (3.36) of the text is derived by substituting equation (B.35) into the bundling technology (equation B.33) to yield:

$$P_{h,t} = \left[\int_0^1 P_{h,t}(z_h)^{1-\epsilon_h}\, dz_h\right]^{\frac{1}{1-\epsilon_h}}. \tag{B.36}$$

Intermediate goods producers

Each intermediate goods producer chooses optimal quantities of factor inputs to employ by minimizing its cost:

$$\min_{N_t(z_h),K_{h,t}(z_h),O_t(z_h)} W_t N_t(z_h) + R_{h,t} K_{h,t}(z_h) + P_{ro,t} O_t(z_h), \tag{B.37}$$

subject to a constant returns to scale Cobb-Douglas technology:

$$Y_{h,t}(z_h) = A_{h,t} K_{h,t}(z_h)^{\alpha_h^k}\, O_{h,t}(z_h)^{\alpha_h^o}\, N_t(z_h)^{\alpha_h^n}. \tag{B.38}$$

The Lagrangian for the firm's optimization problem can be written as:

$$\mathcal{L} = -\left[W_t N_t\left(z_h\right) + R_{h,t} K_{h,t}\left(z_h\right) + P_{ro,t} O_t\left(z_h\right)\right] \\ + \lambda_t^g\left(z_h\right) P_{h,t}\left[A_{h,t} K_{h,t}\left(z_h\right)^{\alpha_h^k} O_{h,t}\left(z_h\right)^{\alpha_h^o} N_t\left(z_h\right)^{\alpha_h^n} - Y_{h,t}\left(z_h\right)\right]. \quad \text{(B.39)}$$

The first-order condition with respect to $N_t\left(z_h\right)$ is:

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial N_t\left(z_h\right)} &= -W_t + \lambda_t^g\left(z_h\right) \alpha_h^n P_{h,t} \frac{Y_{h,t}\left(z_h\right)}{N_t\left(z_h\right)} = 0, \\ \frac{W_t}{P_t} &= mc_t \alpha_h^n p_{h,t} \frac{Y_{h,t}\left(z_h\right)}{N_t\left(z_h\right)} = w_t, \qquad \text{(B.40)} \\ N_t\left(z_H\right) &= \frac{mc_t \alpha_h^n p_{h,t} Y_{h,t}\left(z_h\right)}{w_t}. \qquad \text{(B.41)} \end{aligned}$$

where $mc_t = \frac{MC_t}{P_t}, p_{h,t} = \frac{P_{h,t}}{P_t}, w_t = \frac{W_t}{P_t}$. The intermediate firm's demand for labour is given by equation (B.41). Similarly, the first-order condition with respect to $K_{h,t}\left(z_h\right)$ is:

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial K_{h,t}\left(z_h\right)} &= -R_{h,t} + \lambda_t^g\left(z_h\right) \alpha_h^k P_{h,t} \frac{Y_{h,t}\left(z_h\right)}{K_{h,t}\left(z_h\right)} = 0, \\ \frac{R_{h,t}}{P_t} &= mc_t \alpha_h^k p_{h,t} \frac{Y_{h,t}\left(z_h\right)}{K_{h,t}\left(z_h\right)} = r_{h,t}, \qquad \text{(B.42)} \\ K_{h,t}\left(z_h\right) &= \frac{mc_t \alpha_h^k p_{h,t} Y_{h,t}\left(z_h\right)}{r_{h,t}}, \qquad \text{(B.43)} \end{aligned}$$

where $w_t = \frac{R_{h,t}}{P_t}$. From equation (B.42), the real rental rate is derived, while the intermediate firm's demand for capital is given by equation (B.43). Finally, the first-order condition with respect to $O_{h,t}\left(z_h\right)$ is:

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial O_{h,t}\left(z_h\right)} &= -P_{ro,t} + \lambda_t^g\left(z_h\right) \alpha_h^o P_{h,t} \frac{Y_{h,t}\left(z_h\right)}{O_{h,t}\left(z_h\right)} = 0, \\ \frac{P_{ro,t}}{P_t} &= mc_t \alpha_h^o p_{h,t} \frac{Y_{h,t}\left(z_h\right)}{O_{h,t}\left(z_h\right)} = p_{ro,t}, \\ O_{h,t}\left(z_h\right) &= \frac{mc_t \alpha_h^o p_{h,t} Y_{h,t}\left(z_h\right)}{p_{ro,t}}. \qquad \text{(B.44)} \end{aligned}$$

where $p_{ro,t} = \frac{P_{ro,t}}{P_t}$. The intermediate firm's demand for oil input is given by equation

(B.44). Based on equations (B.41), (B.43) and (B.44), we obtain the intermediate firm's input combinations as follows:

$$\frac{K_{h,t}(z_h)}{N_t(z_h)} = \frac{\alpha_h^k w_t}{\alpha_h^n r_{h,t}}, \tag{B.45}$$

$$\frac{O_{h,t}(z_h)}{N_t(z_h)} = \frac{\alpha_h^o w_t}{\alpha_h^n p_{ro,t}}, \tag{B.46}$$

which are shown in the text as equations (3.41) and (3.42). By putting equations (B.41), (B.43) and (B.44) into the production function (equation B.38), we obtain the firm's marginal cost displayed as equation (3.43) in the text as:

$$mc_t = \frac{1}{A_{h,t} p_{h,t}} \left(\frac{r_{h,t}}{\alpha_h^k}\right)^{\alpha_h^k} \left(\frac{p_{ro,t}}{\alpha_h^o}\right)^{\alpha_h^o} \left(\frac{w_t}{\alpha_h^n}\right)^{\alpha_h^n}. \tag{B.47}$$

Price setting by domestic firms: An intermediate firm that qualifies to optimally reset its price, $P_{h,t}^{\bullet}(j)$, for home goods meant for the domestic market does so by maximising profit:

$$\max_{P_{h,t}^{\bullet}(z_h)} E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s Y_{h,t}(z_h) \left[P_{h,t}^{\bullet}(z_h) - P_{h,t+s} mc_{t+s}\right], \tag{B.48}$$

subject to the demand for its product:

$$Y_{h,t+s}(z_h) = \left[\frac{P_{h,t}(z_h)}{P_{h,t}}\right]^{-\epsilon_h} Y_{h,t+s}. \tag{B.49}$$

The optimal reset price is obtained by solving:

$$\max_{P_{h,t}^{\bullet}(z_h)} E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s Y_{h,t+s} \left[\frac{P_{h,t}(z_h)}{P_{h,t+s}}\right]^{-\epsilon_h} \left[P_{h,t}^{\bullet}(z_h) - P_{h,t+s} mc_{t+s}\right]. \tag{B.50}$$

Since firms face the same marginal cost, we can suppress the index (z_h), and write the first-order condition as:

$$(1-\epsilon_h)\left(P_{h,t}^{\bullet}\right)^{-\epsilon_h} E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s P_{h,t+s}^{\epsilon_h} Y_{h,t+s} + \epsilon_h \left(P_{h,t}^{\bullet}\right)^{-\epsilon_h-1} E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s P_{h,t+s}^{1+\epsilon_h} mc_{t+s} Y_{h,t+s} = 0. \tag{B.51}$$

Solving equation (B.51) for $P^{\bullet}_{h,t}$, we obtain the optimal reset price shown in equation (3.44) of the text as:

$$P^{\bullet}_{h,t} = \frac{\epsilon_h}{\epsilon_h - 1} \frac{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_h)^s P_{h,t+s} Y_{h,t+s} mc_{t+s}}{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_h)^s Y_{h,t+s}}. \tag{B.52}$$

Solving analogously for the optimal reset price for export-bound intermediate goods yields:

$$P^{*\bullet}_{h,t} = \frac{\epsilon_h}{\epsilon_h - 1} \frac{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_{hf})^s P^{*}_{h,t+s} Y^{*}_{h,t+s} mc_{t+s}}{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_{hf})^s \varepsilon_{t+s} Y^{*}_{h,t+s}}. \tag{B.53}$$

Import goods retailers

A set of competitive assemblers combine a continuum of differentiated imported varieties, $Y_{f,t}(z_f)$ to produce a final foreign good, $Y_{f,t}$, using a Dixit-Stiglitz aggregation technology given by:

$$Y_{f,t} = \left[\int_0^1 Y_{f,t}(z_f)^{\frac{\epsilon_f - 1}{\epsilon_f}} dz_f \right]^{\frac{\epsilon_f}{\epsilon_f - 1}}, \tag{B.54}$$

In order to determine their demand for differentiated imported goods, these firms maximize:

$$\Pi_{f,t}(z_f) = P_{f,t} Y_{f,t} - \int_0^1 P_{f,t}(z_f) Y_{f,t}(z_f) dz_f, \tag{B.55}$$

subject to equation (B.54) above. In order to solve the firm's optimization problem, we put equation (B.54) into (B.55) as follows:

$$\max_{Y_{f,t}(z_f)} \Pi_{f,t}(z_f) = P_{f,t} \left[\int_0^1 Y_{f,t}(z_f)^{\frac{\epsilon_f - 1}{\epsilon_f}} dz_f \right]^{\frac{\epsilon_f}{\epsilon_f - 1}} - \int_0^1 P_{f,t}(z_f) Y_{f,t}(z_f) dz_f. \tag{B.56}$$

Taking the partial derivative of equation (B.56) with respect to $Y_{f,t}(z_f)$ yields:

$$\frac{\partial \Pi_{f,t}}{\partial Y_{f,t}(z_f)} = (Y_{f,t})^{-1} Y_{f,t}(z_f) - \left[\frac{P_{f,t}(z_f)}{P_{f,t}} \right]^{-\epsilon_f} = 0,$$

$$Y_{f,t}\left(z_f\right) = \left[\frac{P_{f,t}\left(j\right)}{P_{f,t}}\right]^{-\epsilon_f} Y_{f,t}, \tag{B.57}$$

where equation (B.57) is the firm's demand for differentiated foreign goods, $Y_{f,t}\left(z_f\right)$ as claimed in equation (3.49) of the text. The final goods pricing rule shown in equation (3.50) of the text is derived by substituting equation (B.57) into the bundling technology (equation B.54) to yield:

$$P_{f,t} = \left[\int_0^1 P_{f,t}\left(z_f\right)^{1-\epsilon_f} dz_f\right]^{\frac{1}{1-\epsilon_f}}. \tag{B.58}$$

Price setting by import goods retailers: An intermediate firm that qualifies to optimally reset its price, $P^{\bullet}_{f,t}\left(z_f\right)$ does so by solving:

$$\max_{P^{\bullet}_{f,t}\left(z_f\right)} E_t \sum_{s=0}^{\infty} \left(\beta\theta_f\right)^s Y_{f,t}\left(z_f\right) \left[P^{\bullet}_{f,t}\left(z_f\right) - \varepsilon_{t+s} P^*_{f,t+s}\right], \tag{B.59}$$

subject to the demand for its product:

$$Y_{f,t+s}\left(z_f\right) = \left[\frac{P_{f,t}\left(z_f\right)}{P_{f,t}}\right]^{-\epsilon_f} Y_{f,t+s}. \tag{B.60}$$

Substituting equation (B.60) into (B.59) yields:

$$\max_{P^{\bullet}_{f,t}(j)} E_t \sum_{s=0}^{\infty} \left(\beta\theta_f\right)^s Y_{f,t+s} \left[\frac{P_{f,t}\left(z_f\right)}{P_{f,t+s}}\right]^{-\epsilon_f} \left[P^{\bullet}_{f,t}\left(z_f\right) - \varepsilon_{t+s} P^*_{f,t+s}\right]. \tag{B.61}$$

Multiplying things out in equation (B.61) and recalling the definition of the law of one price,$\Psi_t = \epsilon_t P^*_t / P_{f,t}$, we can write the first-order condition as (after suppressing the index (z_f), since all import goods retailers face similar marginal cost):

$$\begin{aligned} &\left(1-\epsilon_f\right)\left(P^{\bullet}_{f,t}\right)^{-\epsilon_f} E_t \sum_{s=0}^{\infty} \left(\beta\theta_f\right)^s P^{\epsilon_f}_{f,t+s} Y_{f,t+s} \\ &\qquad + \epsilon_f \left(P^{\bullet}_{f,t}\right)^{-\epsilon_f-1} E_t \sum_{s=0}^{\infty} \left(\beta\theta_f\right)^s P^{\epsilon_f+1}_{f,t+s} Y_{f,t+s} \Psi_{t+s} = 0. \end{aligned} \tag{B.62}$$

Solving equation (B.62) for $P^{\bullet}_{f,t}$, we obtain the optimal reset price for imported goods shown in equation (3.52) of the text as:

$$P^{\bullet}_{f,t} = \frac{\epsilon_f}{\epsilon_f - 1} \frac{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_f)^s P_{h,t+s} Y_{h,t+s} \Psi_{t+s}}{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_f)^s Y_{f,t+s}}. \tag{B.63}$$

By law of large numbers, the pricing rule for imported goods based on equation (B.58) is given by:

$$P_{f,t} = \left[\theta_f P_{f,t-1}^{1-\epsilon_f} + (1-\theta_f)\left(P^{\bullet}_{f,t}\right)^{1-\epsilon_f}\right]^{\frac{1}{1-\epsilon_f}}. \tag{B.64}$$

Oil producing firms

The oil firm seeks to maximize its profit:

$$\mathit{\Pi}_{o,t} = \varepsilon_t P^*_{o,t} Y_{o,t} - R_{o,t} K_{o,t} - P_{h,t} M_t, \tag{B.65}$$

subject to the production technology given as:

$$Y_{o,t} = A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m}. \tag{B.66}$$

Substituting equation (B.66) into (B.65), the firm's optimization problem can be written as:

$$\max_{K_{o,t}, M_t} \mathit{\Pi}_{o,t} = \varepsilon_t P^*_{o,t} A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m} - R_{o,t} K_{o,t} - P_{h,t} M_t, \tag{B.67}$$

In line with the expression for the optimal demand for oil-related capital by the oil firm shown in equation (3.56) of the text, the first order conditions with respect to oil related capital, $K_{o,t}$ yields:

$$\begin{aligned} \frac{\partial \mathit{\Pi}_{o,t}}{\partial K_{o,t}} =& \alpha_o^k \varepsilon_t P^*_{o,t} \frac{Y_{o,t}}{K_{o,t}} - R_{o,t} = 0, \\ K_{o,t} =& \frac{\alpha_o^k q_t p^*_{o,t} Y_{o,t}}{r_{o,t}}, \end{aligned} \tag{B.68}$$

while the first order condition with respect to materials input is:

$$
\begin{aligned}
\frac{\partial \Pi_{o,t}}{\partial M_t} =& \alpha_o^m \varepsilon_t P_{o,t}^* \frac{Y_{o,t}}{M_{o,t}} - P_{h,t} = 0, \\
M_t =& \frac{\alpha_o^m q_t p_{o,t}^* Y_{o,t}}{p_{h,t}},
\end{aligned} \tag{B.69}
$$

as shown in equation (3.57) of the text; where $p_{o,t}^* = \frac{P_{o,t}^*}{P_t}, r_{o,t} = \frac{R_{o,t}}{P_t}, p_{h,t} = \frac{P_{h,t}}{P_t}$ and q_t is the real exchange rate. As explained in the text, the process for the accumulation of oil-related capital, $K_{o,t}$, is given by:

$$
K_{o,t} = (1 - \delta_o) K_{o,t-1} + FDI_t, \tag{B.70}
$$

while oil-related foreign direct investment (FDI_t) and international price of oil evolve as follows:

$$
FDI_t = (FDI_{t-1})^{\rho_{fdi}} \left(P_{O,t}^*\right)^{1-\rho_{fdi}}. \tag{B.71}
$$

$$
P_{o,t}^* = \left(P_{o,t-1}^*\right)^{\rho_o} \exp\left(\xi_t^{p_o^*}\right) \tag{B.72}
$$

B.2 The non-linear system

Here, we summarise the non-linear equations of the model. Variables in real terms are denoted as small letters while bars denote steady state levels.

Households' intra-temporal decisions

$$C_{no,t}(j) = (1-\gamma_o)\left[\frac{P_{no,t}}{P_t}\right]^{-\eta_o} C_t(j) \tag{B.73}$$

$$C_{o,t}(j) = \gamma_o \left[\frac{P_{ro,t}}{P_t}\right]^{-\eta_o} C_t(j) \tag{B.74}$$

$$P_t = \left[(1-\gamma_o) P_{no,t}^{1-\eta_o} + \gamma_o P_{o,t}^{1-\eta_o}\right]^{\frac{1}{1-\eta_o}} \tag{B.75}$$

$$C_{h,t}(j) = (1-\gamma_c)\left[\frac{P_{h,t}}{P_{no,t}}\right]^{-\eta_c} C_{no,t}(j) \tag{B.76}$$

$$C_{f,t}(j) = \gamma_C \left[\frac{P_{f,t}}{P_{no,t}}\right]^{-\eta_c} C_{no,t}(j) \tag{B.77}$$

$$P_{no,t} = \left[(1-\gamma_c) P_{h,t}^{1-\eta_c} + \gamma_c P_{f,t}^{1-\eta_c}\right]^{\frac{1}{1-\eta_c}} \tag{B.78}$$

$$I_{h,t} = (1-\gamma_i)\left[\frac{P_{h,t}}{P_{i,t}}\right]^{-\eta_i} I_{no,t} \tag{B.79}$$

$$I_{f,t} = \gamma_I \left[\frac{P_{f,t}}{P_{i,t}}\right]^{-\eta_I} I_{no,t} \tag{B.80}$$

$$P_{i,t} = \left[(1-\gamma_i) P_{h,t}^{1-\eta_i} + \gamma_i P_{f,t}^{1-\eta_i}\right]^{\frac{1}{1-\eta_i}} \tag{B.81}$$

Households' inter-temporal decisions

$$\frac{1}{R_t \mu_t} = \beta E_t \left[\left(\frac{C_{t+1}^R(j) - \phi_c C_t}{C_t^R(j) - \phi_c C_{t-1}}\right)^{-\sigma} \frac{1}{\pi_{t+1}}\right] \tag{B.82}$$

$$\frac{1}{R_t^* \mu_t^*} = \beta E_t \left[\frac{\varepsilon_{t+1}}{\varepsilon_t}\left(\frac{C_{t+1}^R(j) - \phi_c C_t}{C_t^R(j) - \phi_c C_{t-1}}\right)^{-\sigma} \frac{1}{\pi_{t+1}}\right] \tag{B.83}$$

$$\lambda_{K,t}^R = \beta E_t \left[\frac{1}{\left(C_{t+1}^R(j) - \phi_c C_t\right)^{\sigma}} r_{h,t+1} + \lambda_{K,t+1}^R (1-\delta_h)\right] \tag{B.84}$$

$$
\begin{aligned}
\left(C_t^R(j) - \phi_c C_{t-1}\right)^{-\sigma} =& \lambda_{K,t}^R \left[1 - \frac{\chi}{2} - \frac{3}{2}\chi\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)}\right)^2 + 2\chi\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)}\right)\right] \\
& + \chi\beta E_t \lambda_{K,t+1}^R \left[\left(\frac{I_{no,t+1}(j)}{I_{no,t}(j)} - 1\right)\left(\frac{I_{no,t+1}(j)}{I_{no,t}(j)}\right)^2\right] \qquad \text{(B.85)} \\
K_{h,t+1}(j) =& \left(1 - \delta_h\right) K_{h,t}(j) + I_{no,t}(j)\left[1 - \frac{\chi}{2}\left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)} - 1\right)^2\right] \qquad \text{(B.86)} \\
\lambda_{C,t}^{NR} =& \frac{\left(C_t^{NR}(j) - \phi_c C_{t-1}\right)^{-\sigma}}{P_t} \qquad \text{(B.87)} \\
P_t C_t^{NR}(j) =& W_t N_t^{NR}(j) - TX_t \qquad \text{(B.88)}
\end{aligned}
$$

Labour supply and wage setting

$$
\begin{aligned}
W_t^{\bullet}(j) &= \left(\frac{\eta_w}{\eta_w - 1}\right) E_t \sum_{s=0}^{\infty} \left(\beta\theta_w\right)^s \left[\frac{\left(N_{t+s}(j)\right)^{\varphi}}{\lambda_{c,t+s}^i}\right] \qquad \text{(B.89)} \\
W_t &= \left[\theta_w W_{t-1}^{1-\eta_w} + \left(1 - \theta_w\right) W_t^{\bullet 1-\eta_w}\right]^{\frac{1}{1-\eta_w}} \qquad \text{(B.90)}
\end{aligned}
$$

Aggregate consumption and hours

$$
\begin{aligned}
C_t =& \gamma_R C_t^R + \left(1 - \gamma_R\right) C_t^{NR} \qquad \text{(B.91)} \\
N_t =& \gamma_R N_t^R + \left(1 - \gamma_R\right) N_t^{NR} \qquad \text{(B.92)}
\end{aligned}
$$

Small open economy features

$$
\begin{aligned}
\Psi_t =& \frac{q_t}{p_{f,t}} \qquad \text{(B.93)} \\
q_t =& \frac{\varepsilon_t P_t^*}{P_t} \qquad \text{(B.94)} \\
S_t =& \frac{P_{f,t}}{P_{h,t}} \qquad \text{(B.95)} \\
C_t^R(j) - \phi_c C_{t-1} =& \varrho q_t^{\frac{1}{\sigma}} \left(C_t^*(j) - \phi_c C_{t-1}^*\right) \qquad \text{(B.96)}
\end{aligned}
$$

Intermediate goods producers

$$Y_{h,t}\left(z_h\right) = A_{h,t}K_{h,t}\left(z_h\right)^{\alpha_h^k} O_{h,t}\left(z_h\right)^{\alpha_h^o} N_t\left(z_h\right)^{\alpha_h^n} \tag{B.97}$$

$$\frac{K_{h,t}\left(z_h\right)}{N_t\left(z_h\right)} = \frac{\alpha_h^k w_t}{\alpha_h^n r_{h,t}} \tag{B.98}$$

$$\frac{O_{h,t}\left(z_h\right)}{N_t\left(z_h\right)} = \frac{\alpha_h^o w_t}{\alpha_h^n p_{ro,t}} \tag{B.99}$$

$$mc_t = \frac{1}{A_{h,t}p_{h,t}}\left(\frac{r_{h,t}}{\alpha_h^k}\right)^{\alpha_h^k}\left(\frac{p_{ro,t}}{\alpha_h^o}\right)^{\alpha_h^o}\left(\frac{w_t}{\alpha_h^n}\right)^{\alpha_h^n} \tag{B.100}$$

$$P_{h,t}^{\bullet} = \frac{\epsilon_h}{\epsilon_h - 1}\frac{E_t\sum_{s=0}^{\infty}\left(\beta\theta_h\right)^s P_{h,t+s}Y_{h,t+s}mc_{t+s}}{E_t\sum_{s=0}^{\infty}\left(\beta\theta_h\right)^s Y_{h,t+s}} \tag{B.101}$$

$$P_{h,t} = \left[\theta_h P_{h,t-1}^{1-\epsilon_h} + \left(1-\theta_h\right)\left(P_{h,t}^{\bullet}\right)^{1-\epsilon_h}\right]^{\frac{1}{1-\epsilon_h}} \tag{B.102}$$

$$P_{h,t}^{*\bullet} = \frac{\epsilon_h}{\epsilon_h - 1}\frac{E_t\sum_{s=0}^{\infty}\left(\beta\theta_{hf}\right)^s P_{h,t+s}^{*}Y_{h,t+s}^{*}mc_{t+s}}{E_t\sum_{s=0}^{\infty}\left(\beta\theta_{hf}\right)^s \varepsilon_{t+s}Y_{h,t+s}^{*}} \tag{B.103}$$

$$P_{h,t}^{*} = \left[\theta_h P_{h,t-1}^{*1-\epsilon_h} + \left(1-\theta_h\right)\left(P_{h,t}^{*\bullet}\right)^{1-\epsilon_h}\right]^{\frac{1}{1-\epsilon_h}} \tag{B.104}$$

Oil producing firm

$$Y_{o,t} = A_{o,t}K_{o,t}^{\alpha_o^k}M_t^{\alpha_o^m} \tag{B.105}$$

$$K_{o,t} = \frac{\alpha_o^k q_t p_{o,t}^{*} Y_{o,t}}{r_{o,t}} \tag{B.106}$$

$$M_t = \frac{\alpha_o^m q_t p_{o,t}^{*} Y_{o,t}}{p_{h,t}} \tag{B.107}$$

$$K_{o,t} = \left(1-\delta_o\right)K_{o,t-1} + FDI_t \tag{B.108}$$

$$FDI_t = \left(FDI_{t-1}\right)^{\rho_{fdi}}\left(P_{o,t}^{*}\right)^{1-\rho_{fdi}} \tag{B.109}$$

Import goods pricing

$$P_{f,t}^{\bullet} = \frac{\epsilon_f}{\epsilon_f - 1} \frac{E_t \sum_{s=0}^{\infty} (\beta\theta_f)^s P_{h,t+s} Y_{h,t+s} \Psi_{t+s}}{E_t \sum_{s=0}^{\infty} (\beta\theta_f)^s Y_{f,t+s}} \tag{B.110}$$

$$P_{f,t} = \left[\theta_f P_{f,t-1}^{1-\epsilon_f} + (1-\theta_f)\left(P_{f,t}^{\bullet}\right)^{1-\epsilon_f}\right]^{\frac{1}{1-\epsilon_f}} \tag{B.111}$$

Fiscal policy

$$OR_t = P_{g,t} G_{c,t} + OS_t - B_t - TX_t + \frac{B_{t+1}}{R_t} \tag{B.112}$$

$$G_{h,t} = (1-\gamma_g)\left[\frac{P_{h,t}}{P_{g,t}}\right]^{-\eta_g} G_{c,t} \tag{B.113}$$

$$G_{f,t} = \gamma_g \left[\frac{P_{f,t}}{P_{g,t}}\right]^{-\eta_g} G_{c,t} \tag{B.114}$$

$$P_{g,t} = \left[(1-\gamma_g) P_{h,t}^{1-\eta_g} + \gamma_g P_{f,t}^{1-\eta_g}\right]^{\frac{1}{1-\eta_g}} \tag{B.115}$$

$$OS_t = (P_{lo,t} - P_{ro,t}) O_t \tag{B.116}$$

$$OR_t = \tau \varepsilon_t P_{o,t}^* Y_{o,t} \tag{B.117}$$

$$P_{lo,t} = \varepsilon_t \frac{P_{o,t}^*}{P_t^*} \psi_t^o = q_t p_{o,t}^* \Psi_t^o \tag{B.118}$$

$$P_{ro,t} = (P_{ro,t-1})^{(1-\nu)} (P_{lo,t})^{\nu} \tag{B.119}$$

$$\frac{g_{c,t}}{\overline{g_c}} = \left(\frac{g_{c,t-1}}{\overline{g_c}}\right)^{\rho_g} \left[\left(\frac{y_{o,t}}{\overline{y_o}}\right)^{\omega_{yo}} \left(\frac{b_{t-1}}{\overline{b}}\right)^{-\omega_b} \left(\frac{or_t}{\overline{or}}\right)^{\omega_{or}}\right]^{1-\rho_g} \exp\left(\xi_t^{G_c}\right) \tag{B.120}$$

$$\frac{tx_t}{\overline{tx}} = \left(\frac{b_{t-1}}{\overline{b}}\right)^{\varphi_b} \left(\frac{g_{c,t-1}}{\overline{g_c}}\right)^{\varphi_g} \left(\frac{os_t}{\overline{os}}\right)^{\varphi_{os}} \left(\frac{or_t}{\overline{or}}\right)^{\varphi_{or}} \tag{B.121}$$

$$\psi_t^o = \left(\psi_{t-1}^o\right)^{\rho_{\psi^o}} \exp\left(\xi_t^{\psi_o}\right) \tag{B.122}$$

$$P_{o,t}^* = \left(P_{o,t-1}^*\right)^{\rho_{P_o^*}} \exp\left(\xi_t^{p_o^*}\right) \tag{B.123}$$

Monetary policy

$$R_t = (R_{t-1})^{\rho_r} \left[(\pi_{h,t})^{\omega_\pi} (Y_{h,t})^{\omega_y} (q_t)^{\omega_q}\right]^{(1-\rho_r)} \exp\left(\xi_t^r\right) \tag{B.124}$$

Foreign economy

$$\frac{1}{R_t^* \mu_t^*} = \beta E_t \left[\left(\frac{C_{t+1}^* (j) - \phi_c^* C_t}{C_t^* (j) - \phi_c^* C_{t-1}} \right)^{-\sigma_c^*} \frac{1}{\pi_{t+1}^*} \right] \tag{B.125}$$

$$R_t^* = \left(R_{t-1}^*\right)^{\rho_{r^*}} \left[(\pi_t^*)^{\omega_{\pi^*}} \left(Y_{h,t}^*\right)^{\omega_{y^*}} \right]^{1-\rho_{r^*}} \exp\left(\xi_t^{r^*}\right) \tag{B.126}$$

$$\pi_t^* = \left(\pi_{t-1}^*\right)^{\rho_{\pi^*}} \exp\left(\xi_t^{\pi^*}\right) \tag{B.127}$$

Market clearing and aggregation

$$Y_{h,t} = C_{h,t} + C_{h,t}^* + M_t + I_{h,t} + G_{h,t} \tag{B.128}$$

$$Y_t = C_t + M_t + I_{no,t} + G_{h,t} + nx_t \tag{B.129}$$

$$NX_t = EX_t - IM_t \tag{B.130}$$

$$EX_t = \varepsilon_t P_{h,t}^* C_{h,t}^* + \varepsilon_t P_{o,t}^* Y_{o,t} \tag{B.131}$$

$$IM_t = P_{lo,t} O_t + P_{f,t} Y_{f,t} \tag{B.132}$$

$$Y_{f,t} = C_{f,t} + I_{f,t} + G_{f,t} \tag{B.133}$$

$$C_{h,t}^* = \gamma^* \left[\frac{P_{h,t}^*}{P_{,t}^*} \right]^{-\omega^*} C_t^* \tag{B.134}$$

$$\frac{q_t b_t^*}{R_t^* \mu_t^*} = q_t b_{t-1}^* + nx_t - (1-\tau)\, q_t p_{o,t}^* y_{o,t} + q_t f di_t^* \tag{B.135}$$

B.3 Log-linearized equations

In this Appendix, we summarise the log-linearised equations of the model. Variables with tildes represent log-deviations of such variables from their steady state values while the steady state variables are represented with bars. Thus, for any variable say Y_t,the following notations apply: $y_t = \frac{Y_t}{P_t}$, and $\tilde{Y}_t \equiv \log\left(\frac{Y_t}{\overline{Y}}\right)$

Households' intra-temporal decisions

$$\widetilde{c}_{no,t} = \widetilde{c}_t - \eta_o \left(\widetilde{p}_{no,t}\right) \tag{B.136}$$

$$\widetilde{c}_{o,t} = \widetilde{c}_t - \eta_o \left(\widetilde{p}_{ro,t}\right) \tag{B.137}$$

$$\widetilde{c}_{h,t} = \widetilde{c}_{no,t} - \eta_c \left(\widetilde{p}_{h,t} - \widetilde{p}_{no,t}\right) \tag{B.138}$$

$$\widetilde{c}_{f,t} = \widetilde{c}_{no,t} - \eta_c \left[\widetilde{q}_t - \widetilde{\psi}_t - \widetilde{p}_{no,t}\right] \tag{B.139}$$

$$\widetilde{i}_{h,t} = \widetilde{i}_{no,t} - \eta_i \left(\widetilde{p}_{h,t} - \widetilde{p}_{i,t}\right) \tag{B.140}$$

$$\widetilde{i}_{f,t} = \widetilde{i}_{no,t} - \eta_i \left(\widetilde{p}_{f,t} - \widetilde{p}_{i,t}\right) \tag{B.141}$$

Ricardian households' inter-temporal decisions

$$\widetilde{c}_t^R = \frac{\phi_c}{1+\phi_c}\widetilde{c}_{t-1} + \frac{1}{1+\phi_c}\widetilde{c}_{t+1} - \frac{1-\phi_c}{\sigma\left(1+\phi_c\right)}\left(\widetilde{R}_t - E_t\widetilde{\pi}_{t+1} + \widetilde{\mu}_t\right) \tag{B.142}$$

$$\widetilde{\lambda}_{c,t}^{NR} = -\sigma\left[\frac{\widetilde{c}_t^R - \phi_c\widetilde{c}_{t-1}}{1-\phi_c}\right] \tag{B.143}$$

$$\widetilde{\lambda}_{k,t}^R = \beta E_t\left[\overline{r_k}\left(\widetilde{r}_{h,t+1} - \sigma\widetilde{c}_{t+1}\right) + \left(1-\delta_h\right)\widetilde{\lambda}_{k,t+1}^R\right] \tag{B.144}$$

$$\widetilde{\lambda}_{k,t}^R = \chi\left[\left(\widetilde{i}_{no,t} - \widetilde{i}_{no,t-1}\right) - \beta E_t\left(\widetilde{i}_{no,t+1} - \widetilde{i}_{no,t}\right)\right] - \sigma\widetilde{c}_t^R \tag{B.145}$$

$$\widetilde{k}_{h,t+1} = \left(1-\delta_h\right)\widetilde{k}_{h,t} + \delta_h\widetilde{i}_{no,t} \tag{B.146}$$

Non-Ricardian households' decisions

$$\widetilde{c}_t^{NR} = \frac{W\bar{N}^{NR}}{P\bar{C}^{NR}}\left(\widetilde{w}_t + \widetilde{n}_t^{NR}\right) - \frac{T\bar{X}}{P\bar{C}^{NR}}\widetilde{tx}_t \tag{B.147}$$

$$\widetilde{\lambda}_{c,t}^{NR} = -\sigma\left[\frac{\widetilde{c}_t^{NR} - \phi_c\widetilde{c}_{t-1}}{1-\phi_c}\right] \tag{B.148}$$

Aggregate consumption and hours

$$\widetilde{c}_t = \gamma_R\widetilde{c}_t^R + \left(1-\gamma_R\right)\widetilde{c}_t^{NR} \tag{B.149}$$

$$\widetilde{n}_t = \gamma_R\widetilde{n}_t^R + \left(1-\gamma_R\right)\widetilde{n}_t^{NR} \tag{B.150}$$

Small open economy features

$$\widetilde{\psi}_t = \widetilde{q}_t - \widetilde{p}_{f,t} \tag{B.151}$$

$$\widetilde{q}_t = \widetilde{q}_{t-1} + \Delta\widetilde{\varepsilon}_t - \widetilde{\pi}_t + \widetilde{\pi}_t^* \tag{B.152}$$

$$\widetilde{S}_t = \widetilde{p}_{f,t} - \widetilde{p}_{h,t} \tag{B.153}$$

$$\widetilde{q}_t = \frac{\sigma}{1-\phi_c}\left(\widetilde{c}_t - \phi_c \widetilde{c}_{t-1}\right) - \frac{\sigma}{1-\phi_c^*}\left(\widetilde{c}_t^* - \phi_c \widetilde{c}_{t-1}^*\right) \tag{B.154}$$

Inflation and prices

$$\widetilde{p}_{h,t} = \widetilde{p}_{h,t-1} + \widetilde{\pi}_{h,t} - \widetilde{\pi}_t \tag{B.155}$$

$$\widetilde{p}_{hf,t} = \widetilde{p}_{hf,t-1} + \widetilde{\pi}_{hf,t} - \widetilde{\pi}_t^* \tag{B.156}$$

$$\widetilde{p}_{f,t} = \widetilde{p}_{f,t-1} + \widetilde{\pi}_{f,t} - \widetilde{\pi}_t \tag{B.157}$$

$$\widetilde{w}_t = \widetilde{w}_{t-1} + \widetilde{\pi}_{w,t} - \widetilde{\pi}_t \tag{B.158}$$

$$\widetilde{p}_{no,t} = (1-\gamma_c)\,\widetilde{p}_{h,t} + \gamma_c\left(\widetilde{q}_t - \widetilde{\psi}_t\right) \tag{B.159}$$

$$\widetilde{p}_{ro,t} = (1-\nu)\,\widetilde{p}_{ro,t-1} + \nu\left(\widetilde{q}_t + \widetilde{p}_{o,t}^* + \widetilde{\psi}_t^o\right) \tag{B.160}$$

$$\widetilde{p}_{i,t} = (1-\gamma_i)\,\widetilde{p}_{h,t} + \gamma_i \widetilde{p}_{f,t} \tag{B.161}$$

$$\tilde{p}_{g,t} = (1-\gamma_g)\,\widetilde{p}_{h,t} + \gamma_g\left(\widetilde{q}_t - \widetilde{\psi}_t\right) \tag{B.162}$$

$$\widetilde{mc}_t = \alpha_h^k \widetilde{r}_{h,t} + \alpha_h^o \widetilde{p}_{ro,t} + \alpha_h^n \widetilde{w}_t - \widetilde{A}_{h,t} - \widetilde{p}_{h,t} \tag{B.163}$$

$$\widetilde{\pi}_{h,t} = \beta\widetilde{\pi}_{h,t+1} + \frac{(1-\beta\theta_h)(1-\theta_h)}{\theta_h}\widetilde{mc}_t + \xi_t^{\pi_h} \tag{B.164}$$

$$\widetilde{\pi}_{hf,t} = \beta\widetilde{\pi}_{hf,t+1} + \frac{(1-\beta\theta_{hf})(1-\theta_{hf})}{\theta_{hf}}\widetilde{mc}_t - \widetilde{q}_t - \widetilde{p}_{hf,t} \tag{B.165}$$

$$\widetilde{\pi}_{w,t} = \beta\widetilde{\pi}_{w,t+1} + \frac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w}\left(\varphi\widetilde{n}_t^R - \widetilde{\lambda}_{c,t}^R\right) \tag{B.166}$$

$$\widetilde{\pi}_{w,t} = \beta\widetilde{\pi}_{w,t+1} + \frac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w}\left(\varphi\widetilde{n}_t^{NR} - \widetilde{\lambda}_{c,t}^{NR}\right) \tag{B.167}$$

$$\widetilde{\pi}_{f,t} = \beta\widetilde{\pi}_{f,t+1} + \frac{(1-\beta\theta_f)(1-\theta_f)}{\theta_f}\widetilde{\psi}_t \tag{B.168}$$

$$\widetilde{\pi}_{no,t} = \widetilde{p}_{no,t} - \widetilde{p}_{no,t-1} + \widetilde{\pi}_t \tag{B.169}$$

$$\widetilde{\pi}_{o,t} = \widetilde{p}_{ro,t} - \widetilde{p}_{ro,t-1} + \widetilde{\pi}_t \tag{B.170}$$

$$0 = \gamma_o \widetilde{p}_{ro,t} + (1-\gamma_o)\,\widetilde{p}_{no,t} \tag{B.171}$$

Oil production

$$\begin{aligned}
\widetilde{y}_{o,t} =& \widetilde{A}_{o,t} + \alpha_o^k \widetilde{k}_{o,t} + \alpha_o^m \widetilde{m}_t && \text{(B.172)}\\
\widetilde{r}_{o,t} =& \widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{y}_{o,t} - \widetilde{k}_{o,t} && \text{(B.173)}\\
\widetilde{m}_t =& \widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{y}_{o,t} - \widetilde{p}_{h,t} && \text{(B.174)}\\
\widetilde{fdi}_t =& \rho_{fdi} \widetilde{fdi}_{t-1} + (1-\rho_{fdi}) \widetilde{p}^*_{o,t} && \text{(B.175)}\\
\widetilde{k}_{o,t} =& (1-\delta_o) \widetilde{k}_{o,t-1} + \delta_o \widetilde{fdi}_t && \text{(B.176)}
\end{aligned}$$

Non-oil production

$$\begin{aligned}
\widetilde{y}_{h,t} =& \widetilde{A}_{h,t} + \alpha_h^k \widetilde{k}_{h,t} + \alpha_h^o \widetilde{o}_{h,t} + \alpha_h^n \widetilde{n}_t && \text{(B.177)}\\
\widetilde{k}_{h,t} =& \widetilde{w}_t + \widetilde{n}_t - \widetilde{r}_{h,t} && \text{(B.178)}\\
\widetilde{o}_{h,t} =& \widetilde{w}_t + \widetilde{n}_t - \widetilde{p}_{ro,t} && \text{(B.179)}
\end{aligned}$$

Fiscal policy

$$\begin{aligned}
\widetilde{or}_t =& \frac{\bar{OS}}{\bar{OR}} \widetilde{os}_t + \frac{p_g \bar{G}_c}{\bar{OR}} (\widetilde{p}_{g,t} + \widetilde{g}_{c,t}) - \frac{\bar{TX}}{\bar{OR}} \widetilde{tx}_t - \frac{\bar{B}}{\bar{OR}} \widetilde{b}_t + \frac{\bar{B/R}}{\bar{OR}} \left(\widetilde{b}_{t+1} - \widetilde{R}_t\right) && \text{(B.180)}\\
\widetilde{or}_t =& \widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{y}_{o,t} && \text{(B.181)}\\
\widetilde{os}_t =& \frac{q\bar{P^*_o}O}{\bar{OS}} \left(\widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{o}_t\right) - \frac{\bar{P_{ro}}O}{\bar{OS}} (\widetilde{p}_{ro,t} + \widetilde{o}_t) && \text{(B.182)}\\
\widetilde{g}_{c,t} =& \rho_{g_c} \widetilde{g}_{c,t-1} + (1-\rho_g) \left[\omega_{yo} \widetilde{y}_{o,t} - \omega_b \widetilde{b}_t + \omega_{or} \widetilde{or}_t\right] + \xi_t^{G_c} && \text{(B.183)}\\
\widetilde{tx}_t =& \varphi_b \widetilde{b}_{t-1} + \varphi_g \widetilde{g}_{c,t} + \varphi_{os} \widetilde{os}_t - \varphi_{or} \widetilde{or}_t && \text{(B.184)}\\
\widetilde{g}_{h,t} =& \widetilde{g}_{c,t} - \eta_g (\widetilde{p}_{h,t} - \widetilde{p}_{g,t}) && \text{(B.185)}\\
\widetilde{g}_{f,t} =& \widetilde{g}_{c,t} - \eta_g (\widetilde{p}_{f,t} - \widetilde{p}_{g,t}) && \text{(B.186)}
\end{aligned}$$

Monetary policy

$$\widetilde{R}_t = \rho_r \widetilde{R}_{t-1} + (1-\rho_r) [\omega_\pi \widetilde{\pi}_t + \omega_y \widetilde{y}_{h,t} + \omega_q \widetilde{q}_t] + \xi_t^r \qquad \text{(B.187)}$$

Market clearing and aggregation

$$\widetilde{y}_{h,t} = \frac{\bar{C}_h}{\bar{Y}_h}\widetilde{c}_{h,t} + \frac{\bar{C}_h^*}{\bar{Y}_h}\widetilde{c}^*_{h,t} + \frac{\bar{I_{no}}}{\bar{Y}_h}\widetilde{i}_{no,t} + \frac{\bar{M}}{\bar{Y}_h}\widetilde{m}_t + \frac{\bar{G}_c}{\bar{Y}_h}\widetilde{g}_{c,t} \tag{B.188}$$

$$\widetilde{y}_t = \frac{1-\bar{Y}_o}{\bar{Y}}\widetilde{y}_{h,t} + \frac{\bar{Y}_o}{\bar{Y}}\widetilde{y}_{o,t} \tag{B.189}$$

$$\widetilde{o}_t = \gamma_{gp}\widetilde{c}_{o,t} + (1-\gamma_{gp})\,\widetilde{o}_{h,t} \tag{B.190}$$

$$\widetilde{nx}_t = \frac{\bar{EX}}{\bar{NX}}\widetilde{ex}_t - \frac{1-\bar{EX}}{\bar{NX}}\widetilde{im}_t \tag{B.191}$$

$$\widetilde{ex}_t = \frac{1-\bar{Y}_o}{\bar{EX}}\widetilde{c}^*_t + \frac{\bar{Y}_o}{\bar{EX}}\widetilde{y}_{o,t} \tag{B.192}$$

$$\widetilde{im}_t = \frac{\bar{O}}{\bar{IM}}\widetilde{o}_t + \frac{\bar{C}_f}{\bar{IM}}\widetilde{c}_{f,t} + \frac{\bar{G}_f}{\bar{IM}}\widetilde{g}_{f,t} + \frac{1-\bar{O}-\bar{C}_f-\bar{G}_f}{\bar{IM}}\widetilde{i}_{f,t} \tag{B.193}$$

$$\widetilde{c}^*_{h,t} = \widetilde{c}^*_t - \eta_{c_h^*}\left(\widetilde{p}_{h,t} - \widetilde{q}_t\right) \tag{B.194}$$

$$\begin{aligned}\widetilde{nx}_t =& \frac{q\bar{B^*}R^*}{\bar{NX}}\left(\widetilde{q}_t + \widetilde{b}_t - \widetilde{R}^*_t - \widetilde{\mu}^*_t\right) - \frac{q\bar{B}^*}{\bar{NX}}\left(\widetilde{q}_t + \widetilde{b}^*_{t-1}\right) \\ &+ \frac{(1-\tau)\,q\bar{P_o^*}Y_o}{\bar{NX}}\left(\widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{y}_{o,t}\right) - \frac{q\bar{FDI}}{\bar{NX}}\left(\widetilde{q}_t + \widetilde{fdi}^*_t\right)\end{aligned} \tag{B.195}$$

Foreign economy

$$\widetilde{c}^*_t = \frac{1}{1+\phi^*_c}\widetilde{c}^*_{t+1} + \frac{\phi^*_c}{1+\phi^*_c}\widetilde{c}^*_{t-1} - \frac{1-\phi^*_c}{\sigma^*(1+\phi^*_c)}\left(\widetilde{R}^*_t - E_t\widetilde{\pi}^*_{t+1} + \widetilde{\mu}^*_t\right) \tag{B.196}$$

$$\widetilde{R}^*_t = \rho_{r^*}\widetilde{R}^*_{t-1} + (1-\rho_{r^*})\left[\omega^*_\pi\widetilde{\pi}^*_t + \omega^*_y\widetilde{y}^*_t\right] + \xi^{r^*}_t \tag{B.197}$$

$$\widetilde{\pi}^*_t = \rho_{\pi^*}\widetilde{\pi}^*_{t-1} + \xi^{\pi^*}_t \tag{B.198}$$

Shock processes

$$\widetilde{A}_{h,t} = \rho_{a_h}\widetilde{A}_{h,t-1} + \xi^{a_h}_t \tag{B.199}$$

$$\widetilde{A}_{o,t} = \rho_{a_0}\widetilde{A}_{o,t-1} + \xi^{a_o}_t \tag{B.200}$$

$$\widetilde{p}^*_{o,t} = \rho_{p^*_o}\widetilde{p}^*_{o,t-1} + \xi^{p^*_o}_t \tag{B.201}$$

$$\widetilde{\mu}_t = \rho_\mu\widetilde{\mu}_{t-1} + \xi^\mu_t \tag{B.202}$$

$$\widetilde{\mu}^*_t = \rho_{\mu^*}\widetilde{\mu}^*_{t-1} + \xi^{\mu^*}_t \tag{B.203}$$

$$\widetilde{\psi}^o_t = \rho_{\psi^o}\widetilde{\psi}^o_{t-1} + \xi^{\psi^o}_t \tag{B.204}$$

B.4 Estimation results

B.4.1 Univariate and multivariate convergence diagnostics

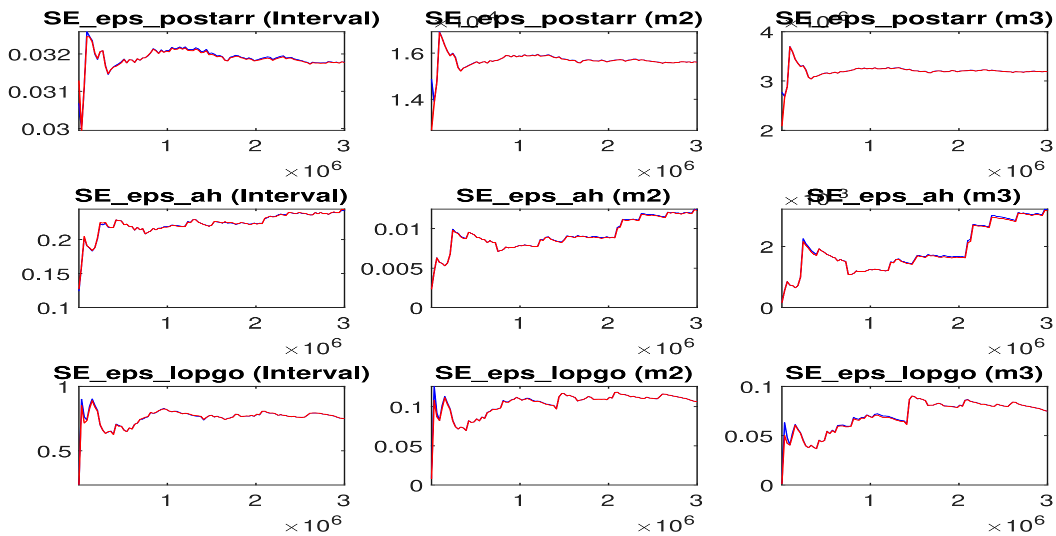

Figure B.1: Univariate convergence diagnostics

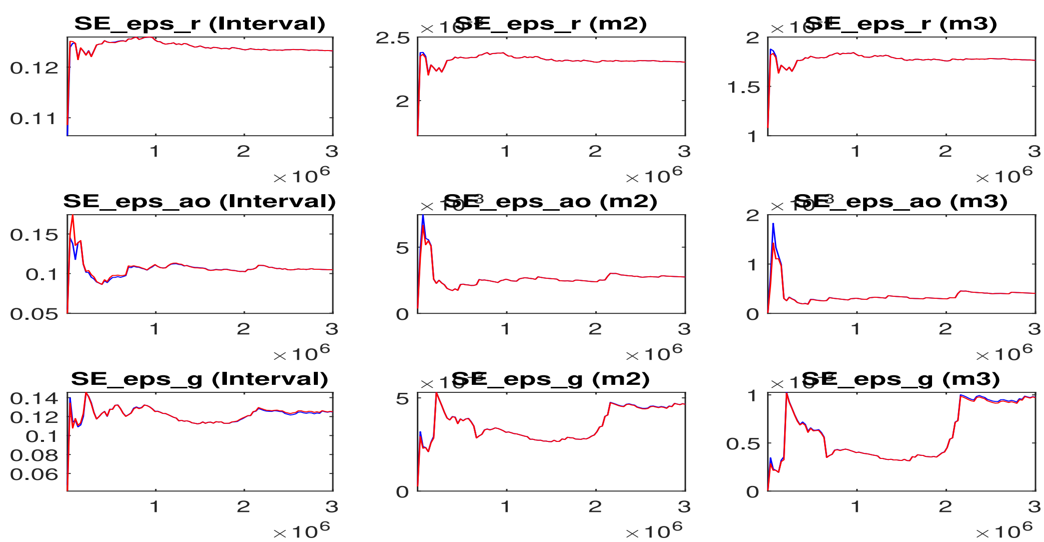

Figure B.2: Univariate convergence diagnostics

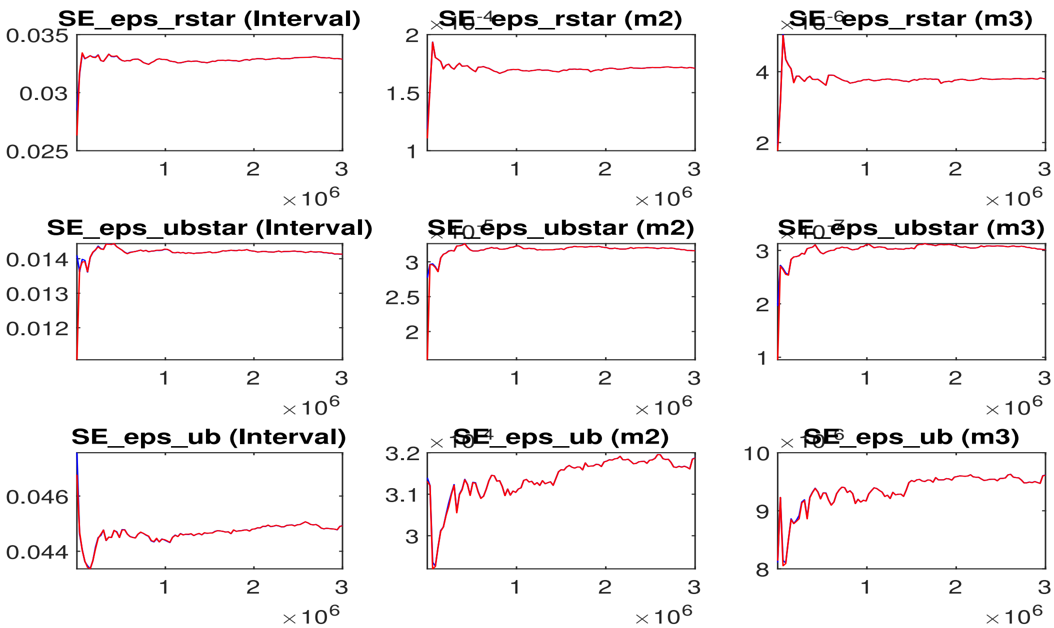

Figure B.3: Univariate convergence diagnostics

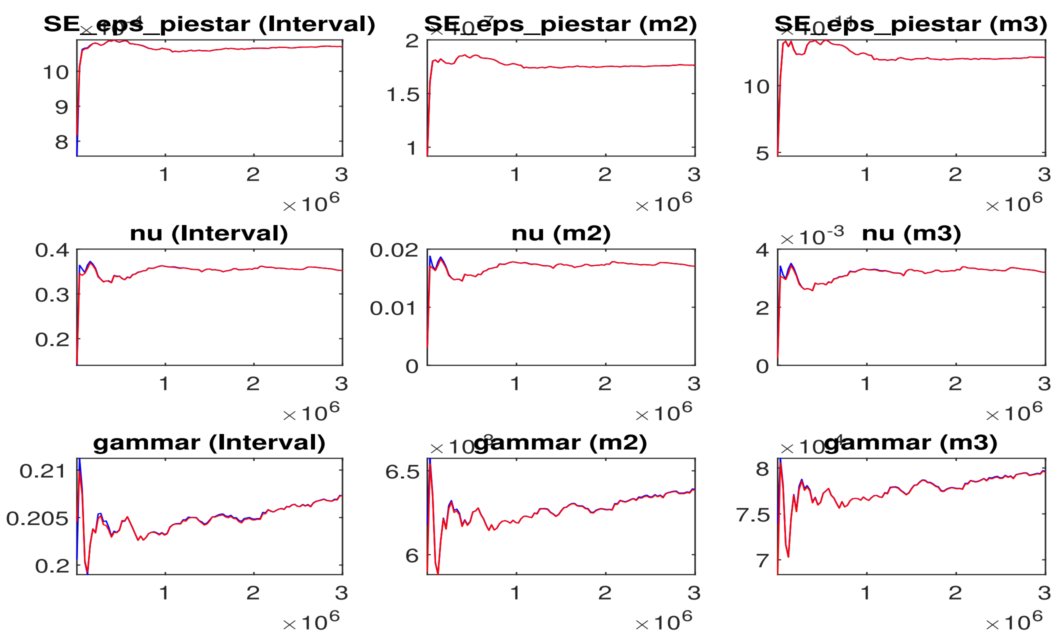

Figure B.4: Univariate convergence diagnostics

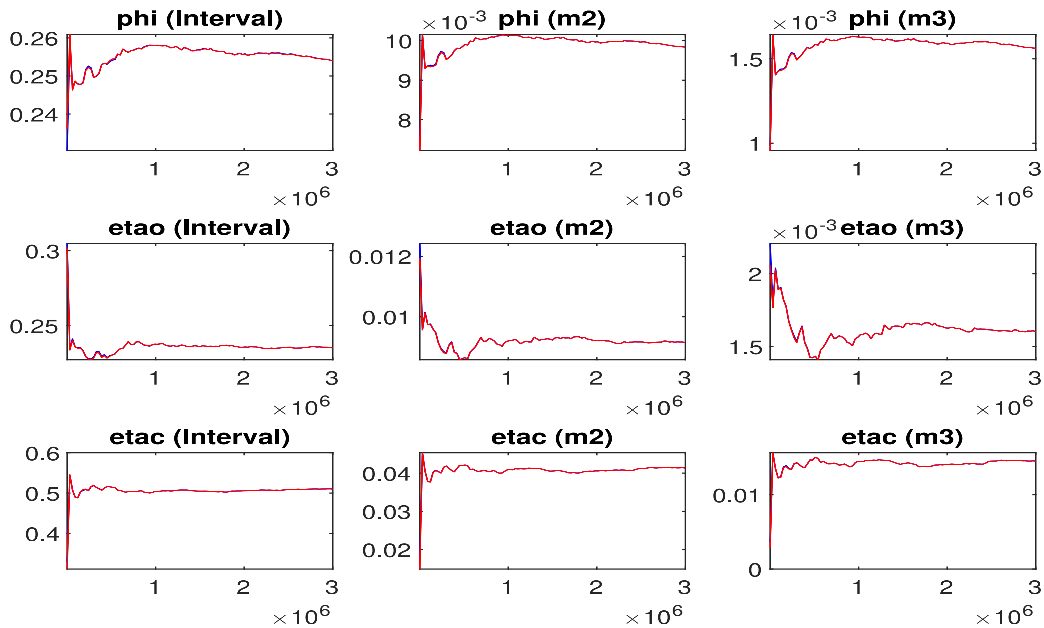

Figure B.5: Univariate convergence diagnostics

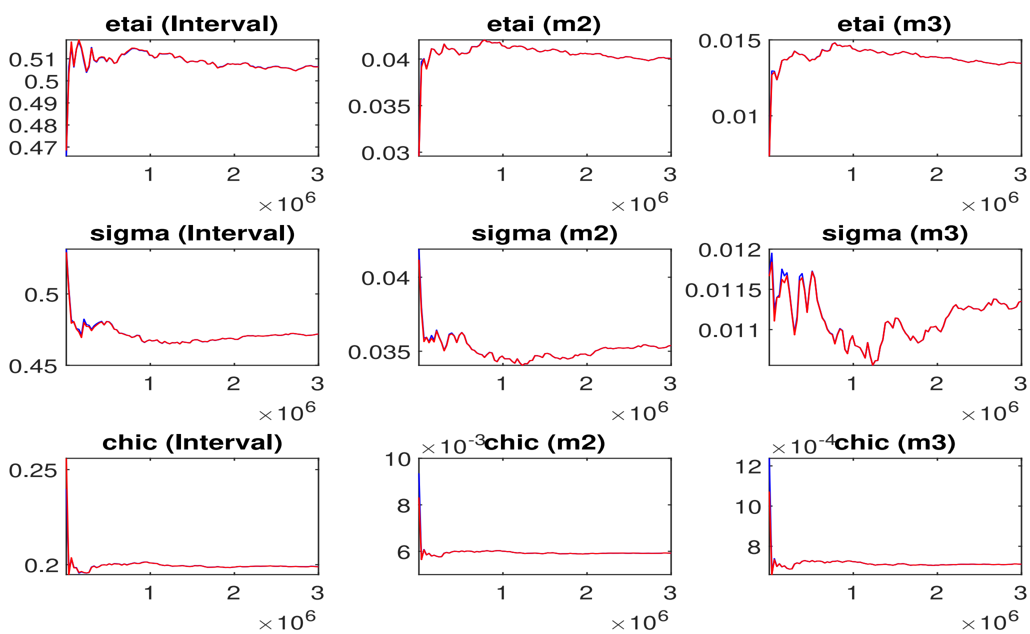

Figure B.6: Univariate convergence diagnostics

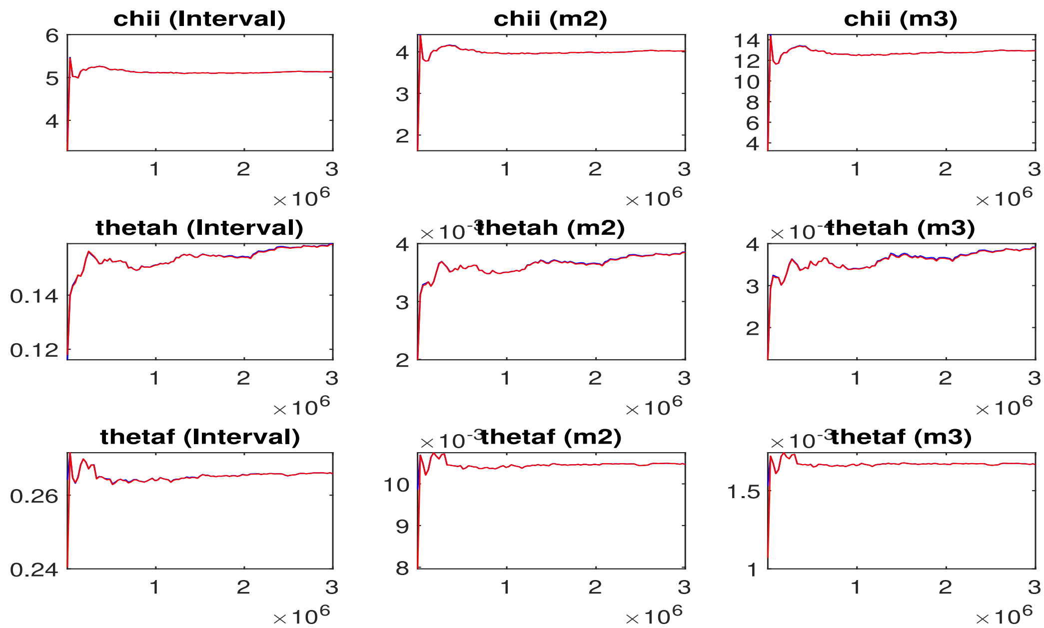

Figure B.7: Univariate convergence diagnostics

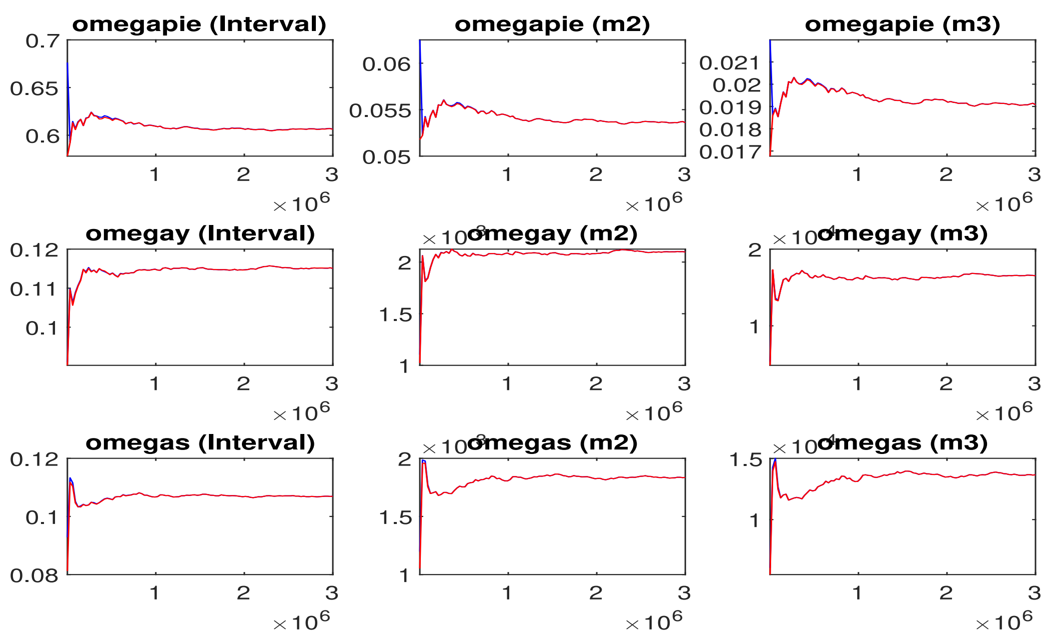

Figure B.8: Univariate convergence diagnostics

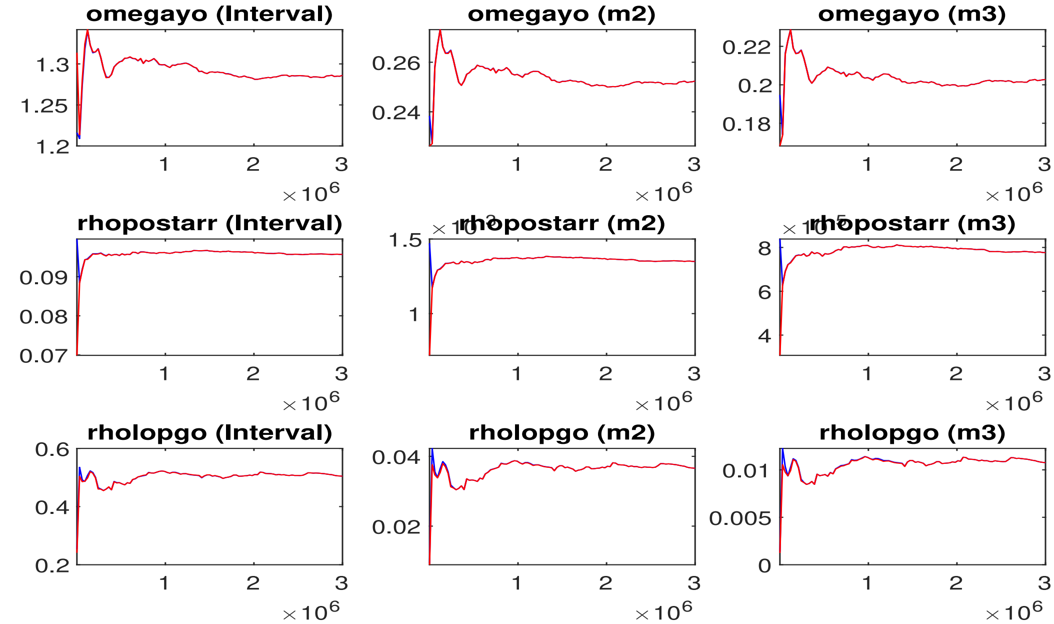

Figure B.9: Univariate convergence diagnostics

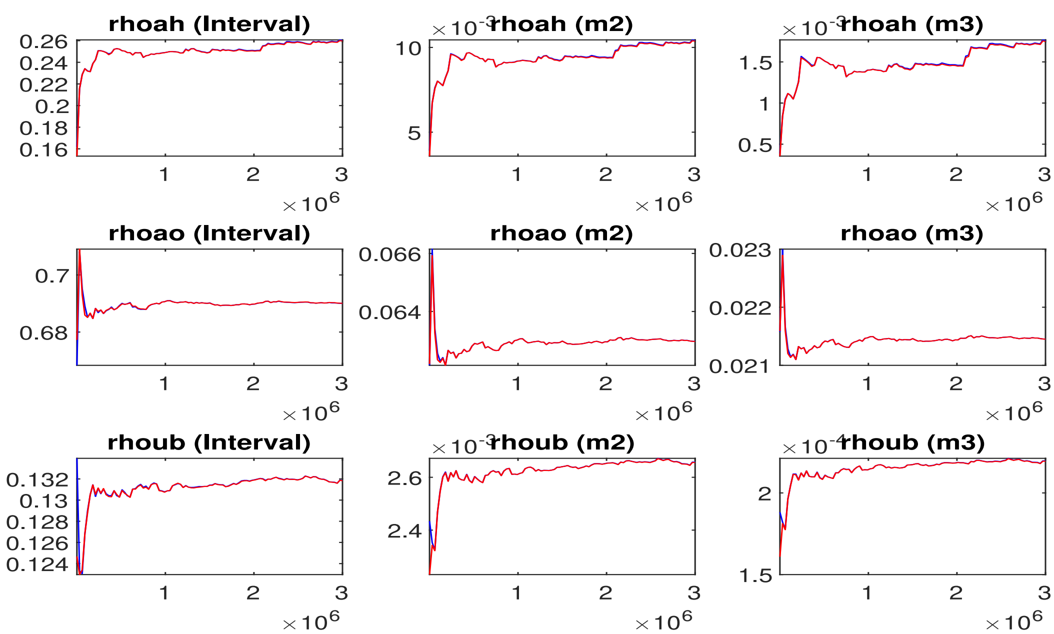

Figure B.10: Univariate convergence diagnostics

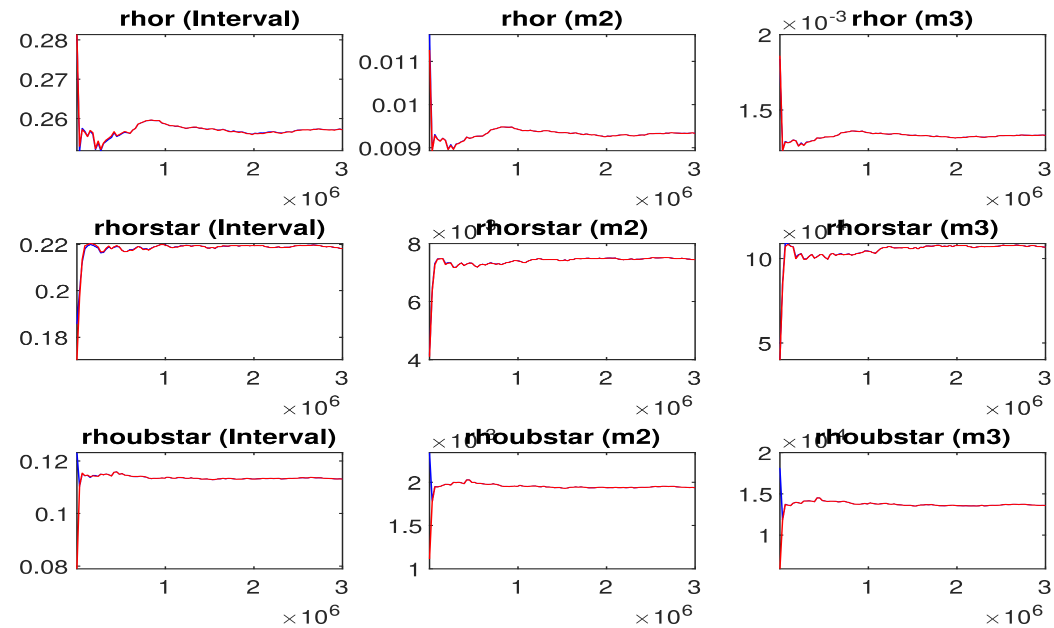

Figure B.11: Univariate convergence diagnostics

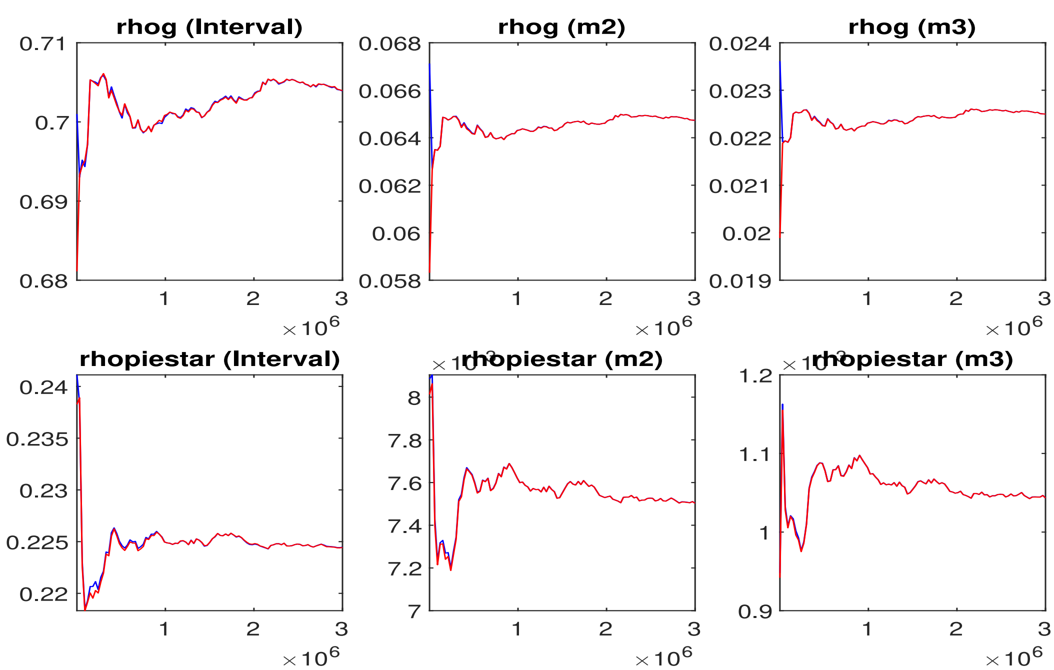

Figure B.12: Univariate convergence diagnostics

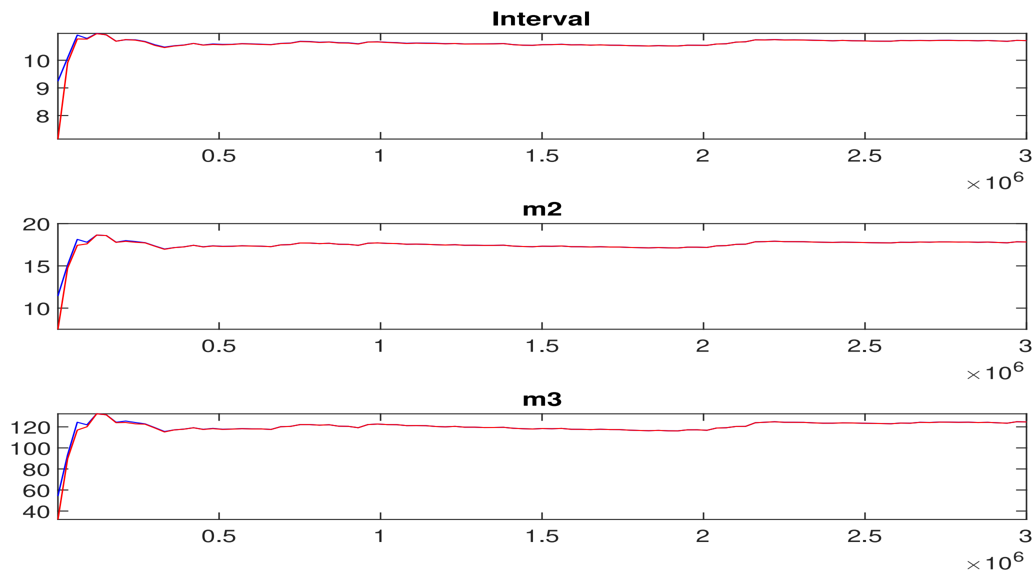

Figure B.13: Multivariate convergence diagnostics

B.4.2 Priors and posteriors

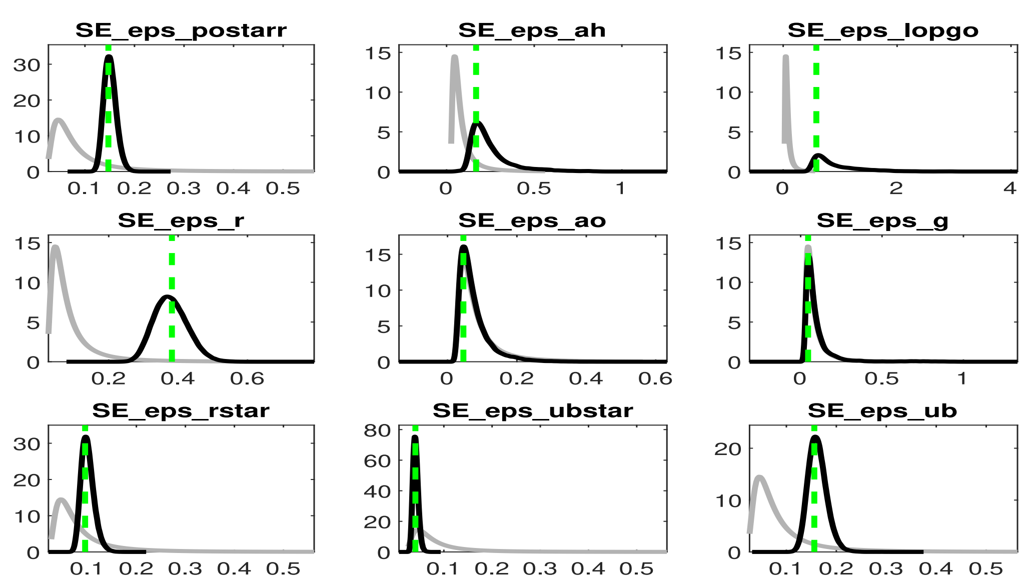

Figure B.14: Priors and posteriors

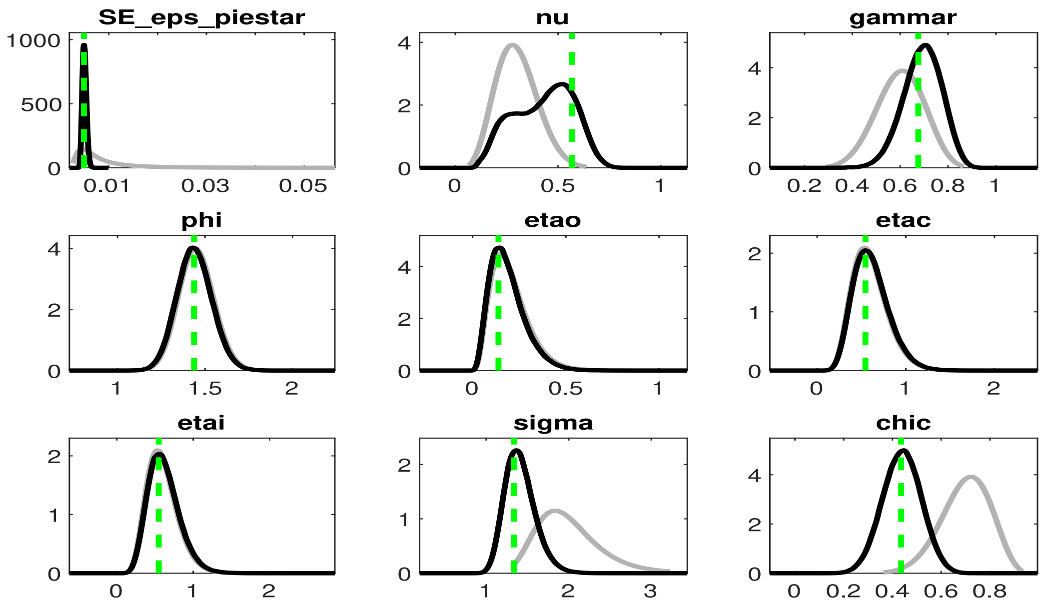

Figure B.15: Priors and posteriors

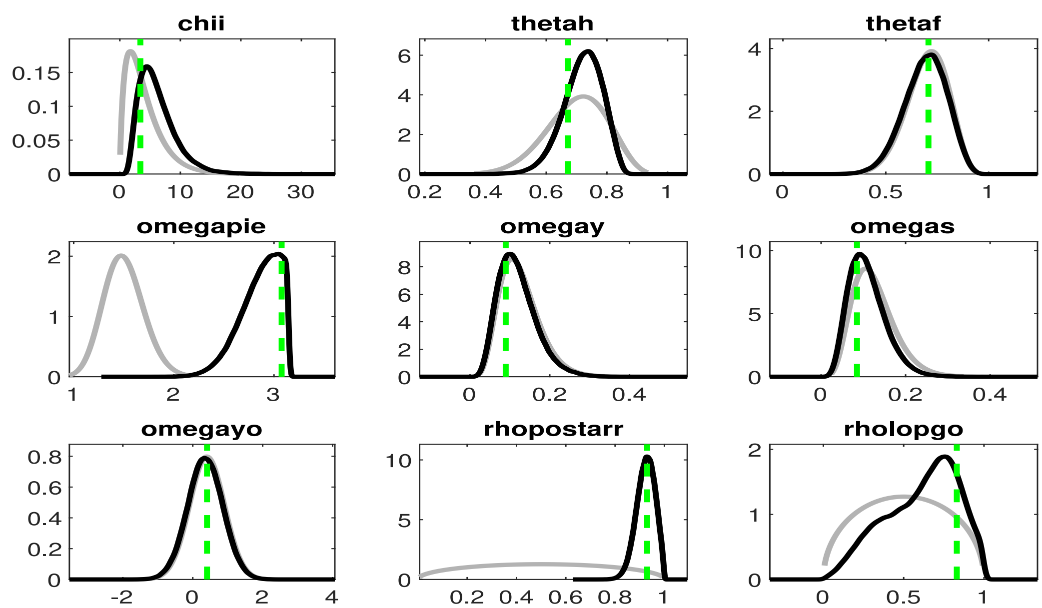

Figure B.16: Priors and posteriors

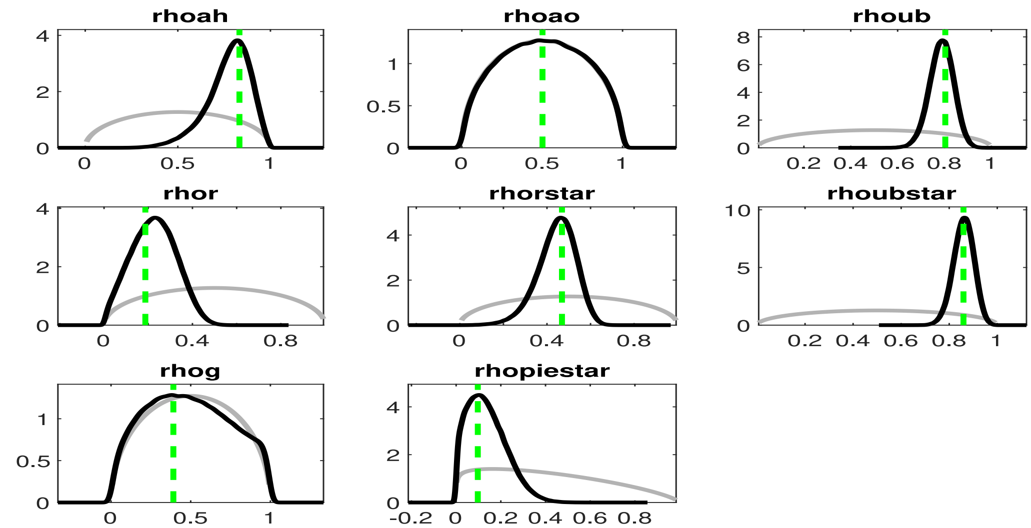

Figure B.17: Priors and posteriors

B.4.3 Identification diagnostics

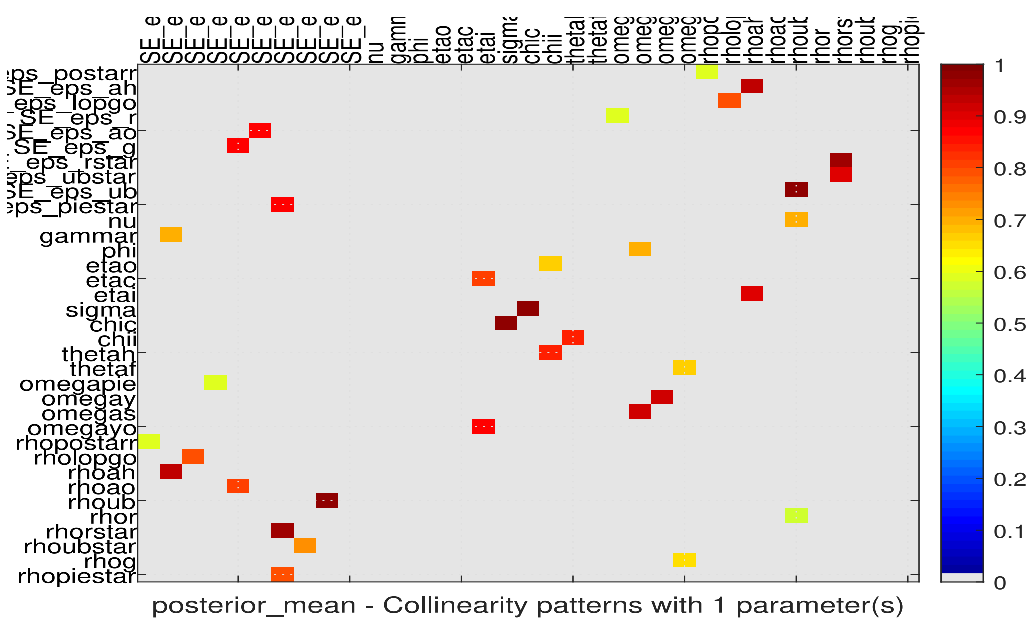

Figure B.18: Pairwise collinearity patterns in the model

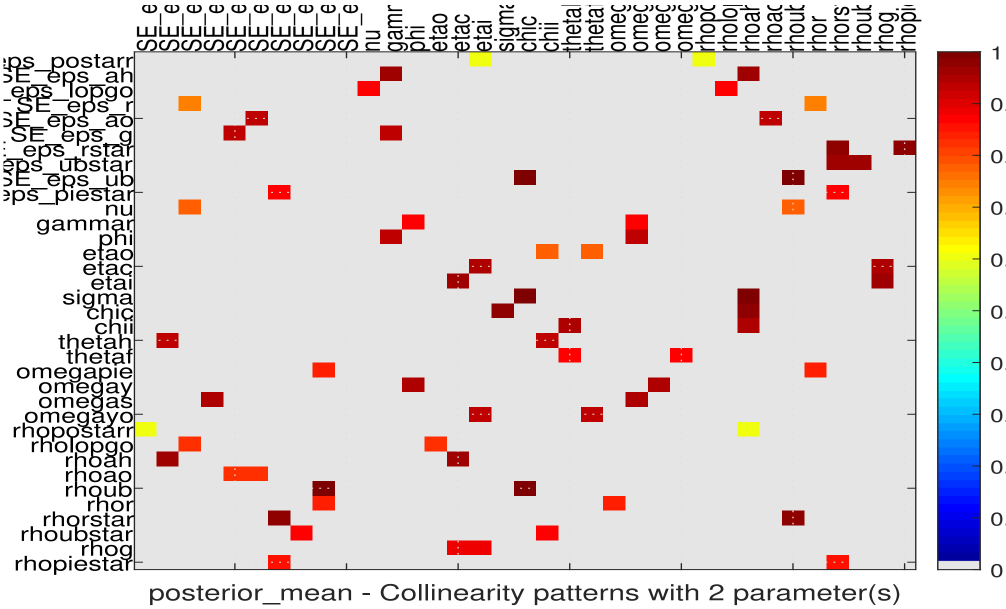

Figure B.19: Pairwise collinearity patterns in the model

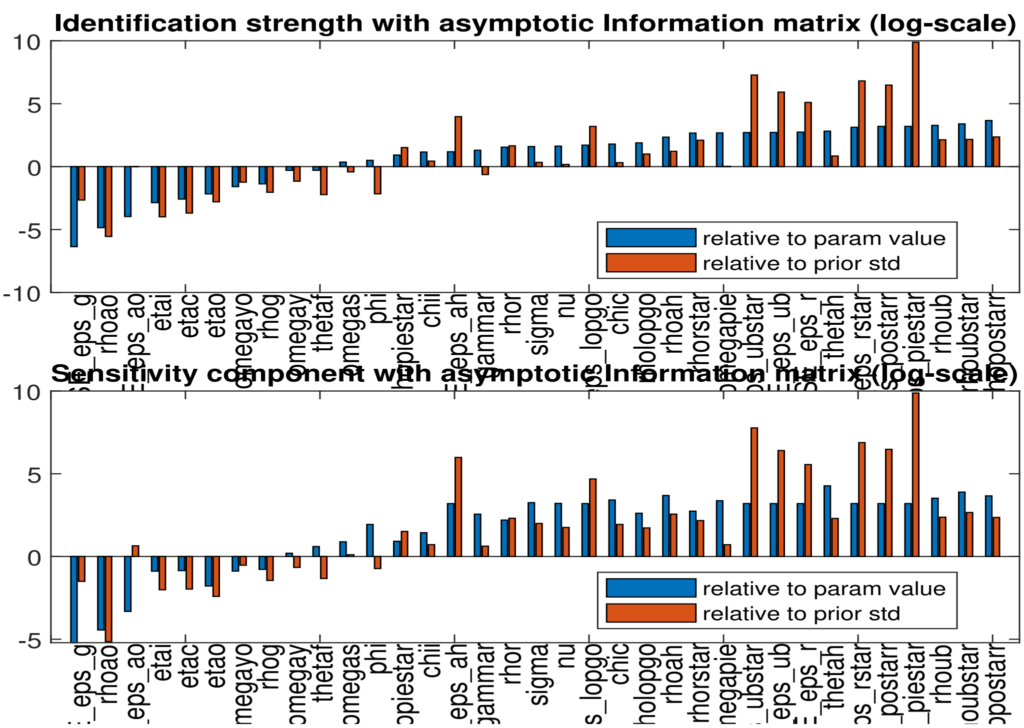

Figure B.20: Identification of prior means

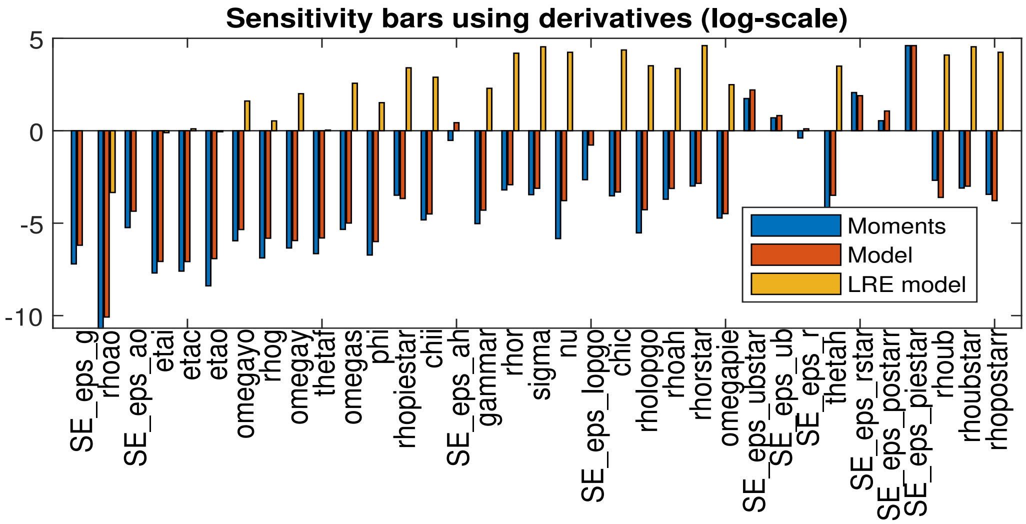

Figure B.21: Identification of prior means

Appendix C

Appendix for Chapter 3

C.1 First order conditions

Households

Ricardian consumers

The representative Ricardian household maximizes a utility function given by:

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

subject to the nominal budget constraint:

$$P_t C_t^R + P_{i,t} I_{no,t} + \frac{B_{t+1}}{R_t \mu_t} + \frac{\varepsilon_t B_{t+1}^*}{R_t^* \mu_t^*} = W_t N_t^R + R_{h,t} K_{h,t} + B_t + \varepsilon_t B_t^* + D_t - TX_t \tag{C.2}$$

and the process of capital accumulation:

$$K_{h,t+1} = (1-\delta_h) K_{h,t} + I_{no,t} \left[1 - S \left(\frac{I_{no,t}}{I_{no,t-1}} \right)^2 \right]. \tag{C.3}$$

The Lagrangian for this problem can be written as:

$$\mathcal{L} = E_0 \sum_{s=0}^{\infty} \beta^s \Bigg\{ \frac{\left(C_{t+s}^R - \phi_c C_{t+s-1}\right)^{1-\sigma}}{1-\sigma} - \frac{\left(N_{t+s}^R\right)^{1+\varphi}}{1+\varphi}$$
$$- \lambda_{C,t}^R \Bigg[P_t C_t^R + P_{i,t} I_{no,t} + \frac{B_{t+1}}{R_t \mu_t} + \frac{\varepsilon_t B_{t+1}^*}{R_t^* \mu_t^*}$$
$$- W_t N_t^R - R_{h,t} K_{h,t} - B_t - \varepsilon_t B_t^* - D_t + TX_t \Bigg]$$
$$- \lambda_{K,t}^R \left[K_{h,t+1} - (1-\delta_h) K_{h,t} - I_{no,t} \left(1 - \frac{\chi}{2} \left(\frac{I_{no,t}}{I_{no,t-1}} \right)^2 \right) \right] \Bigg\} \quad \text{(C.4)}$$

where $\lambda_{C,t}^R$ and $\lambda_{K,t}^R$ are the Lagrange multipliers associated with household budget constraint and the law of motion for capital, respectively. In order to derive the first-order conditions, we set the partial derivatives of $\mathcal{L}$ with respect to C_t^R, B_{t+1}, B_{t+1}^*, $K_{h,t+1}$, $I_{no,t}$, $\lambda_{C,t}^R$ and $\lambda_{K,t}^R$ equal to zero. Thus, the first-order conditions for C_t^R, B_{t+1}, B_{t+1}^*, $K_{h,t+1}$, and $I_{no,t}$ are respectively given by:

$$\frac{\partial L}{\partial C_t^R} = \left(C_t^R - \phi_c C_{t-1}\right)^{-\sigma} - \lambda_{C,t}^R P_t = 0, \quad \text{(C.5)}$$

$$\frac{\partial L}{\partial B_{t+1}} = - \frac{\lambda_{C,t}^R}{R_t \mu_t} + \beta E_t \lambda_{C,t+1}^R = 0, \quad \text{(C.6)}$$

$$\frac{\partial L}{\partial B_{t+1}^*} = - \frac{\lambda_{C,t}^R \varepsilon_t}{R_t^* \mu_t^*} + \beta E_t \lambda_{C,t+1}^R = 0, \quad \text{(C.7)}$$

$$\frac{\partial L}{\partial K_{h,t+1}} = \beta E_t \lambda_{C,t+1}^R R_{h,t+1} - \lambda_{K,t}^R + \beta E_t \lambda_{K,t+1}^R (1-\delta_h) = 0, \quad \text{(C.8)}$$

$$\frac{\partial L}{\partial I_{no,t+1}} = - \lambda_{C,t}^R P_{i,t} + \lambda_{K,t}^R - \frac{\chi}{2} \lambda_{K,t}^R \left(\frac{I_{no,t}}{I_{no,t-1}} - 1 \right)^2$$
$$- \chi \lambda_{K,t}^R I_{no,t} \left(\frac{I_{no,t}}{I_{no,t-1}} - 1 \right) \frac{1}{I_{no,t-1}}$$
$$+ \chi \beta E_t \lambda_{K,t+1}^R I_{no,t+1} (j) \left(\frac{I_{no,t+1}}{I_{no,t}} - 1 \right) \frac{I_{no,t+1}}{(I_{no,t})^2} = 0. \quad \text{(C.9)}$$

Combining equations (C.5) and (C.6), we derive the consumption Euler equation as:

$$\frac{1}{R_t \mu_t} = \beta E_t \left[\left(\frac{C_{t+1}^R - \phi_c C_t}{C_t^R - \phi_c C_{t-1}} \right)^{-\sigma} \frac{1}{\pi_{t+1}} \right]. \tag{C.10}$$

The demand for foreign bonds is derived by combining equations (C.5) and (C.7) to yield:

$$\frac{1}{R_t^* \mu_t^*} = \beta E_t \left[\frac{\varepsilon_{t+1}}{\varepsilon_t} \left(\frac{C_{t+1}^R - \phi_c C_t}{C_t^R - \phi_c C_{t-1}} \right)^{-\sigma} \frac{1}{\pi_{t+1}} \right], \tag{C.11}$$

where $\pi_t = \frac{P_t}{P_{t-1}}$. Substituting for $\lambda_{C,t}^R = \frac{1}{P_t \left(C_t^R - \phi_c C_{t-1} \right)^\sigma}$ from equation (C.5) into equation (C.8) and defining real rental rate as $r_{h,t} = \frac{R_{h,t}}{P_t}$, we derive the expression for capital as follows:

$$\lambda_{K,t}^R = \beta E_t \left[\frac{1}{\left(C_{t+1}^R - \phi_c C_t \right)^\sigma} r_{h,t+1} + \lambda_{K,t+1}^R \left(1 - \delta_h \right) \right], \tag{C.12}$$

where the real rental rate is derived from the non-oil producing firm's optimization problem. Lastly, we apply equation (C.5) to (C.9) to derive the expression for non-oil investment as:

$$\begin{aligned} \left(C_t^R - \phi_c C_{t-1} \right)^{-\sigma} - \lambda_{K,t}^R \left[1 - \frac{\chi}{2} - \frac{3}{2} \chi \left(\frac{I_{no,t}}{I_{no,t-1}} \right)^2 + 2\chi \left(\frac{I_{no,t}}{I_{no,t-1}} \right) \right] \\ = \chi \beta E_t \lambda_{K,t+1}^R \left[\left(\frac{I_{no,t+1}}{I_{no,t}} - 1 \right) \left(\frac{I_{no,t+1}}{I_{no,t}} \right)^2 \right]. \end{aligned} \tag{C.13}$$

Non-Ricardian consumers

The representative non-Ricardian household maximize a utility function given by:

$$U_0^{NR} = \frac{\left(C_{t+s}^{NR} - \phi_c C_{t+s-1} \right)^{1-\sigma}}{1-\sigma} - \frac{\left(N_{t+s}^{NR} \right)^{1+\varphi}}{1+\varphi}, \tag{C.14}$$

subject to the nominal budget constraint:

$$P_t C_t^{NR} = W_t N_t^{NR} - TX_t. \tag{C.15}$$

As earlier assumed, this group of households neither invest in bonds nor accumulate capital. Since they are non-optimizers, their entire disposable income is used to purchase consumption goods. The Lagrangian for this problem can be written as:

$$\mathcal{L} = \frac{\left(C_{t+s}^{NR} - \phi_c C_{t+s-1}\right)^{1-\sigma}}{1-\sigma} - \frac{\left(N_{t+s}^{NR}\right)^{1+\varphi}}{1+\varphi} \\ - \lambda_{C,t}^{NR}\left(P_t C_t^{NR} - W_t N_t^{NR} - TX_t\right), \tag{C.16}$$

where $\lambda_{C,t}^{R}$ is the Lagrange multiplier associated with household budget constraint of the non-Ricardian household. Since the representative household chooses $\left\{C_t^R\right\}_{s=0}^{\infty}$, we set the partial derivatives of $\mathcal{L}$ in equation (C.16) with respect to C_t^R and $\lambda_{C,t}^{NR}$ equal to zero. The first-order conditions for C_t^R is:

$$\begin{aligned} \frac{\partial L}{\partial C_t^{NR}} &= \left(C_t^{NR} - \phi_c C_{t-1}\right)^{-\sigma} - \lambda_{C,t}^{R} P_t = 0, \\ \lambda_{C,t}^{NR} &= \frac{1}{\left(C_t^{NR} - \phi_c C_{t-1}\right)^{\sigma} P_t}. \end{aligned} \tag{C.17}$$

The equilibrium conditions of the representative non-Ricardian household are described by the optimal consumption level (equation C.17) and the budget constraint (equation C.15).

Labour supply and wage setting

The labour-aggregating firm uses the following technology:

$$N_t = \left[\int_0^1 N_t(j)^{\frac{\eta_w - 1}{\eta_w}} dj\right]^{\frac{\eta_w}{\eta_w - 1}}, \tag{C.18}$$

and seeks to maximise a profit function given by:

$$\max_{N_t(j)} \mathit{\Pi}_{w,t} = W_t N_t - \int_0^1 W_t(j) N_t(j)\, dj. \tag{C.19}$$

Putting equation (C.18) into (C.19) yields:

$$\max_{N_t(j)} \Pi_{W,t} = W_t \left[\int_0^1 N_t(j)^{\frac{\eta_w - 1}{\eta_w}} dj \right]^{\frac{\eta_w}{\eta_w - 1}} - W_t(j) \int_0^1 N_t(j) \, dj. \tag{C.20}$$

The first order condition of the above problem with respect to $N_t(j)$ yields the labour-aggregating firm's demand for differentiated labour as:

$$N_t(j) = \left[\frac{W_t(j)}{W_t} \right]^{-\eta_w} N_t. \tag{C.21}$$

Substituting equation (C.21) into (C.18), we can derive the aggregate wage level as:

$$W_t = \left[\int_0^1 W_t(j)^{1-\eta_w} dj \right]^{\frac{1}{1-\eta_w}}, \tag{C.22}$$

In line with Calvo (1983), we assume that $1 - \theta_w$ fraction of households optimally define their wages while the remaining fraction, θ_w, follows a rule that enables them to retain the wage level in the previous period as follows:

$$W_t(j) = W_{t-1}(j). \tag{C.23}$$

A representative household that is able to reset wage level in period t does so by maximizing its utility subject to its budget constraint, the capital accumulation process and the demand for its differentiated labour shown in equation (C.21). Thus, the maximization problem can be written as:

$$\begin{aligned}
\max_{W_t^\bullet(j)} E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \Bigg\{ & \frac{(C_{t+s}(j) - \phi_c C_{t+s-1})^{1-\sigma}}{1-\sigma} - \frac{1}{1+\varphi} \left(N_{t+s} \left(\frac{W_{t+s}}{W_t^\bullet(j)} \right)^{\eta_w} \right)^{1+\varphi}) \\
& - \lambda_{C,t+s}^R \Bigg[P_t C_t(j) + P_{i,t} I_{no,t}(j) + \frac{B_{t+1}(j)}{R_t \mu_t} + \frac{\varepsilon_t B_{t+1}^*(j)}{R_t^* \mu_t^*} \\
& - W_t^\bullet(j) \left(N_{t+s}(j) \left(\frac{W_{t+s}}{W_t^\bullet(j)} \right)^{\eta_w} \right) - R_{h,t} K_{h,t}(j) - B_t(j) - \varepsilon_t B_t^*(j) - D_t + TX_t \Bigg] \\
& - \lambda_{K,t}^R \left[K_{h,t+1}(j) - (1-\delta_h) K_{h,t}(j) - I_{no,t} \left(1 - \frac{\chi}{2} \left(\frac{I_{no,t}(j)}{I_{no,t-1}(j)} \right)^2 \right) \right] \Bigg\}.
\end{aligned} \tag{C.24}$$

Taking the first order condition of equation (C.24) with respect to $W_t^{\bullet}(j)$ yields:

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

and substituting the demand for differentiated labour, $N_t(j)$, in (equation C.21) into the above expression yields:

$$E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left\{ \eta_w \left[N_{t+s}(j) \right]^{\varphi} \frac{1}{W_t^{\bullet}(j)} + (1-\eta_w) \lambda_{C,t+s} \right\} = 0. \tag{C.25}$$

Finally, the optimal reset wage can be written as:

$$W_t^{\bullet}(j) = \left(\frac{\eta_w}{\eta_w - 1} \right) E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\frac{(N_{t+s}(j))^{\varphi}}{\lambda_{C,t+s}} \right]. \tag{C.26}$$

Equation (C.26) can be re-written specifically for each category, $i = R, NR$, of household as follows:

$$W_t^{\bullet}(j) = \left(\frac{\eta_w}{\eta_w - 1} \right) E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\frac{\left(N_{t+s}^{R}(j)\right)^{\varphi}}{\lambda_{C,t+s}^{R}} \right], \tag{C.27}$$

$$W_t^{\bullet}(j) = \left(\frac{\eta_w}{\eta_w - 1} \right) E_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\frac{\left(N_{t+s}^{NR}(j)\right)^{\varphi}}{\lambda_{C,t+s}^{NR}} \right]. \tag{C.28}$$

Equations (C.27) and (C.28) define the labour supply by Ricardian and non-Ricardian households, respectively. By law of large numbers, the aggregate wage level (equation C.22) can be written as:

$$W_t = \left[\theta_w W_{t-1}^{1-\eta_w} + (1-\theta_w) W_t^{\bullet 1-\eta_w} \right]^{\frac{1}{1-\eta_w}}, \tag{C.29}$$

Finally, consumption demand and hours of Ricardian and non-Ricardian households can be aggregated as follows:

$$C_t = \gamma_R C_t^R + (1-\gamma_R) C_t^{NR}, \tag{C.30}$$

$$N_t = \gamma_R N_t^R + (1 - \gamma_R) N_t^{NR}, \tag{C.31}$$

where for Ricardian households, $C_t^R = \int_0^1 C_t^R(j)\, dj$ and $N_t^R = \int_0^1 N_t^R(j)\, dj$. For non-Ricardian households, $C_t^{NR} = \int_0^1 C_t^{NR}(j)\, dj$ and $N_t^{NR} = \int_0^1 N_t^{NR}(j)\, dj$.

Final-goods producers

The representative final goods producer seeks to maximize its profit given by:

$$\mathit{\Pi}_{h,t}(z_h) = P_{h,t} Y_{h,t} - \int_0^1 P_{h,t}(z_h)\, Y_{h,t}(z_h)\, dz_h, \tag{C.32}$$

subject to the constant returns to scale bundling technology:

$$Y_{h,t} = \left[\int_0^1 Y_{h,t}(z_h)^{\frac{\epsilon_h - 1}{\epsilon_h}} dz_h \right]^{\frac{\epsilon_h}{\epsilon_h - 1}}. \tag{C.33}$$

To describe the firm's optimization problem, we put equation (C.33) into (C.32) as follows:

$$\max_{Y_{h,t}(z_h)} \mathit{\Pi}_{h,t}(z_h) = P_{h,t} \left[\int_0^1 Y_{h,t}(z_h)^{\frac{\epsilon_h - 1}{\epsilon_h}} dz_h \right]^{\frac{\epsilon_h}{\epsilon_h - 1}} - \int_0^1 P_{h,t}(z_h)\, Y_{h,t}(z_h)\, dz_h. \tag{C.34}$$

Taking the partial derivative of equation (C.34) with respect to $Y_{H,t}(z_h)$ yields:

$$\frac{\partial \mathit{\Pi}_{h,t}}{\partial Y_{h,t}(z_h)} = (Y_{h,t})^{-1} Y_{h,t}(z_h) - \left[\frac{P_{h,t}(z_h)}{P_{h,t}} \right]^{-\epsilon_h} = 0,$$

$$Y_{h,t}(z_h) = \left[\frac{P_{h,t}(z_h)}{P_{h,t}} \right]^{-\epsilon_h} Y_{h,t}, \tag{C.35}$$

where equation (C.35) is the firm's demand for intermediate goods, $Y_{H,t}(z_h)$ as claimed in equation (2.30) of the text. The final goods pricing rule is derived by substituting equation

(C.35) into the bundling technology (equation C.33) to yield:

$$P_{h,t} = \left[\int_0^1 P_{h,t}(z_h)^{1-\epsilon_h} \, dz_h \right]^{\frac{1}{1-\epsilon_h}}. \tag{C.36}$$

Intermediate-goods producers

Each intermediate goods producer chooses optimal quantities of factor inputs to employ by minimizing cost:

$$\min_{N_t(z_h), K_{h,t}(z_h), O_t(z_h)} W_t N_t(z_h) + R_{h,t} K_{h,t}(z_h) + P_{ro,t} O_t(z_h), \tag{C.37}$$

subject to a constant returns to scale Cobb-Douglas technology:

$$Y_{h,t}(z_h) = A_{h,t} K_{h,t}(z_h)^{\alpha_h^k} O_{h,t}(z_h)^{\alpha_h^o} N_t(z_h)^{\alpha_h^n}. \tag{C.38}$$

The Lagrangian for the firm's optimization problem can be written as:

$$\begin{aligned} \mathcal{L} = & - \left[W_t N_t(z_h) + R_{h,t} K_{h,t}(z_h) + P_{ro,t} O_t(z_h) \right] \\ & + \lambda_t^g(z_h) P_{h,t} \left[A_{h,t} K_{h,t}(z_h)^{\alpha_h^k} O_{h,t}(z_h)^{\alpha_h^o} N_t(z_h)^{\alpha_h^n} - Y_{h,t}(z_h) \right]. \end{aligned} \tag{C.39}$$

The first-order condition with respect to $N_t(z_h)$ is:

$$\frac{\partial \mathcal{L}}{\partial N_t(z_h)} = -W_t + \lambda_t^g(z_h) \alpha_h^n P_{h,t} \frac{Y_{h,t}(z_h)}{N_t(z_h)} = 0,$$

$$\frac{W_t}{P_t} = mc_t \alpha_h^n p_{h,t} \frac{Y_{h,t}(z_h)}{N_t(z_h)} = w_t, \tag{C.40}$$

$$N_t(z_h) = \frac{mc_t \alpha_h^n p_{h,t} Y_{h,t}(z_h)}{w_t}. \tag{C.41}$$

where $mc_t = \frac{MC_t}{P_t}, p_{h,t} = \frac{P_{h,t}}{P_t}, w_t = \frac{W_t}{P_t}$. The intermediate firm's demand for labour is given by equation (C.41). Similarly, the first-order condition with respect to $K_{h,t}(z_h)$ is:

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial K_{h,t}(z_h)} &= -R_{h,t} + \lambda_t^g(z_h)\,\alpha_h^k P_{h,t}\frac{Y_{h,t}(z_h)}{K_{h,t}(z_h)} &=& \ 0, \\ \frac{R_{h,t}}{P_t} &= mc_t\alpha_h^k p_{h,t}\frac{Y_{h,t}(z_h)}{K_{h,t}(z_h)} &=& \ r_{h,t}, && \text{(C.42)} \\ K_{h,t}(z_h) &= \frac{mc_t\alpha_h^k p_{h,t} Y_{h,t}(z_h)}{r_{h,t}}, && && \text{(C.43)} \end{aligned}$$

where $w_t = \frac{R_{h,t}}{P_t}$. From equation (C.42), the real rental rate is derived, while the intermediate firm's demand for capital is given by equation (C.43). Finally, the first-order condition with respect to $O_{h,t}(z_h)$ is:

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial O_{h,t}(z_h)} &= -P_{ro,t} + \lambda_t^g(z_h)\,\alpha_h^o P_{h,t}\frac{Y_{h,t}(z_h)}{O_{h,t}(z_h)} &=& \ 0, \\ \frac{P_{ro,t}}{P_t} &= mc_t\alpha_h^o p_{h,t}\frac{Y_{h,t}(z_h)}{O_{h,t}(z_h)} &=& \ p_{ro,t}, \\ O_{h,t}(z_h) &= \frac{mc_t\alpha_h^o p_{h,t} Y_{h,t}(z_h)}{p_{ro,t}}. && && \text{(C.44)} \end{aligned}$$

where $p_{ro,t} = \frac{P_{ro,t}}{P_t}$. The intermediate firm's demand for oil input is given by equation (C.44). Based on equations (C.41), (C.43) and (C.44), we obtain the intermediate firm's input combinations as follows:

$$\frac{K_{h,t}(z_h)}{N_t(z_h)} = \frac{\alpha_h^k w_t}{\alpha_h^n r_{h,t}}, \tag{C.45}$$

$$\frac{O_{h,t}(z_h)}{N_t(z_h)} = \frac{\alpha_h^o w_t}{\alpha_h^n p_{ro,t}}, \tag{C.46}$$

By putting equations (C.41), (C.43) and (C.44) into the production function (equation C.38), we obtain the firm's marginal cost as:

$$mc_t = \frac{1}{A_{h,t} p_{h,t}} \left(\frac{r_{h,t}}{\alpha_h^k} \right)^{\alpha_h^k} \left(\frac{p_{ro,t}}{\alpha_h^o} \right)^{\alpha_h^o} \left(\frac{w_t}{\alpha_h^n} \right)^{\alpha_h^n}. \tag{C.47}$$

Price setting by domestic firms: An intermediate firm that qualifies to optimally reset its price, $P_{h,t}^{\bullet}(j)$, for home goods to be sold in the domestic market does so by maximising profit:

$$\max_{P_{h,t}^{\bullet}(z_h)} E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s Y_{h,t}(z_h) \left[P_{h,t}^{\bullet}(z_h) - P_{h,t+s} mc_{t+s} \right], \tag{C.48}$$

subject to the demand for its product:

$$Y_{h,t+s}(z_h) = \left[\frac{P_{h,t}(z_h)}{P_{h,t}} \right]^{-\epsilon_h} Y_{h,t+s}. \tag{C.49}$$

The optimal reset price is obtained by solving:

$$\max_{P_{h,t}^{\bullet}(z_h)} E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s Y_{h,t+s} \left[\frac{P_{h,t}(z_h)}{P_{h,t+s}} \right]^{-\epsilon_h} \left[P_{h,t}^{\bullet}(z_h) - P_{h,t+s} mc_{t+s} \right]. \tag{C.50}$$

Since firms face the same marginal cost, we can suppress the index (z_h), and write the first-order condition as:

$$\begin{aligned} (1-\epsilon_h) \left(P_{h,t}^{\bullet} \right)^{-\epsilon_h} E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s P_{h,t+s}^{\epsilon_h} Y_{h,t+s} \\ + \epsilon_h \left(P_{h,t}^{\bullet} \right)^{-\epsilon_h - 1} E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s P_{h,t+s}^{1+\epsilon_h} mc_{t+s} Y_{h,t+s} = 0. \end{aligned} \tag{C.51}$$

Solving equation (C.51) for $P_{h,t}^{\bullet}$, we obtain the optimal reset price as:

$$P_{h,t}^{\bullet} = \frac{\epsilon_h}{\epsilon_h - 1} \frac{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_h)^s P_{h,t+s} Y_{h,t+s} mc_{t+s}}{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_h)^s Y_{h,t+s}}. \tag{C.52}$$

Solving analogously for the optimal reset price for export-bound intermediate goods yields:

$$P_{h,t}^{*\bullet} = \frac{\epsilon_h}{\epsilon_h - 1} \frac{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_{hf})^s P_{h,t+s}^* Y_{h,t+s}^* mc_{t+s}}{E_t \sum\limits_{s=0}^{\infty} (\beta\theta_{hf})^s \varepsilon_{t+s} Y_{h,t+s}^*}. \tag{C.53}$$

Import-goods retailers

A set of competitive assemblers combine a continuum of differentiated imported varieties, $Y_{f,t}(z_f)$ to produce a final foreign good, $Y_{f,t}$, using a Dixit-Stiglitz aggregation technology given by:

$$Y_{f,t} = \left[\int_0^1 Y_{f,t}(z_f)^{\frac{\epsilon_f - 1}{\epsilon_f}} dz_f \right]^{\frac{\epsilon_f}{\epsilon_f - 1}}, \tag{C.54}$$

In order to determine their demand for differentiated imported goods, these firms maximize:

$$\Pi_{f,t}(z_f) = P_{f,t} Y_{f,t} - \int_0^1 P_{f,t}(z_f) Y_{f,t}(z_f) dz_f, \tag{C.55}$$

subject to equation (C.54) above. In order to solve the firm's optimization problem, we put equation (C.54) into (C.55) as follows:

$$\max_{Y_{f,t}(z_f)} \Pi_{f,t}(z_f) = P_{f,t} \left[\int_0^1 Y_{f,t}(z_f)^{\frac{\epsilon_f - 1}{\epsilon_f}} dz_f \right]^{\frac{\epsilon_f}{\epsilon_f - 1}} - \int_0^1 P_{f,t}(z_f) Y_{f,t}(z_f) dz_f. \tag{C.56}$$

Taking the partial derivative of equation (C.56) with respect to $Y_{f,t}(z_f)$ yields:

$$\frac{\partial \Pi_{f,t}}{\partial Y_{f,t}(z_f)} = (Y_{f,t})^{-1} Y_{f,t}(z_f) - \left[\frac{P_{f,t}(z_f)}{P_{f,t}} \right]^{-\epsilon_f} = 0,$$

$$Y_{f,t}(z_f) = \left[\frac{P_{f,t}(j)}{P_{f,t}} \right]^{-\epsilon_f} Y_{f,t}, \tag{C.57}$$

where equation (C.57) is the firm's demand for differentiated foreign goods, $Y_{f,t}(z_f)$. The final goods pricing rule is derived by substituting equation (C.57) into the bundling technology (equation C.54) to yield:

$$P_{f,t} = \left[\int_0^1 P_{f,t}\left(z_f\right)^{1-\epsilon_f} dz_f \right]^{\frac{1}{1-\epsilon_f}}. \tag{C.58}$$

Price setting by import goods retailers: An intermediate firm that qualifies to optimally reset its price, $P^{\bullet}_{f,t}\left(z_f\right)$ does so by solving:

$$\max_{P^{\bullet}_{f,t}\left(z_f\right)} E_t \sum_{s=0}^{\infty} \left(\beta\theta_f\right)^s Y_{f,t}\left(z_f\right)\left[P^{\bullet}_{f,t}\left(z_f\right) - \varepsilon_{t+s} P^{*}_{f,t+s}\right], \tag{C.59}$$

subject to the demand for its product:

$$Y_{f,t+s}\left(z_f\right) = \left[\frac{P_{f,t}\left(z_f\right)}{P_{f,t}}\right]^{-\epsilon_f} Y_{f,t+s}. \tag{C.60}$$

Substituting equation (C.60) into (C.59) yields:

$$\max_{P^{\bullet}_{f,t}(j)} E_t \sum_{s=0}^{\infty} \left(\beta\theta_f\right)^s Y_{f,t+s} \left[\frac{P_{f,t}\left(z_f\right)}{P_{f,t+s}}\right]^{-\epsilon_f} \left[P^{\bullet}_{f,t}\left(z_f\right) - \varepsilon_{t+s} P^{*}_{f,t+s}\right]. \tag{C.61}$$

Multiplying things out in equation (C.61) and recalling the definition of the law of one price,$\Psi_t = \varepsilon_t P^*_t / P_{F,t}$, we can write the first-order condition as (after suppressing the index (z_f), since all import goods retailers face similar marginal cost):

$$\begin{aligned} &\left(1-\epsilon_f\right)\left(P^{\bullet}_{f,t}\right)^{-\epsilon_f} E_t \sum_{s=0}^{\infty} \left(\beta\theta_f\right)^s P^{\epsilon_f}_{f,t+s} Y_{f,t+s} \\ &\qquad + \epsilon_f \left(P^{\bullet}_{f,t}\right)^{-\epsilon_f - 1} E_t \sum_{s=0}^{\infty} \left(\beta\theta_f\right)^s P^{\epsilon_f+1}_{f,t+s} Y_{f,t+s} \Psi_{t+s} = 0. \end{aligned} \tag{C.62}$$

Solving equation (C.62) for $P^{\bullet}_{f,t}$, we obtain the optimal reset price for imported goods as:

$$P^{\bullet}_{f,t} = \frac{\epsilon_f}{\epsilon_f - 1} \frac{E_t \sum_{s=0}^{\infty} \left(\beta\theta_f\right)^s P_{h,t+s} Y_{h,t+s} \Psi_{t+s}}{E_t \sum_{s=0}^{\infty} \left(\beta\theta_f\right)^s Y_{f,t+s}}. \tag{C.63}$$

By law of large numbers, the pricing rule for imported goods based on equation (C.58) is given by:

$$P_{f,t} = \left[\theta_f P_{f,t-1}^{1-\epsilon_f} + (1-\theta_f)\left(P_{f,t}^{\bullet}\right)^{1-\epsilon_f}\right]^{\frac{1}{1-\epsilon_f}}. \tag{C.64}$$

Oil-producing firms

The oil firm seeks to maximize its profit:

$$\mathit{\Pi}_{o,t} = \varepsilon_t P_{o,t}^{*} Y_{o,t} - R_{o,t} K_{o,t} - P_{h,t} M_t, \tag{C.65}$$

subject to the production technology given as:

$$Y_{o,t} = A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m}. \tag{C.66}$$

Substituting equation (C.66) into (C.65), the firm's optimization problem can be written as:

$$\max_{K_{o,t}, M_t} \mathit{\Pi}_{o,t} = \varepsilon_t P_{o,t}^{*} A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m} - R_{o,t} K_{o,t} - P_{h,t} M_t, \tag{C.67}$$

In line with the expression for the optimal demand for oil-related capital by the oil firm, the first order conditions with respect to oil related capital, $K_{o,t}$ yields:

$$\begin{aligned} \frac{\partial \mathit{\Pi}_{o,t}}{\partial K_{o,t}} =& \alpha_o^k \varepsilon_t P_{o,t}^{*} \frac{Y_{o,t}}{K_{o,t}} - R_{o,t} = 0, \\ K_{o,t} =& \frac{\alpha_o^k q_t p_{o,t}^{*} Y_{o,t}}{r_{o,t}}, \end{aligned} \tag{C.68}$$

while the first order condition with respect to materials input is:

$$\begin{aligned} \frac{\partial \mathit{\Pi}_{o,t}}{\partial M_t} =& \alpha_o^m \varepsilon_t P_{o,t}^{*} \frac{Y_{o,t}}{M_{o,t}} - P_{h,t} = 0, \\ M_t =& \frac{\alpha_o^m q_t p_{o,t}^{*} Y_{o,t}}{p_{h,t}}, \end{aligned} \tag{C.69}$$

where $p_{o,t}^{*} = \frac{P_{o,t}^{*}}{P_t}, r_{o,t} = \frac{R_{o,t}}{P_t}, p_{h,t} = \frac{P_{h,t}}{P_t}$ and q_t is the real exchange rate. As explained in the text, the process for the accumulation of oil-related capital, $K_{o,t}$, is given by:

$$K_{o,t} = (1-\delta_o) K_{o,t-1} + FDI_t, \tag{C.70}$$

while oil-related foreign direct investment (FDI_t) and international price of oil evolve as follows:

$$FDI_t = (FDI_{t-1})^{\rho_{fdi}} \left(P^*_{o,t}\right)^{1-\rho_{fdi}}, \tag{C.71}$$

$$P^*_{o,t} = \left(P^*_{o,t-1}\right)^{\rho_o} \exp\left(\xi_t^{p_o^*}\right). \tag{C.72}$$

C.2 Log-linearized equations

The log-linearised equations of the model are presented in this section. We denote variables in log-deviations from steady state with tildes and represent steady state variables with bars.
Household decisions and small open economy features:

$$\widetilde{c}_{no,t} = \widetilde{c}_t - \eta_o \left(\widetilde{p}_{no,t}\right) \tag{C.73}$$

$$\widetilde{c}_{o,t} = \widetilde{c}_t - \eta_o \left(\widetilde{p}_{ro,t}\right) \tag{C.74}$$

$$\widetilde{c}_{h,t} = \widetilde{c}_{no,t} - \eta_c \left(\widetilde{p}_{h,t} - \widetilde{p}_{no,t}\right) \tag{C.75}$$

$$\widetilde{c}_{f,t} = \widetilde{c}_{no,t} - \eta_c \left[\widetilde{q}_t - \widetilde{\psi}_t - \widetilde{p}_{no,t}\right] \tag{C.76}$$

$$\widetilde{i}_{h,t} = \widetilde{i}_{no,t} - \eta_i \left(\widetilde{p}_{h,t} - \widetilde{p}_{i,t}\right) \tag{C.77}$$

$$\widetilde{i}_{f,t} = \widetilde{i}_{no,t} - \eta_i \left(\widetilde{p}_{f,t} - \widetilde{p}_{i,t}\right) \tag{C.78}$$

$$\widetilde{c}^R_t = \frac{\phi_c}{1+\phi_c}\widetilde{c}_{t-1} + \frac{1}{1+\phi_c}\widetilde{c}_{t+1} - \frac{1-\phi_c}{\sigma\left(1+\phi_c\right)}\left(\widetilde{R}_t - E_t\widetilde{\pi}_{t+1} + \widetilde{\mu}_t\right) \tag{C.79}$$

$$\widetilde{\lambda}^{NR}_{c,t} = -\sigma\left[\frac{\widetilde{c}^R_t - \phi_c\widetilde{c}_{t-1}}{1-\phi_c}\right] \tag{C.80}$$

$$\widetilde{\lambda}^R_{k,t} = \beta E_t\left[\overline{r_k}\left(\widetilde{r}_{h,t+1} - \sigma\widetilde{c}_{t+1}\right) + \left(1-\delta_h\right)\widetilde{\lambda}^R_{k,t+1}\right] \tag{C.81}$$

$$\widetilde{\lambda}^R_{k,t} = \chi\left[\left(\widetilde{i}_{no,t} - \widetilde{i}_{no,t-1}\right) - \beta E_t\left(\widetilde{i}_{no,t+1} - \widetilde{i}_{no,t}\right)\right] - \sigma\widetilde{c}^R_t \tag{C.82}$$

$$\widetilde{k}_{h,t+1} = \left(1-\delta_h\right)\widetilde{k}_{h,t} + \delta_h\widetilde{i}_{no,t} \tag{C.83}$$

$$\widetilde{c}^{NR}_t = \frac{W\bar{N}^{NR}}{P\bar{C}^{NR}}\left(\widetilde{w}_t + \widetilde{n}^{NR}_t\right) - \frac{T\bar{X}}{P\bar{C}^{NR}}\widetilde{tx}_t \tag{C.84}$$

$$\widetilde{\lambda}^{NR}_{c,t} = -\sigma\left[\frac{\widetilde{c}^{NR}_t - \phi_c\widetilde{c}_{t-1}}{1-\phi_c}\right] \tag{C.85}$$

$$\widetilde{c}_t = \gamma_R\widetilde{c}^R_t + \left(1-\gamma_R\right)\widetilde{c}^{NR}_t \tag{C.86}$$

$$\widetilde{n}_t = \gamma_R\widetilde{n}^R_t + \left(1-\gamma_R\right)\widetilde{n}^{NR}_t \tag{C.87}$$

$$\widetilde{\psi}_t = \widetilde{q}_t - \widetilde{p}_{f,t} \tag{C.88}$$

$$\widetilde{q}_t = \widetilde{q}_{t-1} + \Delta\widetilde{\varepsilon}_t - \widetilde{\pi}_t + \widetilde{\pi}^*_t \tag{C.89}$$

$$\widetilde{S}_t = \widetilde{p}_{f,t} - \widetilde{p}_{h,t} \tag{C.90}$$

$$\widetilde{q}_t = \frac{\sigma}{1-\phi_c}\left(\widetilde{c}_t - \phi_c\widetilde{c}_{t-1}\right) - \frac{\sigma}{1-\phi^*_c}\left(\widetilde{c}^*_t - \phi_c\widetilde{c}^*_{t-1}\right) \tag{C.91}$$

Inflation and prices:

$$\widetilde{p}_{h,t} = \widetilde{p}_{h,t-1} + \widetilde{\pi}_{h,t} - \widetilde{\pi}_t \tag{C.92}$$

$$\widetilde{p}_{hf,t} = \widetilde{p}_{hf,t-1} + \widetilde{\pi}_{hf,t} - \widetilde{\pi}^*_t \tag{C.93}$$

$$\widetilde{p}_{f,t} = \widetilde{p}_{f,t-1} + \widetilde{\pi}_{f,t} - \widetilde{\pi}_t \tag{C.94}$$

$$\widetilde{w}_t = \widetilde{w}_{t-1} + \widetilde{\pi}_{w,t} - \widetilde{\pi}_t \tag{C.95}$$

$$\widetilde{p}_{no,t} = (1-\gamma_c)\,\widetilde{p}_{h,t} + \gamma_c\left(\widetilde{q}_t - \widetilde{\psi}_t\right) \tag{C.96}$$

$$\widetilde{p}_{ro,t} = (1-\nu)\,\widetilde{p}_{ro,t-1} + \nu\left(\widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{\psi}^o_t\right) \tag{C.97}$$

$$\widetilde{p}_{i,t} = (1-\gamma_i)\,\widetilde{p}_{h,t} + \gamma_i\widetilde{p}_{f,t} \tag{C.98}$$

$$\tilde{p}_{g,t} = (1-\gamma_g)\,\widetilde{p}_{h,t} + \gamma_g\left(\widetilde{q}_t - \widetilde{\psi}_t\right) \tag{C.99}$$

$$\widetilde{mc}_t = \alpha^k_h\widetilde{r}_{h,t} + \alpha^o_h\widetilde{p}_{ro,t} + \alpha^n_h\widetilde{w}_t - \widetilde{A}_{h,t} - \widetilde{p}_{h,t} \tag{C.100}$$

$$\widetilde{\pi}_{h,t} = \beta\widetilde{\pi}_{h,t+1} + \frac{(1-\beta\theta_h)(1-\theta_h)}{\theta_h}\widetilde{mc}_t + \xi^{\pi_h}_t \tag{C.101}$$

$$\widetilde{\pi}_{hf,t} = \beta\widetilde{\pi}_{hf,t+1} + \frac{(1-\beta\theta_{hf})(1-\theta_{hf})}{\theta_{hf}}\widetilde{mc}_t - \widetilde{q}_t - \widetilde{p}_{hf,t} \tag{C.102}$$

$$\widetilde{\pi}_{w,t} = \beta\widetilde{\pi}_{w,t+1} + \frac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w}\left(\varphi\widetilde{n}^R_t - \widetilde{\lambda}^R_{c,t}\right) \tag{C.103}$$

$$\widetilde{\pi}_{w,t} = \beta\widetilde{\pi}_{w,t+1} + \frac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w}\left(\varphi\widetilde{n}^{NR}_t - \widetilde{\lambda}^{NR}_{c,t}\right) \tag{C.104}$$

$$\widetilde{\pi}_{f,t} = \beta\widetilde{\pi}_{f,t+1} + \frac{(1-\beta\theta_f)(1-\theta_f)}{\theta_f}\widetilde{\psi}_t \tag{C.105}$$

$$\widetilde{\pi}_{no,t} = \widetilde{p}_{no,t} - \widetilde{p}_{no,t-1} + \widetilde{\pi}_t \tag{C.106}$$

$$\widetilde{\pi}_{o,t} = \widetilde{p}_{ro,t} - \widetilde{p}_{ro,t-1} + \widetilde{\pi}_t \tag{C.107}$$

$$0 = \gamma_o\widetilde{p}_{ro,t} + (1-\gamma_o)\,\widetilde{p}_{no,t} \tag{C.108}$$

Foreign economy:

$$\widetilde{c}^*_t = \frac{1}{1+\phi^*_c}\widetilde{c}^*_{t+1} + \frac{\phi^*_c}{1+\phi^*_c}\widetilde{c}^*_{t-1} - \frac{1-\phi^*_c}{\sigma^*(1+\phi^*_c)}\left(\widetilde{R}^*_t - E_t\widetilde{\pi}^*_{t+1} + \widetilde{\mu}^*_t\right) \tag{C.109}$$

$$\widetilde{R}^*_t = \rho_{r^*}\widetilde{R}^*_{t-1} + (1-\rho_{r^*})\left[\omega^*_\pi\widetilde{\pi}^*_t + \omega^*_y\widetilde{y}^*_t\right] + \xi^{r^*}_t \tag{C.110}$$

$$\widetilde{\pi}^*_t = \rho_{\pi^*}\widetilde{\pi}^*_{t-1} + \xi^{\pi^*}_t \tag{C.111}$$

Firms:

$$\widetilde{y}_{h,t} = \widetilde{A}_{h,t} + \alpha_h^k \widetilde{k}_{h,t} + \alpha_h^o \widetilde{o}_{h,t} + \alpha_h^n \widetilde{n}_t \tag{C.112}$$

$$\widetilde{k}_{h,t} = \widetilde{w}_t + \widetilde{n}_t - \widetilde{r}_{h,t} \tag{C.113}$$

$$\widetilde{o}_{h,t} = \widetilde{w}_t + \widetilde{n}_t - \widetilde{p}_{ro,t} \tag{C.114}$$

$$\widetilde{y}_{o,t} = \widetilde{A}_{o,t} + \alpha_o^k \widetilde{k}_{o,t} + \alpha_o^m \widetilde{m}_t \tag{C.115}$$

$$\widetilde{r}_{o,t} = \widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{y}_{o,t} - \widetilde{k}_{o,t} \tag{C.116}$$

$$\widetilde{m}_t = \widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{y}_{o,t} - \widetilde{p}_{h,t} \tag{C.117}$$

$$\widetilde{fdi}_t = \rho_{fdi} \widetilde{fdi}_{t-1} + (1 - \rho_{fdi})\, \widetilde{p}^*_{o,t} \tag{C.118}$$

$$\widetilde{k}_{o,t} = (1 - \delta_o)\, \widetilde{k}_{o,t-1} + \delta_o \widetilde{fdi}_t \tag{C.119}$$

Market clearing and aggregation:

$$\widetilde{y}_{h,t} = \frac{\bar{C}_h}{\bar{Y}_h} \widetilde{c}_{h,t} + \frac{\bar{C_h}^*}{\bar{Y}_h} \widetilde{c}^*_{h,t} + \frac{\bar{I_{no}}}{\bar{Y}_h} \widetilde{i}_{no,t} + \frac{\bar{M}}{\bar{Y}_h} \widetilde{m}_t + \frac{\bar{G}_c}{\bar{Y}_h} \widetilde{g}_{c,t} \tag{C.120}$$

$$\widetilde{y}_t = \frac{1 - \bar{Y}_o}{\bar{Y}} \widetilde{y}_{h,t} + \frac{\bar{Y}_o}{\bar{Y}} \widetilde{y}_{o,t} \tag{C.121}$$

$$\widetilde{o}_t = \gamma_{gp} \widetilde{c}_{o,t} + (1 - \gamma_{gp})\, \tilde{o}_{h,t} \tag{C.122}$$

$$\widetilde{nx}_t = \frac{\bar{EX}}{\bar{NX}} \widetilde{ex}_t - \frac{1 - \bar{EX}}{\bar{NX}} \widetilde{im}_t \tag{C.123}$$

$$\widetilde{ex}_t = \frac{1 - \bar{Y}_o}{\bar{EX}} \widetilde{c}^*_t + \frac{\bar{Y}_o}{\bar{EX}} \widetilde{y}_{o,t} \tag{C.124}$$

$$\widetilde{im}_t = \frac{\bar{O}}{\bar{IM}} \widetilde{o}_t + \frac{\bar{C}_f}{\bar{IM}} \widetilde{c}_{f,t} + \frac{\bar{G}_f}{\bar{IM}} \widetilde{g}_{f,t} + \frac{1 - \bar{O} - \bar{C}_f - \bar{G}_f}{\bar{IM}} \widetilde{i}_{f,t} \tag{C.125}$$

$$\widetilde{c}^*_{h,t} = \widetilde{c}^*_t - \eta_{c_h^*} (\widetilde{p}_{h,t} - \widetilde{q}_t) \tag{C.126}$$

$$\begin{aligned}\widetilde{nx}_t =& \frac{q\bar{B^*}R^*}{\bar{NX}} \left(\widetilde{q}_t + \widetilde{b}_t - \widetilde{R}^*_t - \widetilde{\mu}^*_t \right) - \frac{q\bar{B}^*}{\bar{NX}} \left(\widetilde{q}_t + \widetilde{b}^*_{t-1} \right) \\ &+ \frac{(1-\tau)\, q\bar{P_o^*}Y_o}{\bar{NX}} \left(\widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{y}_{o,t} \right) - \frac{q\bar{FDI}}{\bar{NX}} \left(\widetilde{q}_t + \widetilde{fdi}_t^{\,*} \right)\end{aligned} \tag{C.127}$$

Fiscal policy:

$$\widetilde{g}_{c,t} = \rho_g \widetilde{g}_{c,t-1} + (1 - \rho_g) \left[\omega_b \widetilde{b}_{t-1} + \omega_{gy} \widetilde{y}_{t-1} + \omega_{os} \widetilde{os}_t + \omega_{or} \widetilde{or}_t \right] + \xi_t^{G_c} \tag{C.128}$$

$$\widetilde{tx}_t = \rho_{tx} \widetilde{tx}_{t-1} - (1 - \rho_{tx}) \left[\varphi_b \widetilde{b}_{t-1} + \varphi_g \widetilde{y}_{t-1} + \varphi_{os} \widetilde{os}_t + \varphi_{or} \widetilde{or}_t \right] + \xi_t^{tx} \tag{C.129}$$

Government:

$$\widetilde{or}_t = \frac{\bar{OS}}{\bar{OR}}\widetilde{os}_t + \frac{p_g\bar{G}_c}{\bar{OR}}\left(\widetilde{p}_{g,t} + \widetilde{g}_{c,t}\right) - \frac{\bar{TX}}{\bar{OR}}\widetilde{tx}_t - \frac{\bar{B}}{\bar{OR}}\widetilde{b}_t + \frac{\bar{B/R}}{\bar{OR}}\left(\widetilde{b}_{t+1} - \widetilde{R}_t\right) \tag{C.130}$$

$$\widetilde{or}_t = \widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{y}_{o,t} \tag{C.131}$$

$$\widetilde{os}_t = \frac{q\bar{P^*_o}O}{\bar{OS}}\left(\widetilde{q}_t + \widetilde{p}^*_{o,t} + \widetilde{o}_t\right) - \frac{\bar{P_{ro}}O}{\bar{OS}}\left(\widetilde{p}_{ro,t} + \widetilde{o}_t\right) \tag{C.132}$$

$$\widetilde{g}_{h,t} = \widetilde{g}_{c,t} - \eta_g\left(\widetilde{p}_{h,t} - \widetilde{p}_{g,t}\right) \tag{C.133}$$

$$\widetilde{g}_{f,t} = \widetilde{g}_{c,t} - \eta_g\left(\widetilde{p}_{f,t} - \widetilde{p}_{g,t}\right) \tag{C.134}$$

Monetary policy:

$$\widetilde{R}_t = \rho_r\widetilde{R}_{t-1} + (1-\rho_r)\left[\omega_\pi\widetilde{\pi}_t + \omega_y\widetilde{y}_{h,t} + \omega_q\widetilde{q}_t\right] + \xi^r_t \tag{C.135}$$

Shock processes:

$$\widetilde{p}^*_{o,t} = \rho_{p^*_o}\widetilde{p}^*_{o,t-1} + \xi^{p^*_o}_t \tag{C.136}$$

$$\widetilde{A}_{o,t} = \rho_{a_0}\widetilde{A}_{o,t-1} + \xi^{a_o}_t \tag{C.137}$$

$$\widetilde{A}_{h,t} = \rho_{a_h}\widetilde{A}_{h,t-1} + \xi^{a_h}_t \tag{C.138}$$

$$\widetilde{\psi}^o_t = \rho_{\psi^o}\widetilde{\psi}^o_{t-1} + \xi^{\psi^o}_t \tag{C.139}$$

$$\widetilde{\mu}_t = \rho_\mu\widetilde{\mu}_{t-1} + \xi^\mu_t \tag{C.140}$$

$$\widetilde{\mu}^*_t = \rho_{\mu^*}\widetilde{\mu}^*_{t-1} + \xi^{\mu^*}_t \tag{C.141}$$

C.3 Tables

Table C.1: Persistence and std. dev. of shocks under the benchmark model

Parameter	**Prior distribution**			**Posterior distribution**		
	Density	Mean	Std. Dev.	Mean	90% HPD Int.	
Shock persistence						
Dom. productivity: ρ_{a_h}	Beta	0.50	0.25	0.823	0.605	0.998
Oil productivity: ρ_{a_0}	Beta	0.50	0.25	0.986	0.972	1.000
Dom. risk premium: ρ_{μ}	Beta	0.50	0.25	0.704	0.579	0.818
Law of one price gap-oil: ρ_{ψ^o}	Beta	0.50	0.25	0.962	0.923	0.998
Int'l oil price shock: $\rho_{p_o^*}$	Beta	0.50	0.25	0.896	0.838	0.958
Tax: ρ_{tx}	Beta	0.50	0.25	0.539	0.370	0.718
For. risk premium: ρ_{μ^*}	Beta	0.50	0.25	0.831	0.767	0.895
For. inflation: ρ_{π^*}	Beta	0.40	0.25	0.139	0.000	0.259
For. monetary policy: ρ_{r^*}	Beta	0.50	0.25	0.447	0.305	0.585
Standard deviation of shocks						
Dom. productivity: $\xi_t^{a_h}$	Inv. Gamma	0.10	4.00	0.071	0.030	0.171
Oil productivity: $\xi_t^{a_o}$	Inv. Gamma	0.10	4.00	0.212	0.183	0.241
Dom. risk premium: ξ_t^{μ}	Inv. Gamma	0.10	4.00	0.179	0.135	0.230
Dom. fiscal policy:$\xi_t^{g_c}$	Inv. Gamma	0.10	4.00	0.096	0.064	0.119
Law of one price gap-oil: $\xi_t^{\psi^o}$	Inv. Gamma	0.10	4.00	1.397	0.474	2.688
Dom. monetary policy: ξ_t^{r}	Inv. Gamma	0.10	4.00	0.360	0.275	0.440
Int'l oil price: $\xi_t^{p_o^*}$	Inv. Gamma	0.10	4.00	0.151	0.131	0.171
Domestic supply: $\xi_t^{\pi_h}$	Inv. Gamma	0.01	4.00	0.021	0.002	0.075
Tax: ξ_t^{ts}	Inv. Gamma	0.10	2.00	0.169	0.145	0.193
For. risk premium: $\xi_t^{\mu^*}$	Inv. Gamma	0.10	4.00	0.044	0.035	0.054
For. inflation: $\xi_t^{\pi^*}$	Inv. Gamma	0.01	4.00	0.005	0.004	0.006
For. monetary policy: $\xi_t^{r^*}$	Inv. Gamma	0.10	4.00	0.100	0.079	0.122

Table C.2: Prior and posterior estimates for the pre- and post-GFC periods

Parameter	**Pre-GFC**			**Post-GFC**		
	Mean	90% HPD Int.		Mean	90% HPD Int.	
Structural parameters						
Ricardian consumers: γ_R	0.695	0.568	0.828	0.611	0.455	0.770
Labour supply elasticity: φ	1.462	1.314	1.624	1.453	1.290	1.622
Relative risk aversion: σ	1.485	1.174	1.788	1.565	1.205	1.908
External habit: ϕ_c	0.508	0.359	0.655	0.504	0.358	0.643
Investment adj. cost: χ	9.032	2.412	15.049	6.181	1.060	11.604
Fuel pricing parameter: ν	0.374	0.207	0.537	0.189	0.079	0.298
Oil - core cons. elast.: η_o	0.186	0.051	0.324	0.205	0.043	0.361
For. - dom. cons. elast.: η_c	0.599	0.286	0.920	0.596	0.270	0.901
For. - dom. inv. elast.: η_i	0.618	0.274	0.945	0.586	0.272	0.881
Calvo - domestic prices: θ_h	0.820	0.686	0.984	0.677	0.528	0.825
Calvo - import prices: θ_f	0.693	0.533	0.854	0.655	0.483	0.845
Monetary policy parameters						
Taylor, π: ω_π	2.048	1.601	2.497	2.217	1.797	2.639
Taylor, y: ω_y	0.142	0.048	0.229	0.141	0.052	0.227
Taylor, q: ω_q	0.122	0.044	0.195	0.133	0.049	0.209
Taylor, smoothing: ρ_r	0.350	0.149	0.557	0.267	0.063	0.446
Fiscal policy rules parameters						
Tax, b: φ_b	-0.046	-0.727	0.858	-1.704	-2.954	-0.754
Tax, or: φ_{or}	0.263	-0.430	0.884	0.148	-0.283	0.574
Tax, os: φ_{os}	0.245	-0.596	1.124	1.808	1.212	2.396
Tax, y: φ_y	0.105	-0.661	0.893	0.151	-0.652	0.905
Tax, smoothing: ρ_{tx}	0.698	0.473	0.949	0.281	0.098	0.464
Govt. Cons., b: ω_b	-0.291	-0.577	0.019	-0.149	-0.429	0.127
Govt. Cons., or: ω_{or}	0.184	-0.216	0.595	0.926	0.771	1.107
Govt. Cons., os: ω_{os}	0.951	-0.036	2.044	0.071	-0.094	0.238
Govt. Cons., y: ω_{gy}	-0.073	-0.843	0.729	0.396	-0.182	0.992
Govt. cons., smoothing: ρ_{g_c}	0.844	0.711	0.990	0.064	0.002	0.127

Table C.3: Prior and posterior estimates under alternative fiscal rules

Parameter	**Benchmark fiscal rule**			**Alternative fiscal rule**		
	Mean	90% HPD Int.		Mean	90% HPD Int.	
Structural parameters						
Ricardian consumers: γ_R	0.438	0.310	0.574	0.717	0.594	0.841
Labour supply elasticity: φ	1.473	1.312	1.631	1.434	1.266	1.592
Relative risk aversion: σ	1.347	1.077	1.596	1.414	1.120	1.709
External habit: ϕ_c	0.413	0.285	0.538	0.438	0.308	0.565
Investment adj. cost: χ	2.995	1.076	4.800	7.768	2.171	13.043
Fuel pricing parameter: ν	0.338	0.113	0.553	0.414	0.191	0.621
Oil - core cons. elast.: η_o	0.158	0.038	0.272	0.187	0.049	0.328
For. - dom. cons. elast.: η_c	0.631	0.295	0.945	0.614	0.283	0.929
For. - dom. inv. elast.: η_i	0.613	0.297	0.919	0.607	0.284	0.913
Calvo - domestic prices: θ_h	0.592	0.463	0.732	0.761	0.627	0.909
Calvo - import prices: θ_f	0.594	0.432	0.758	0.681	0.515	0.850
Monetary policy parameters						
Taylor, π: ω_π	2.866	2.588	3.141	2.809	2.474	3.141
Taylor, y: ω_y	0.086	0.033	0.137	0.138	0.049	0.229
Taylor, q: ω_q	0.127	0.040	0.209	0.114	0.038	0.183
Taylor, smoothing: ρ_r	0.279	0.082	0.478	0.243	0.062	0.404
Fiscal policy rules parameters						
Tax, b: φ_b	-0.053	-1.158	1.114	0.025	-0.732	0.698
Tax, or: φ_{or}	-0.051	-0.333	0.235	-	-	
Tax, os: φ_{os}	0.836	0.343	1.283	-	-	
Tax, y: φ_y	0.107	-0.650	0.885	0.136	-0.673	0.933
Tax, smoothing: ρ_{tx}	0.539	0.370	0.718	0.643	0.499	0.797
Govt. Cons., b: ω_b	-0.171	-0.453	0.130	-0.312	-0.607	-0.023
Govt. Cons., or: ω_{or}	1.207	1.156	1.265	-	-	
Govt. Cons., os: ω_{os}	-0.047	-0.215	0.093	-	-	
Govt. Cons., y: ω_{gy}	1.188	0.673	1.704	0.032	-0.758	0.879
Govt. cons., smoothing: ρ_{g_c}	0.139	0.041	0.233	0.936	0.886	0.992

Table C.4: Prior and posterior estimates under alternative Taylor rules

Parameter	**Benchmark Taylor rule**			**Alternative Taylor rule**		
	Mean	90% HPD Int.		Mean	90% HPD Int.	
Structural parameters						
Ricardian consumers: γ_R	0.438	0.310	0.574	0.448	0.317	0.580
Labour supply elasticity: φ	1.473	1.312	1.631	1.465	1.298	1.626
Relative risk aversion: σ	1.347	1.077	1.596	1.381	1.105	1.628
External habit: ϕ_c	0.413	0.285	0.538	0.447	0.321	0.574
Investment adj. cost: χ	2.995	1.076	4.800	2.944	1.431	4.467
Fuel pricing parameter: ν	0.338	0.113	0.553	0.336	0.138	0.534
Oil - core cons. elast.: η_o	0.158	0.038	0.272	0.162	0.038	0.276
For. - dom. cons. elast.: η_c	0.631	0.295	0.945	0.605	0.276	0.917
For. - dom. inv. elast.: η_i	0.613	0.297	0.919	0.590	0.277	0.887
Calvo - domestic prices: θ_h	0.592	0.463	0.732	0.638	0.514	0.787
Calvo - import prices: θ_f	0.594	0.432	0.758	0.609	0.451	0.764
Monetary policy parameters						
Taylor, π: ω_π	2.866	2.588	3.141	2.867	2.590	3.141
Taylor, y: ω_y	0.086	0.033	0.137	0.089	0.029	0.145
Taylor, q: ω_q	0.127	0.040	0.209	-	-	
Taylor, smoothing: ρ_r	0.279	0.082	0.478	0.319	0.115	0.531
Fiscal policy rules parameters						
Tax, b: φ_b	-0.053	-1.158	1.114	0.043	-1.102	1.208
Tax, or: φ_{or}	-0.051	-0.333	0.235	-0.075	-0.355	0.205
Tax, os: φ_{os}	0.836	0.343	1.283	0.794	0.329	1.290
Tax, y: φ_y	0.107	-0.650	0.885	0.120	-0.657	0.886
Tax, smoothing: ρ_{tx}	0.539	0.370	0.718	0.543	0.364	0.722
Govt. Cons., b: ω_b	-0.171	-0.453	0.130	-0.167	-0.439	0.116
Govt. Cons., or: ω_{or}	1.207	1.156	1.265	1.211	1.164	1.272
Govt. Cons., os: ω_{os}	-0.047	-0.215	0.093	-0.075	-0.258	0.111
Govt. Cons., y: ω_{gy}	1.188	0.673	1.704	1.187	0.642	1.730
Govt. cons., smoothing: ρ_{g_c}	0.139	0.041	0.233	0.125	0.022	0.227