CENTRAL BANK OF NIGERIA

DYNAMIC STOCHASTIC GENERAL EQUILIBRIUM MODEL FOR MONETARY POLICY ANALYSIS IN NIGERIA

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Executive Summary

1. *Recent Inter-agency efforts, comprising CBN, NISER, AIAE and CEAR, produced an operational macroeconomic model of Nigeria to serve as a guide to policy analysis. However, the literature and country experiences indicate that no single model handles the complexities involved in carrying out different roles and responsibilities of the central bank and other government institutions. Consequently, central banks, as a practice, build a "suite of models" that aid policy making and formulation. In this regard, the CBN is in the process of building complementary models that would aid monetary policy analysis for decision making.*

2. *The preoccupation of this study, therefore, is to develop a Dynamic Stochastic General Equilibrium (DSGE) model that will address the following objectives. First, to establish whether or not a monetary target could be met in the future given the contemporaneous stance of monetary policy; second, to determine the size and the speed of exchange rate pass-through; third, to estimate the sacrifice ratio -- the amount of output to be foregone to achieve a given permanent reduction in the rate of inflation; fourth, to know how the inflation rate responds to the output gap; and finally, to shed light on the implications of alternative policy rule.*

3. *To achieve these objectives, this study is organized in seven chapters. Chapter 1 introduces the motivation for the study, while chapter two reviews the literature on the theory of business cycle, the evolution of macroeconometric models and the survey of DSGE models. Chapter 3 discusses the stylized facts of the Nigerian economy, while the microfoundation of the DSGE models, focusing on the optimization behaviour of economic agents is discussed in chapter 4. Chapter 5 covers the empirical analysis, including data description, calibration and choice of priors, and posterior estimation using Bayesian technique. The empirical results are discussed in chapter 6, while the summary, conclusions, policy implications and direction for further studies are contained in chapter 7.*

4. *The study fitted the Bayesian estimation technique to Nigerian data spanning the period 1985q1 - 2009q4. The model is based on the standard New Keynesian framework comprising three rational economic agents -- households, firms and the monetary authority. Overall, the log-linearised*

version of the model contains five main equations -- an output gap (aggregate demand), inflation (aggregate supply), a monetary policy rule (Taylor-type rule), an uncovered interest rate parity condition (to capture the small open economy nature of the Nigerian economy) and government expenditure. In specifying the equations, attention is paid to the peculiarities of the Nigerian economy with particular reference to its dependence on the oil sector.

5. *The estimation process is carried out in two phases. First, as a means of evaluation and validation, parameters of the model were initially calibrated based on expert knowledge, understanding of the Nigerian economy, sound economic theory, reliance on parameters of countries with similar economic structure as Nigeria and value judgement. Second, is to take the model to data.*

6. *The following findings are derived from the model.*

   i. *The habit persistence parameter is 0.94, indicating that only 5.0 per cent of the consumers are forward looking in the formation of their consumption behaviour.*

   ii. *Price stickiness is established for Nigeria, which indicates that firms in Nigeria seldom change their prices downward.*

   iii. *The estimate of the exchange rate pass-through to prices is 0.25 per quarter which implies that imported inflation feed into domestic inflation and this has implications for price stability.*

   iv. *The output cost of disinflation (the sacrifice ratio) is estimated to be 1.32, which is quite high. This implies that there is a significant trade-off between output growth and inflation.*

   v. *The Taylor-type monetary policy rule indicates that the CBN accords priority to output stabilization rather than price stability in the conduct of monetary policy.*

   vi. *A positive supply shock reduces output by 1.34 and 0.47 per cent respectively, in the 1st and 3rd quarter. Thereafter, output gap increases by 0.055 per cent in the 7th quarter before returning to steady state. This result points out that supply shocks produce short term effects.*

vii. *A positive monetary policy shock (monetary tightening) produces a hump-shaped effect on output and inflation. The relative contribution of monetary policy shocks are rather small in explaining the fluctuations in most of the variables and could plausibly be dampened due to domestic supply and interest rate shocks.*

viii. *A positive external reserve shock appreciates the exchange rate by 0.08 and 0.002 per cent in the 1st and 7th quarters, respectively. In response, output gap and inflation decline by 0.002 and 0.042 per cent in the 3rd quarter. However, inflation restore to equilibrium faster than output in the long-term.*

ix. *Oil price shocks decelerate inflation but increase output gap by 1.01 and 0.56 per cent, respectively, in the 1st quarter. However, in the 8th quarter, inflation rises to 0.07 per cent due to the expansion in fiscal activities by 0.53 per cent.*

x. *Interest rate account for 42.9, 29.3, 55.9, 45.9 and 7.7 per cent of the fluctuations in aggregate demand, aggregate supply, interest rate, exchange rate and government expenditure, respectively.*

xi. *Oil price shocks explain 54 per cent of the forecast error variance decomposition of government expenditure, while government expenditure and equilibrium interest rate shocks contribute, 14.3 and 18.4 per cent of the fluctuations in government expenditure, respectively. There exist a positive contemporaneous correlation between oil price shocks, output gap and government expenditure.*

Chapter One
Introduction

1.1 Background

In any economy, the central bank acts as the economic agent charged with the responsibility to formulate and implement monetary policy. Given that the actions of the central bank exert significant influence on the behaviour of other economic agents and to a large extent on the overall performance of the macroeconomy, policy pronouncements by the central bank generally tend to attract considerable attention and close scrutiny by economic commentators, academia, policy analysts and the media. The announced policy decisions often times tend to reflect the central bank's assessment of the economy but more importantly, its current and future monetary policy stance. Economic agents rely on the information provided by the central bank to make informed decisions with regard to their various activities.

In spite of having an overwhelming influence and being a key participant in the management of the overall economy, the behaviour of central banks in arriving at monetary policy decisions is not often understood by non-policymakers. Thus, an analysis of a central bank's behaviour in formulating monetary policy is of considerable interest to both academic and non-academic researchers and financial market participants/analysts. In the quest to gain further insight on this issue, non-policy makers tend to raise the following key questions regarding the behaviour of a central bank: How do the central banks actually formulate monetary policy? Do they follow any form of policy rule? What are the different policy objectives they want to achieve and how are they prioritized? How has this behaviour evolve over time? And what happens to the economic outcomes if central banks behave differently?

Several studies in the literature tried to describe, analyze and evaluate central bank behavior in the formulation of monetary policy over time. Recent Inter-agency efforts in Nigeria, comprising (CBN), NISER, AIAE and CEAR, produced an operational macroeconometric model of Nigeria to serve as a guide to policy analysis.

However, the literature and country experiences indicate that no single model handles the complexities involved in carrying out different roles and responsibilities of the central bank and other government institutions. Against this background, small scale models such as univariate time series models, vector autoregressive (VAR) models, and dynamic stochastic general equilibrium (DSGE) models have found their way in the arsenal of central banks' toolkit. Indeed, the DSGE models have become very popular as a veritable tool for monetary policy analysis in a large number of central banks with the adoption of inflation targeting as a monetary policy framework since the 1990s. Thus, central banks, as a practice, build a "suite of models" that aid policy making and formulation. Given the different institutional structure and nature of constraints as well as shocks that central banks in developing countries face, the CBN is in the process of building complementary models that would aid monetary policy analysis for decision making.

1.2 Motivation for the Study

The preoccupation of this study is to develop a Dynamic Stochastic General Equilibrium (DSGE) model for Nigeria. Though, the literature on DSGE is growing in developed and some developing countries, few of such studies have been carried out for Nigeria (Olekah and Oyaromade, 2007; Olayeni, 2009; Alege, 2009; Garcia, 2009; and Adebiyi and Mordi, 2010). None of these studies have been able to apply the DSGE models for policy analysis and few have paid little attention to the in-depth analysis of the impulse response functions. Thus, an attempt is made in this study to contribute to the literature in these directions. Specifically, the paper develops a macro-based approach that can be used to achieve the following objectives. First, is to know whether or not a monetary target could be met in the future given the contemporaneous stance of monetary policy. Second, is to determine the size and the speed of exchange rate pass-through. Third, is to determine the sacrifice ratio -- the amount of output to be foregone to achieve a given permanent reduction in the rate of inflation. Fourth, is to know how the inflation rate responds to the output gap. Finally, is to shed light on the implications of alternative policy rule.

1.3 Expected Output

The outcome would be a DSGE model that is useful for monetary policy analysis.

1.4 Structure of the Study

The work is organised as follows. Following the introduction is the theoretical framework and empirical literature review in chapter two. Under the theoretical framework, theory of business cycle, the evolution of macroeconometric models and the survey of DSGE models are reviewed. Chapter 3 presents the stylised facts of the Nigerian economy, covering developments in the real, financial, fiscal and external sectors. The interactions and inter-linkages in the sectors are highlighted.

The microfoundation of the DSGE models, focusing on the optimisation behaviour of economic agents -- households, firms and government, is examined in chapter 4. Chapter 5 focuses on the empirical analysis, which includes data description, calibration and choice of priors, and Bayesian estimation technique. The empirical results, reflecting the posterior means, stability results, impulse response functions, variance decomposition and model simulations are discussed in chapter 6; while the summary and conclusions are enumerated in chapter 7.

Chapter Two
Literature Review

A model by nature is only an approximation of reality. It is an art that operates on a scientific platform, and provides explanations of inter linkages between sets of variables in the system. A model thus mimics what the researcher envisions and tries to explain using data or statistics. Typically, researchers build models to enable them establish the in-built fundamental relationships between economic variables. This is done to either validate existing economic theory or better still define the direction and magnitude of causation of a change or shock by any one variable on the others in the system.

The importance of economic models for policy analysis cannot be overemphasized. They guide economists to understand the workings of the economy and to predict future outcomes. Using an economic model affords policy-makers to assess the impact of a particular economic variable (oil price increase) or alternative policy choices on the economy. In addition, economic models provide a structural framework for economic analysis and formalise views that may be based largely on intuition. Models also assist policy-makers to validate and evaluate different policy scenarios.

Broadly, models are categorized into structural and non-structural. The non-structural models include the simple linear difference equations like the autoregressive moving average (ARMA), autoregressive integrated moving average (ARIMA), vector autoregressive models (VAR), among others. These models use economic time series data to make short-run forecast for policy or impact analysis. However, because of the inherent serial correlation in data, their forecasts are not always as accurate in the long-run due to the lack of structural determinants in the forecast functions (Klien, 1960, 1993, 2002). This limitation, according to Diebold (1998), led to the emergence of macroeconometric models in the 1970s.

2.1 Macroeconometric Models

Economic literature credit Tinbergen as the pioneer of macroeconometric modeling when he constructed a macroeconometric model for the Dutch economy in 1936, and later the League of Nations model for the United States. This seminal effort spurred the constitution of a special team of researchers at the Cowles Commission by Marschak, after the Second World War, to replicate the Tinbergen-type macroeconometric model. Since then, macroeconometric models have assumed international dimensions with the construction of several large scale models undertaken by several institutions.

According to Henry (2001), a macro-econometric model is a system of inter-linked macroeconomic equations which are estimated from time series data. Jayawickrama (2007) defines a macro-econometric model as a set of stochastic equations and definitional and institutional relationships representing the behaviours of economic agents, thus of the whole economy. Macro-econometric models are of different sizes (small, medium or large) depending on the purpose for which they are meant to serve as well as the time and financial constraints faced by the researchers. While some models are built specifically to validate theoretical consistencies, others are constructed for policy evaluation, impact analysis and forecasting purposes.

Macro-econometric models are also constructed to 'examine the impact of certain policy changes such as fiscal and monetary policies and other disturbances such as terms of trade shocks, supply-side shocks and to forecast future values of variables concerned' (Jayawickrama, 2007, p.81). However, irrespective of whether the models are small, medium or large scale, Jayawickrama (2007) (cited Pesaran and Smith, 1985) suggested that models constitute three basic fundamental characteristics: relevance (suited to purpose for which it was designed), consistency (with existing theory and inter-workings of the system), and adequacy (involves better within-sample and out-of-sample predictive accuracy).

In spite of the fact that large scale macroeconometric models were used for applied macroeconomic analysis, the large number of equations and problem of the choice of variables to be included in the equation significantly inhibit the widespread use of the models. From the theoretical perspective, Lucas (1976) criticized macroeconometric model for assuming that economic relationships that hitherto hold forth in the past would explain the future developments in the economy even if the fundamentals changed. He argued that over time, economic agents alter their preferences by invalidating previously estimated relationships. In other words, because economic agents behave in an optimizing dynamic way, their future behavior is informed by their past and anticipated changes in the economic environment.

2.2 Real Business Cycle Models

Responding to the identified weaknesses of the macroeconometric models, Kydland and Prescott (1982) developed the Real Business Cycle (RBC) model of an economy. The RBC model is based on a structural micro-founded platform where economic agents make decisions and form expectations in a dynamic manner. The model assumes that fluctuations arise from economic agents' reactions to random technology shocks and business cycles. This is known as the Real Business Cycle (RBC) approach to macroeconomic modeling and it establishes the DSGE models as the new strand of macroeconomic theory.

Despite the immense contributions of RBC models, they were criticized for the inclusion of flexible prices. Thus, a change in the nominal interest rate is always matched by a proportional change in inflation, leaving the real interest rate unchanged. Contrary to Keynesian proposition that economic recession is often associated with the inefficient utilization of resources, the RBC models assumed that cyclical fluctuations were traced to optimal response to shocks, and that stabilisation policies were not only unnecessary but also counterproductive. Moreso, the introduction of technology shocks in RBC models did not show any long-term growth as proposed by the traditional views. The ability of the models to match empirical evidence with stylized facts on the economy was also criticized.

2.3 New Keynesian Model

The limitations of the RBC model gave birth to a New-Keynesian Macroeconomics (NKM) school of thought. This strand of economic thought is a hybrid of the microfoundation RBC features using the DSGE platform as the workhorse. The NKM assumes that the economy is imperfect and rigid. Hence, NKM introduces monopolistic competition, real and nominal rigidities and a range of disturbances. These include sticky prices (Calvo, 1983); demand shocks (Rotemberg and Woodford, 1995); nominal sticky wages (Erceg, Henderson and Levin, 2000); consumption habits (Abel, 1990); wage and price indexation and the inclusion of investment adjustment costs (Christiano, Eichenbaum and Evans, 2005). As opposed to the view of RBC, these assumptions bring to the limelight the important role of monetary and stabilization policies and extend the usefulness and popularity of the models among the academia and policymakers.

2.4 Computable General Equilibrium Models

Prior to the 1970s, analysis of the general equilibrium was principally theoretical. Championed by Walras (1877) and improved upon by Arrow and Debreu (1954), Debreu (1959), McKenzie (1981) and many others in the 1950s, these models attempted to capture the activities of the real sector at the micro level. Classified under microeconomics, the general equilibrium models adopt the 'bottom-up' approach with a view to gaining an adequate understanding of the whole economy, starting with the individual markets and agents. Given the millions of goods available at any point in time, calculating the equilibrium price of a single good, in theory, was an arduous task. But with the advancement in technology, the computation of the general equilibrium was made possible by the construction of the input-output tables. Attempt at empirically solving for general equilibrium prices and quantities both at national and world levels became possible. Scarf (1967) pioneered the applied general equilibrium (AGE) models which became popular in solving theoretical models. The popularity of AGE models, however, declined because they were computationally inefficient and offered imprecise solution (Velupillai, 2006).

With a view to circumventing the limitation associated with AGE models, the computable general equilibrium models (CGE) were developed as alternative models for the quick solving of large CGE models of the whole economy in the 1980s. Unlike the traditional Keynesian macro-econometric modeling approach which was not only demand-driven but also placed emphasis on simplified structure and economic aggregates, the CGE models focused on individual markets and agents. It is principally a model with microfoundation involving several products in the goods market and offers complex numerical solutions for the economy using computers.

According to Dervis, de Melo and Robinson (1982, p.132), in a CGE modeling framework, 'endogenous price and quantity variables are allowed to interact so as to simulate the workings of at least partly decentralized markets and autonomous decision makers'. Dixon and Parmenter (1996) as cited by Grassini (2007, p.317), indentified the distinguishing characteristics of a CGE as follows:

> *i) They include explicit specification of the behavior of several economic actors, households as utility maximizers and firms as profit maximizers or cost minimizers; ii) they describe how demand and supply decisions made by different economic actors determine the prices of at least some commodities and factors. They employ market equilibrium assumptions; and iii) they produce numerical results (i.e. they are computable).*

CGE models are offshoot of Walras-Johansen and Walras-Leontief models which are multi-sectoral and incorporate the input-output (IO) table into the Walrasian general equilibrium system. According to Valadkhanai (2004), the primary objective of the CGE model is to conduct policy analysis on resource economics, international trade, efficient sectoral production and income distribution. CGE models are different from macro-econometric models in that new equilibrium values are generated for the endogenous variables after some shocks are introduced and also the model do not reveal information about the adjustment process unlike macroeconometric models that provided information on the dynamics of the adjustment process.

2.5 Dynamic Stochastic General Equilibrium (DSGE) Models

The construction of the Dynamic Stochastic General Equilibrium (DSGE) models was necessitated by the neoclassical criticism of the conventional Keynesian models lacking the supply-side determinants in its structure. In order to circumvent this shortcoming, the neoclassical economists, thus, introduced the DSGE as alternative models for describing the aggregate economy premised on the assumption that the economy is not only dynamic but also that the preferences of economic agents' are rational.

The DSGE models are used to 'identify sources of fluctuations, answer questions about structural changes, forecast and predict the effect of policy changes, and perform counterfactual experiments' (Tovar, 2009, p.1). The DSGE also allow for the establishment of the inter-linkages between structural features of the economy. They require less data relative to large scale macro-econometric model. In DSGE model, agents consist of households, firms, government, central banks and other decision makers. The models are not only dynamic but also stochastic implying the impact of random shocks such as changes in technology, oil price and macroeconomic policy-making. This is a departure from CGE models that are deterministic and the micro-simulations are based on borrowed parameters.

According to Hara et. al. (2009), DSGE models are useful for monetary policy practices due to: (1) their micro-foundation characteristics; (2) reliable results obtainable from calibration; (3) the practical use of DSGE models at central banks, and (4) the ability to avoid the Lucas critique. In principle, they can help to identify sources of fluctuations; answer questions about structural changes; forecast and predict the effect of policy changes, and perform counterfactual experiments (Coletti and Murchison, 2002).

In recent years, efforts have been put into building simple, coherent, and plausible models of the monetary policy transmission mechanism capable of merging empirically motivated IS/LM models with DSGE methodologies, which are built on solid microeconomic foundations (Adebiyi and Mordi, 2011).

Currently, several central banks in developed and emerging economies have both built and operationalised DSGE model to aid policy decisions and analysis. Chile, Canada, the US and others are already using these models to forecast major economic indicators in their respective economies. That notwithstanding, the popularity of the DSGE model is limited by its technicality, complexity, absence of strong statistical and programming skills, capital and resource intensive nature and difficulty in communication of results for policy makers and the public.

Sims (2006) criticised DSGE models for being *atheoretical*, lack aggregate capital and consumption goods and excludes the financial markets. According to Mankiw (1989), the nature of preferences and production technology, clearing market, perfect competition, and dynamic optimization behavior are far from reality. For Canova (2007) and DeJong and Dave (2007), in order to take the DSGE models to the data, there is the need to adequately transform the data as well as select an appropriate period with considerable stability in the major economic indicators. Secondly, literature is yet to record a DSGE model that undertake parameter identification even though it is an imperative process in model estimation. In order to improve the forecasting ability of the DSGE models, Tovar (2009) suggests the improvement in the structure of the model, the empirical validation and the effective communication of the model output to policy makers and the public.

2.5.1 DSGE Modelling Efforts

In Spain

The DSGE model of the Spanish Economy, MEDEA (Modelo de Equilibrio Dinámico de la Economía EspañolA), was built on the foundations of the New Keynesian model with real and nominal rigidities.[1] According to Burriel, et al. (2009), MEDEA was a small open economy model that incorporates features of the Spanish economy for policy analysis, for counterfactual exercises, and for forecasting. The open economy features were modeled by the inclusion of exporting and importing firms with incomplete pass-through and by the ability of economic agents to save or borrow on foreign financial instruments. In addition, it reflects the Spanish economy where the monetary authority sets short-term nominal interest rates by following a Taylor-rule based on the economic performance of the Euro currency area.

The MEDEA model was contrived on a neoclassical growth model with optimizing households and firms with a focus on long-run growth propagated by technological change and population growth. According to Burriel, et al. (2009), MEDEA also incorporated prices and wages rigidities, a set of adjustment costs to

[1] This can be found in Christiano, Eichenbaum and Evans (2005), and Smets and Wouters (2003).

investment, exports, and imports, a fiscal and monetary authority that determines a short run nominal interest rate and taxes, and shocks to technology and policy that induces the stochastic dynamics of the economy.

Burriel, et al (2009) identified the major highlights of the MEDEA as a stochastic growth process with features to capture low productivity and the surge in immigration. These include a general technological progress, investment specific technological progress and population growth. The external sector is modeled as an equilibrium that is subordinated to the behavior of the European Central Bank via the Taylor rule. The fiscal sector is well captured with particular attention to three different tax rates on capital income, labor income and consumption. The model solution is designed to undertake higher order approximations in the medium-term and the log-linearized equilibrium conditions is solved around a transformed stationary steady-state.

In Thailand

Like the Spanish model, the underlying theoretical framework of the Thai model was based on a hybrid of New Keynesian notions of nominal and real rigidities with the real business cycle elements of general equilibrium modeling coupled with rational expectation behaviour. As is typical of the New Keynesian tradition, the model allowed for nominal and real inertia as well as the role of aggregate demand in determining output in the short run (Pongsaparn, 2008). In the long-run, macroeconomic variables gravitate towards their corresponding supply-side steady states or equilibrium levels.

A description of the model by Pongsaparn (2008) showed it was flexible, allowing for internal and external adjustments to shocks. Essentially, the multi-country model views the Thai as a small open economy among a group of ten (10) major trading partners: Japan, China, the US, the euro zone, Singapore, Malaysia, Korea, Taiwan, Indonesia and the Philippines. There were five main equations, namely: aggregate demand, aggregate supply, exchange rate equation, monetary policy rule and current account equations. Three other equations capture the rest of the world: aggregate demand, aggregate supply and monetary policy rule equations. For instance, aggregate supply is modeled against output and pass-through effects from foreign inflation and exchange rate. Output was determined by the real interest rate, real exchange rate and foreign output. Inflation and output feed into the interest rate via the monetary policy rule, while the interest rate fed back into output either directly and indirectly through the exchange rate.

In Hungary

Jakab and Világi (2007) developed a two-sector, small-open-economy model for Hungary. The two sectors produce domestic and exported goods. Following Christiano et al. (2005) and Smets and Wouters (2003), the model incorporated different types of frictions to replicate the empirical persistence of Hungarian data. External habit formation was captured in consumption, Calvo-type price and wage rigidity complemented with indexation to past prices and wages, adjustment costs of investments and capital, labor and import utilization and indexed cost in production. Liquidity-constrained rule-of-thumb consumers were incorporated in the tradition of Galí et al. (2007), while the treatment of imports as production input followed McCallum and Nelson (2007).

Following the historical antecedent of Hungarian disinflation process, Jakab and Világi (2007) incorporated inertia in agent's perception of inflation expectations. This was an assumption, which required the treatment of the perceived average inflation rate as one that mimics a real-time adaptive-learning algorithm. The model applied the Bayesian technique and followed An and Schorfheide (2005). The technique was based on maximization of the likelihood function, derived from the rational-expectations solution by the Kalman-filter, combined with prior distributions. The posterior density function of the estimated parameters was characterized by the random-walk Metropolis-Hastings (MH) algorithm.

To handle structural breaks arising from two different monetary regimes, Jakab and Világi (2007) formulated two models over the estimation sample: between 1995 and 2001, a crawling-peg regime and from 2001, an inflation-targeting regime, respectively.

In Estonia

The DSGE experience on Estonia has witnessed several considerations (Colantoni, 2007; Lendvai and Roeger, 2008). According to Gelain and Kulikov (2009), these studies attempted to understand the interest rate channel of the monetary policy transmission between Estonia and the Euro area; and to incorporate several types of households, a housing sector and separate tradable and non-tradable production sectors. Gelain and Kulikov (2009) developed a model reflecting the existing monetary policy regime between the two areas, and to improve on the statistical inference process. Basically, the model was based on the New Keynesian foundations that characterized the complex dynamics and persistence of the real world macroeconomic time series. It followed the works of Smets and Wouters (2003), Christiano, Eichenbaum and Evans (2005) and Adolfson et al. (2005). Specifically, the model incorporated external habit formation in consumption, investment adjustment costs, price and wage rigidities and indexation to the past inflation, and variable capital utilization.

Also, the model contained eleven structural shocks that drive the dynamics of Estonian economy. The key shocks included production technology and investment (specific technology innovations, labour supply and preference shocks, an equity premium shock, and the government consumption innovation). As in Adolfson et al. (2005), the model had 24 state variables and 11 structural shocks.

In the model, households own labor and capital, optimized their consumption and supply of working hours across time. A Calvo-type wage setting behavior was adopted with four types of firms: final good producers operating in perfectly competitive market, monopolistically competitive domestic intermediate goods producers; the government sector was assumed to follow a balanced budget fiscal policy driven by an exogenous government consumption shock; domestic nominal interest rates were linked to the euro area via the uncovered interest rate parity, where the next period expected change in the nominal exchange rate is set to zero because of the currency board.

In South Africa

The open economy New Keynesian model is used as a basis to develop and estimate a DSGE model of the South African economy. The Steinbach, Mathuloe and Smit (2009) model reflected: imperfect pass-through of exchange rate changes, external habit formation, partial indexation of domestic prices and wages to past inflation, and staggered wage and price setting. Bayesian techniques were used to fit South African domestic and trading partner data for the period 1990Q1 to 2007Q4.

Steinbach, Mathuloe and Smit (2009) formulated their model as a two-country New Keynesian DSGE model where the domestic economy was represented by South Africa and the foreign economy by the rest of the world. Firstly, the domestic economy was modelled as a small open economy. The structure provided for incomplete pass-through of exchange rate changes. Furthermore, the model was adapted to include real rigidity in the form of external habit formation in consumption, and additional nominal rigidities through partial indexation of domestic prices to its past inflation, staggered price and wage setting following Calvo (1983), and partial indexation of wages to past consumer price inflation. Secondly, the rest of the world was assumed to be so large that it would not be affected by developments in the South African economy and therefore approximates a closed economy. Hence, the structure of the rest of the world was modelled as a closed economy version of the domestic economy, with the only difference being that, for the sake of simplicity, wages in the foreign economy are flexible.

In Portugal

Almeida (2009) formulated and estimated the Portuguese model based on the New-Keynesian DSGE model for a small open economy within a monetary union using Bayesian techniques. Estimates for some key structural parameters were obtained and a set of exercises exploring the model's statistical and economic properties were performed.

According to Almeida (2009), the model’s features included five types of agents, namely households, firms, aggregators, the rest of the world and the government. The model also included a number of shocks and frictions, which enabled a closer matching of the short-run properties of the data and a more realistic short-term adjustment to shocks. Monetary policy in the model was defined by the Union's central bank and that the domestic economy's size was small, relative to the Union's. Therefore, its specific economic fluctuations had no influence on the Union's macroeconomic aggregates and monetary policy.

An endogenous risk-premium was considered, allowing for deviations of the domestic economy's interest rate from the Union's one. Furthermore, it was assumed that all trade and financial flows were performed with countries belonging to the Union, which implied that the nominal exchange rate was irrevocably set to unity.

***In* Sub-saharan Africa**

Peiris and Saxegaard (2007) made the first attempt to estimate DSGE models for monetary policy analysis using data of the economy of Mozambique. They recognized and incorporated credit frictions faced by firms and a version of the monetary policy reaction function developed in Adam et al (2009). Their model showed that firms borrow to cover their working capital at a premium and assumed a loan market that is perfectly competitive. Different from traditional Taylor rule, Peiris and Saxegaard (2007) included a reaction function for monetary policy where the monetary authority influences the supply of money in the economy through foreign exchange and government bond transactions.

Houssa et al (2009) also developed and estimated an open economy version of New Keynesian DSGE model using Ghanaian data, which is similar to open economy DSGE version developed by Adolfson et al (2007) and Christiano, et al (2005). Moreover, Berg et al (2010) built a multi-sector New Keynesian DSGE model to analyze the impact of aid on some selected macroeconomic variables and evaluated the implications of different policy responses. The model captured some features of low-income countries such as the efficiency of public capital, realistic monetary and fiscal policy rules and the household sector made up of the dynamic optimizing households and the rule-of-thumb households. This model was calibrated for the economy of Uganda and Dagher, et al (2010) calibrated the same model to examine the effect of oil windfalls on Ghanaian economy.

***In* Nigeria**

In Nigeria, there are limited efforts to develop and utilize DSGE models. Earlier works include those of Olekah and Oyaromade (2007), Olayeni (2009), Alege (2009), Garcia (2009), and Adebiyi and Mordi (2010). Although Olekah and Oyaromade (2007) specified a small-scale model of the Nigerian economy in the DSGE tradition. VAR estimates were utilized to generate impulse response functions. The DSGE model as estimated by Alege (2009) focused on identifying sources of the real business cycle in Nigeria using Bayesian techniques.

Similarly, using Bayesian techniques, Olayeni (2009) estimated a DSGE model to analyse the impact of the global financial meltdown on the Nigerian economy. The author finds that the Central Bank of Nigeria (CBN) has preferences for inflation stabilization relative to output.

Garcia (2009) developed a simple Dynamic General Equilibrium New Keynesian macroeconometric model for forecasting and policy analysis for the Nigerian economy. The model incorporated forward-looking characteristics (such as inflation expectation) in the monetary policy objective function of the CBN. Estimating with Nigerian quarterly data from 1995 to 2007, the results justify the current policy actions of the CBN to control inflation.

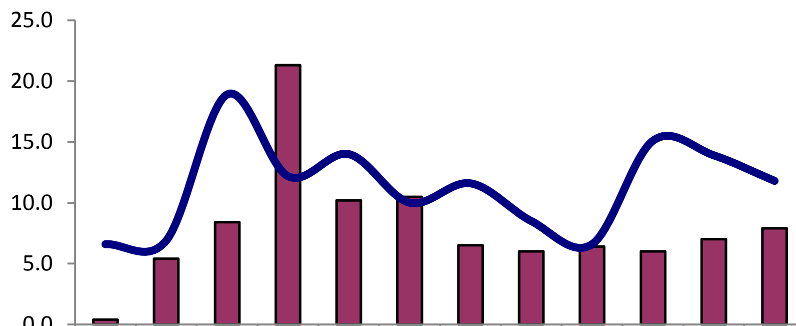
Following Garcia (2009), the DSGE model by Adebiyi and Mordi (2010) applied Bayesian estimation techniques to reveal the channels of monetary policy transmission in a regime of managed exchange rate. The study found that inflation had both forward and backward-looking elements. The study also indicated that the income elasticity of the real demand for money in Nigeria was approximately 0.87, reflecting the cash-based nature of the Nigeria economy. Moreover, the paper identified the existence of an exchange rate pass-through, confirming the import-dependent nature of the Nigerian economy. In addition, the paper estimated a sacrifice ratio of 1.306. Lastly, the paper showed that the best Taylor-type policy rule for Nigeria is a monetary policy rule that gives higher weight to inflation gap than output gap.

Chapter Three
Stylised Facts on the Nigerian Economy

3.1 Output and Inflation

Output growth in Nigeria has remained resilient averaging about 8.0 per cent in the last decade in spite of lingering infrastructure challenges. Although this was slowed down in the wake of the global financial crises, 2007-2008, growth went up from 6.0 per cent in 2008 to 7.9 per cent in 2010. The major driver of growth has remained agriculture accounting for about 60 per cent of GDP, with a strong growth in the non-oil sectors of the economy. The average non-oil sector growth in the last decade stood at 10.3 per cent. The oil sector recorded positive growth in 2009 and 2010, an improvement from several years of negative growth. The expansion in the non-oil sector is attributable to macro-economic stability, favourable weather conditions for agriculture, and sustained reforms in the economy.

Figure 3.1: GDP Growth and Inflation Rate



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
GDP Growth Rate	0.4	5.4	8.4	21.3	10.2	10.5	6.5	6.0	6.4	6.0	7.0	7.9
Inflation Rate	6.6	6.9	18.9	12.19	14	10.01	11.60	8.50	6.60	15.10	13.90	11.80

Source: National Bureau of Statistics, Abuja

Inflation, though recorded mixed developments, decelerated in the last 2 decades. Average inflation rate stood at 11.13 per cent during the period, 1999-2010, a significant decrease from the over 21.0 per cent level in the 1980-1990 era. Still, it remained relatively high compared with the global price trends. The annual inflation rate fluctuated between 18.9 per cent in 2001 and 15.10 per cent in 2008 averaging 11.9 and 12.1 per cent for 1999-2003 and 2004-2010, respectively. The rise in inflation in 2001 was attributed to increases in the domestic pump-prices of petroleum products. The domestic price level has been double digit but the single digit target inflation rate was met in 1999, 2000, 2006 and 2007 at 6.6, 6.9, 8.2 and 5.4 percent, respectively. The observed inflationary trend had both cost-push and demand-pull elements.

3.2 Monetary and Financial Sector

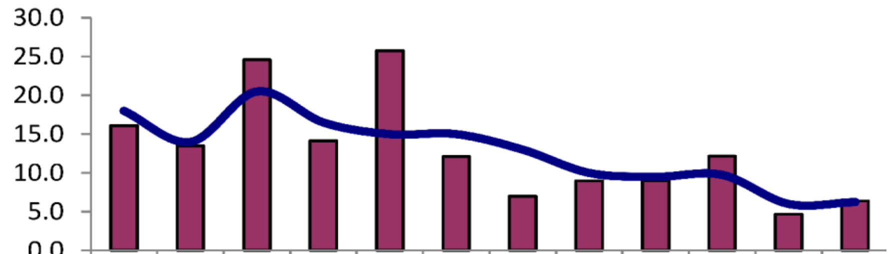
Monetary policy in Nigeria has bordered around promoting a stable macroeconomic environment for the achievement of a non-inflationary output growth, single digit inflation, stability in the naira exchange rate, financial sector soundness and external sector viability, through the effective control of monetary aggregates.

The financial environment for monetary policy implementation is largely dualistic with formal and informal financial intermediation co-existing, reflecting cultural and social factors more than economic forces. The financial landscape was significantly altered when in 2001 the dichotomy between the commercial and merchant banks was removed following the introduction of universal banking. Under this system the deposit money banks (DMBs) could engage in both money and capital market activities as well as in insurance business depending on individual bank's operational preferences. To redress the perennial problem of systemic distress in the banking industry, among other problems, the CBN embarked on the recapitalization and consolidation of the banking industry for efficient service delivery. As at 2010, the number of banks in the banking industry stood at 24, while the number of bank's branches grew by 4.2 per cent from 5,565 in 2009 to 5,799. Other financial institutions have also witnessed tremendous growth.

In terms of monetary regime, monetary targeting has been deployed since 1974, and in recent time, the use of market based (indirect) instruments to achieve monetary policy objective. Mainly, the indirect instrument used is the Open Market Operations (OMO), supplemented by reserve requirements and discount window operations. For discount window operations, the Minimum Rediscount Rate (MRR) was applied with a view to influencing market rates especially the interbank rate. It was later replaced with the Monetary Policy Rate (MPR) in December 2006 under a standing facility arrangement for deposits and lending.

The MRR averaged 15 per cent between 1999 and 2005 before it was replaced by the Monetary Policy Rate (MPR) in December 2006. At inception, the MPR was fixed at 10.0 per cent with a band of ±300 basis points, thus repositioning the CBN as a lender-of-last-resort.

Figure 3.2: MRR/MPR and Inter-bank Rate



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Inter-bank Rate	16.1	13.5	24.6	14.1	25.8	12.1	7.0	9.0	9.0	12.2	4.7	6.4
MRR/MPR Rate	18.0	14.0	20.5	16.5	15.0	15.0	13.0	10.0	9.5	9.8	6.0	6.3

The inter-bank call rate indicated a volatile movement throughout the review period. The irregular trend is a reflection of the liquidity surfeit in the system. The increase in the inter-bank call rate in 2001, for example, reflected the impact of demand pressure and tight monetary policy stance, while its decline in the following year, was as a result of the downward adjustment in MRR. The banking sector consolidation and implementation of the new monetary policy framework generally moderated volatility in the inter-bank rate in those years.

3.3 External Sector

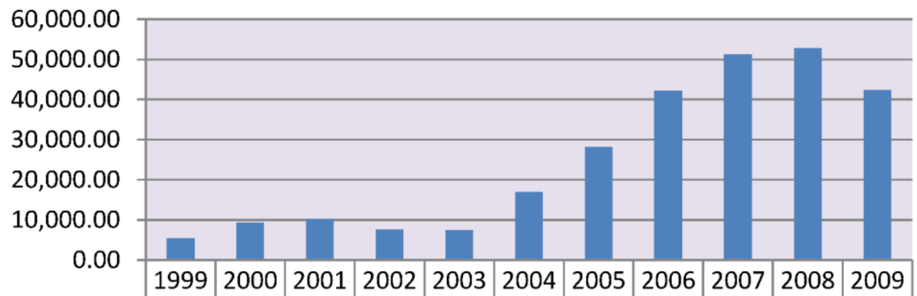
The objectives of exchange rate policy measures has been to preserve the external value of the naira; diversify the productive base of the economy by encouraging non-oil exports; broaden and deepen the foreign exchange market; conserve foreign exchange resources; discourage speculations and ensure that the exchange rate stays with a narrow band; and narrow the arbitrage premium between the official and parallel market rates.

The average exchange rate of the naira was ₦92.30 per US$1 in 1999. It depreciated continuously until it was ₦133.50 per US$ in 2004. The depreciation owed, mainly, to a fall in foreign exchange inflow in the face of increased demand pressure. By 2006 however, the naira appreciated against the US dollar, standing at ₦128.70 per US$1.00. The appreciation and moderation in exchange rate volatility was driven by a number of policy changes introduced by the Central Bank of Nigeria. These include further liberalization of the foreign exchange market through the introduction of the Wholesale Dutch Action System (WDAS), granting of approval to BDC operators to access the CBN foreign exchange window, among others.

External reserve accumulation is exogenously determined by international price of crude oil. With the exception of one or two years, the average price of

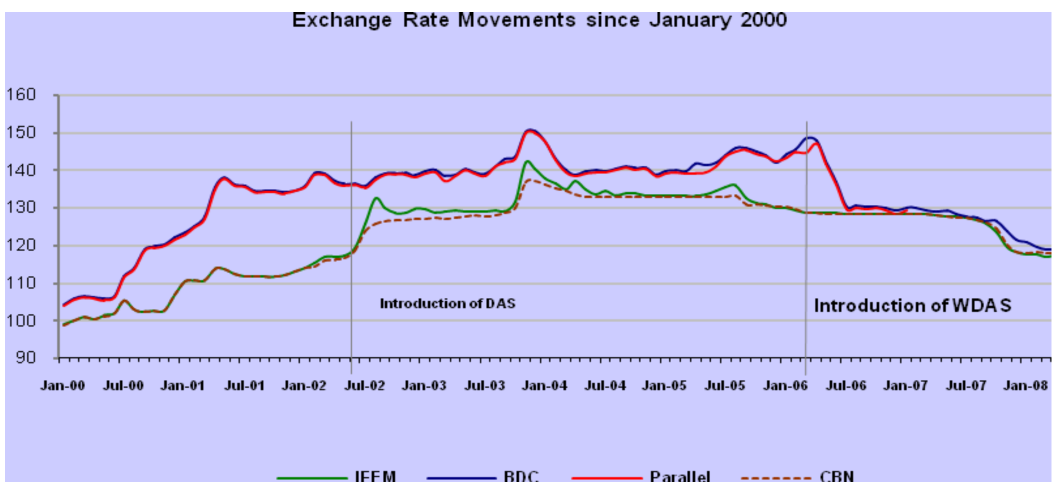
Nigeria's reference crude, the Bonny Light, has been on steady increase since 1999. From just US$17.95 per barrel in 1999, it has risen to more than US$66.81 per barrel. The stock of external reserves rose persistently from US$5,424 million in 1999 to US$10,267 million in 2001. However, in 2009, it declined marginally to US$42,382 million, down from US$52,823 million in 2008.

Figure 3.3: External Reserves (US$'Million)



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
External Reserves	5,424	9,386	10,26	7,681	7,467	16,95	28,27	42,29	51,33	52,82	42,38

Figure 3.4: Exchange Rate Movements since January 2000

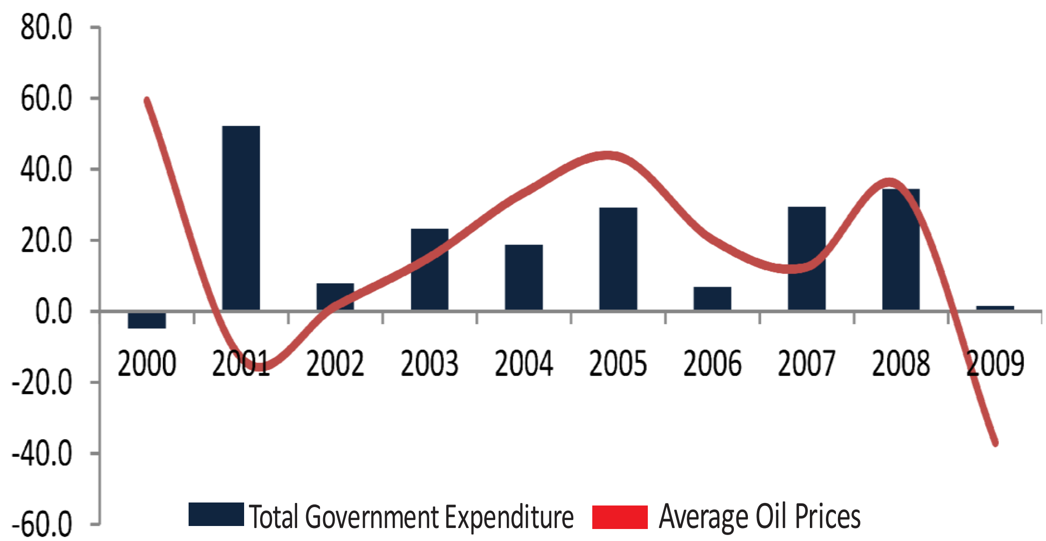


3.4 Fiscal Policy

The fiscal operations of the Government have essentially been characterized by continuing growth in expenditure and have persistently followed the booms and bursts pattern of earnings from the oil sector. The developments in crude-oil earnings have heightened the pro-cyclical nature of fiscal thrusts such that the increase in revenue was most of the time followed by more than proportionate expansion in government expenditure. A cursory look at government outlay indicated that aggregate expenditure of the Federal Government grew at an annual average of about 40.5 per cent between 1990 and 1999, while those of the sub-national governments increased at an average of about 31.9 per cent over the same period (Idowu, 2010).

Total government expenditure grew at an annual average of about 19.9 per cent between 2000 and 2009. Similarly, the expenditure of the federal and the sub-national government grew at an annual average of about 15.5 and 35.6 per cent, respectively.

Figure 3.5: Total Government Expenditure and Average Oil Prices



The fiscal expansion and deficits of the three tiers of government in the 1990s constrained the effectiveness of monetary policy. Thus, huge fiscal operations at all levels and the inflationary financing of large budgetary deficits of the Federal Government vitiated monetary management, particularly, as the CBN had to take-up an annual average of 36.7 per cent of the Federal Government's fiscal deficits with the issuance of high powered money.

Figure 3.6: Fiscal Deficit and Current Account Balance

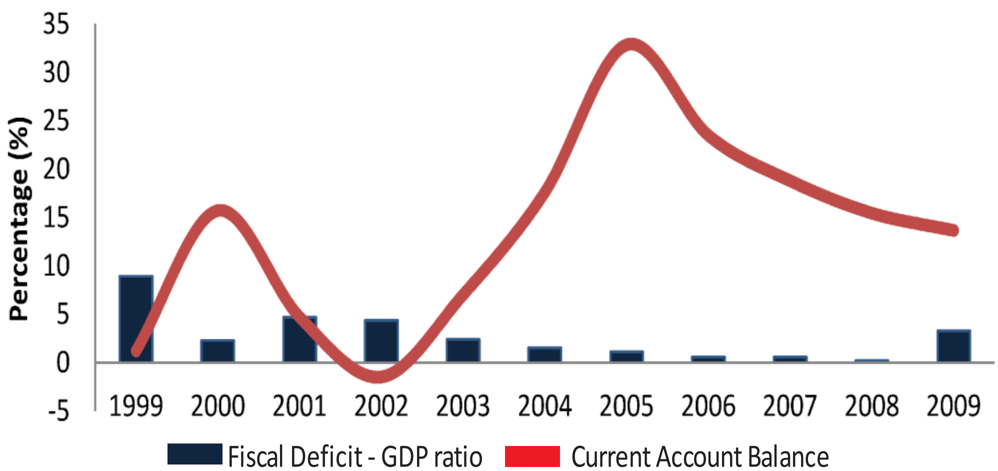


Figure 3.6 indicates that the historical paths of fiscal and current account imbalances during 1999 to 2009. From a surplus of 1.2 per cent of GDP in 1999, the current account balance plummeted abruptly to a deficit of 1.5 per cent of GDP in 2002. By 1998 and 1999, both fiscal and current account balance slipped to a deficit of approximately 9.0 per cent of GDP; and owing to revenue shortfalls in the preceding year, due to drops in oil prices, fiscal policy was geared towards promoting greater budgetary discipline. The fiscal operations in 2000 recorded a surplus of 8.0 per cent, accompanied by 12.5 per cent in a current account surplus.

Post-2000 saw a return to both fiscal and current account deficits, but while fiscal imbalances hovered generally below 5.0 per cent of GDP through 2009, current account deficit surged sporadically from its trough, at about 13.0 per cent of GDP in 2002, to an all-time high of 23.47 per cent surplus in 2006. While still in the surplus region, current account balance has reduced gradually to approximately 14 per cent of GDP in 2009.

Chapter Four
Methodology

4.1 Estimation

4.1.1 Calibration

The Bayesian estimation technique requires an initial calibration of some or all the parameters. This is a strategy to cope with the identification problems associated with DSGE models. One of such problems emanates from the simplicity of solving small scale models relative to the difficulty generating solutions for medium/large-scale models. Calibration in the Bayesian tradition also requires the incorporation of fixed parameters which can be viewed as imposing a very strict prior.

Essentially, the parameters defining the steady-state equilibrium are calibrated and provide the basis for assessing how far the data closely reflect the prior in the estimation process. In other words, the parameters to be calibrated should be those fundamental to achieving steady-states for the model and at the same time replicate the main steady-state key ratios of the Nigerian economy; those for which reliable estimates already exist; and those for which, an initial estimation attempt failed to yield satisfactorily identification.

4.1.2 Prior Distribution

The specification of the prior distribution, $p(\mu)$ follow a probability density function (*pdf*) of a parameter. The *pdf* provides a formal way of specifying probabilities to the values that parameters can assume. Usually, this is based on outcome of previous studies or/and occurrences, subjective views of the researcher and to some extent the opinions of higher management. The prior sums up the researchers' belief in the context of the model set with no particular reference to data, constituting an additional, independent, source of information.

The prior's functional form mimics each parameter's characteristics and is given by a density function,

$$p\left(\lambda_Q | Q\right)$$

Where Q indicates a specific model, λ_Q represents the parameters of model Q, $p\ .$ is the probability density function (pdf) such as a normal gamma, shifted gamma, inverse gamma, beta, generalized beta, or uniform function. Inverse gamma distribution is assigned to parameters bounded, p . >0; beta distribution for parameters bounded, 0 ≤ p . ≤ 1; and normal distribution for non bounded parameters.

To set the parameters defining each distribution (mean and standard deviation) the parameters are grouped into two components: first, for those which we have relatively strong *a priori* convictions (core structural parameters), and, second, those for which significant uncertainty exist (parameters for the shock process). Priors for the first type of parameters are obtained from existing empirical evidence in line with their implications for macroeconomic dynamics. For parameters of the second type, the priors are set through the generation of largely autoregressive processes.

4.1.3 Posterior Distribution

Bayesian estimation is a juxtaposition of calibration and maximum likelihood, connected via the Bayes' rule. While calibration involves the specification of priors, the maximum likelihood relates the model to data through the use of standard econometrics. The density of the observed data is described by the likelihood function given below:

$$L\left(\lambda_Q \middle| K_T Q\right) \equiv p\left(K_T \middle| \lambda_Q, Q\right)$$

Where K_T stands for the observations up to time T, and a recursive form of the likelihood written as:

$$p\left(K_T \middle| \lambda_Q, Q\right) = p\left(y_0 \middle| \lambda_Q, Q\right) \prod_{t=1}^{T} p\left(y_t \middle| K_{t-1}, \lambda_Q, Q\right)$$

Given the prior density $p(\lambda)$ and a likelihood function $p\left(K_T \middle| \lambda\right)$, the posterior density $p\left(\lambda \middle| K_T\right)$ parameters can be obtained knowing the data by using the Bayes theorem:

$$p\left(\lambda \middle| K_T\right) = \frac{p\left(\lambda; K_T\right)}{p\left(K_T\right)},$$

given that

$$p\left(K_T\left|\lambda\right.\right)=\frac{p\left(\lambda;K_T\right)}{p\left(K_T\right)}\Leftrightarrow p\left(\lambda;K_T\right)=p\left(K_T\left|\lambda\right.\right)\times p\left(\lambda\right)$$

Consequently, the posterior density:

$$p\left(\lambda_Q\left|K_T,Q\right.\right)=\frac{p\left(K_T\left|\lambda_Q,Q\right.\right)p\left(\lambda_Q\left|Q\right.\right)}{p\left(K_T\left|Q\right.\right)},$$

where $p\left(K_T\left|Q\right.\right)$ is the marginal density of the data conditional on the model:

$$p\left(K_T\left|Q\right.\right)=\int_{\Theta_Q}p\left(\lambda_Q;K_T\left|Q\right.\right)d\lambda_Q$$

The posterior kernel tallies with the numerator of the posterior density:

$$p\left(\lambda_Q\left|K_T,Q\right.\right)\propto p\left(K_T\left|\lambda_Q,Q\right.\right)p\left(\lambda_Q\left|Q\right.\right)\equiv\kappa\left(\lambda_Q\left|K_T,Q\right.\right)$$

The above equation allows us to update all posterior moments of interest by estimating the likelihood function using the Kalman filter algorithm. The posterior kernel is then simulated using Monte Carlo method such as Metropolis-Hastings.

4.2 Validation and Evaluation

Several criteria exist in the extant literature on the validation and evaluation of Bayesian estimated models. Primarily, the process entails validation of the estimation procedures and evaluation of the outcomes against the backdrop of the model's ability to track the features of the data.

An important way to begin validation is to be sure that the posterior kernel maximization can yield an optimum. This is carried out by plotting the minus of the function for values around the estimated mode, for each parameter. For an optimum to occur, the mode of the function should be at the trough which would mean the priors are appropriate and identification problems do not exist.

Another procedural validation step is to examine the convergence properties of the Metropolis-Hasting (MH) algorithm. To do this, several runs of MH simulations are undertaken, involving a large number of draws for alternative initial values.

Once the optimization algorithm runs without hitch and ends up with similar results in each run's iterations, convergence has been achieved.

In addition, the simulated posteriors should be checked to be sure that they are approximately normal; the posteriors are neither too far off nor too similar to the priors; the modes are not too different from the ones obtained from the maximisation of the posterior kernel.

Sensitivity analysis could also be carried by adjusting some of the prior assumptions and comparing the results obtained with the benchmark model.

Five different ways as documented by Carabenciov et. al. (2008) can be used to assess the quality and fitness of the model. First, the coefficients of the estimated model are examined for degree of variability from the priors. Once the margin of error is relatively miniscule, it would mean that the priors are consistent with the data. Second, is to inspect the impulse response functions (IRFs) generated from the model and see if they reflect the views of the researcher on how the economy responds to shocks. From the IRFs, both the point estimates and confidence intervals are determined by using the draws produced by the MH algorithm. Third, the relative magnitudes of the log data density and root mean squared errors (RMSEs) could be applied to alternative variants of a given macro model[1] to select one that is data consistent. Fourth, the variance decomposition of the variables in the model should be plausible and sensible. And fifth, eye-balling of the estimates' innovations to be sure that their behavior is stationary, i.i.d, and are mean reverting.

[1] For instance, a model that treats shocks to output as largely demand-determined and another that treats shocks as largely supply-determined

Chapter Five
Macroeconomic Foundation of DSGE

5.1 The Basic Model

The DSGE for monetary policy analysis in Nigeria is rooted on the standard New Keynesian framework. The basic structure of the framework comprises three economic agents -- households, firms and the monetary authority. In an attempt to maximize utility, the households supply labor, purchase goods and hold money for transaction and speculative motives. On the other hand, firms are assumed to be monopolistically competitive in the goods markets, while the central bank controls the nominal rate of interest with a view to stabilizing price and output.

5.1.1 Households Behaviour

The preferences of the representative households are defined over a composite consumption goods (C), government spending (G) and leisure (1 - N), where N is the number of hours devoted to work. Households maximize the expected present discounted value of utility in equation 1, subject to the intertemporal budget constraint in equation 2.

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\lambda}}{1-\lambda} + \omega \frac{G_t^{1-\lambda}}{1-\lambda} - \frac{N_t^{1+\delta}}{1+\delta} \right) \tag{1}$$

where $\beta \in (0,1)$ is the household discount factor, λ is inverse intertemporal elasticity of substitution in consumption, δ is inverse labour supply elasticity with respect to real wage and ω is a relative weight on consumption of public goods. The standard form of the household's intertemporal budget constraint is written as follows:

$$P_t C_t + E_t \left\{ R_{t,t+1} D_{t+1} \right\} + T \leq F_t + (1-\tau_t) W_t N_t \tag{2}$$

where $R_{t,t+1}$ = $(1/1+i_t)$ represents one-period ahead stochastic discount factor, i_t is nominal interest rate, T and τ_t stand for constant lump-sum taxes and income tax rate, respectively. W_t is nominal wage, F_t is nominal portfolio, P_t is consumer price index (CPI) and C_t is composite consumption goods made up of

domestically-produced goods ($C_{h,t}$) and imported goods ($C^*_{,t}$). These goods are assumed to be produced by monopolistically competitive firms.
From equations 1 and 2 above, a forward looking open economy IS curve is derived in terms of output instead of consumption by using the national income identity and risk sharing condition, as found in Gali & Monacelli (2005, 2008). From the first order condition of equations 1 and 2, a log-linearised IS curve in terms of deviations from steady state can be expressed as follows:

$$\hat{q}_t = E_t\left\{\hat{q}_{t+1}\right\} - E_t\left\{\Delta \hat{g}_{t+1}\right\} + \theta(\varpi - 1)(\rho_{c*} - 1)\hat{c}_t* - \frac{1}{\lambda_\theta}\left(\hat{r}_t - E_t\left\{\hat{\pi}_{h,t+1}\right\}\right) \qquad (3)$$

Where $\lambda_\theta \equiv \dfrac{\lambda}{(1-\theta)+\theta\varpi}$ and $\varpi \equiv \lambda\gamma + (1-\theta)(\lambda\eta - 1)$. Parameter $\eta > 0$ is the elasticity of substitution between domestic and foreign goods, θ measures the degree of openness, and γ reflects elasticity of substitution between the goods produced in different foreign countries. Output $\hat{q}_t = \ln\left(Q_t \big/ \bar{Q}\right) = q_t - \bar{q},$ is an endogenous variable, government spending $g_t = -\ln(1 - G_t/Q_t)$, nominal interest rate i_t and domestic inflation $\pi_{h,t} = \ln\left(P_{h,t} \big/ P_{h,t-1}\right)$ are endogenous variables with $\bar{q}$ defining the steady state value of q_t. Domestic prices are given by $P_{h,t}$, while $c_t^* = q_t^* - g_t^*$ denotes exogenous world consumption (output). The forward looking open economy IS curve in the gap form is depicted in equation 4.

$$q_t = E_t \; q_{t-1} - E_t \; \Delta g_{t-1} - \frac{1}{\lambda_\theta} \; i_t - E_t \; \pi_{h,t-1} \qquad (4)$$

Where $\tilde{q}_t = \hat{q}_{t_n} - \hat{q}^n_t$, $\tilde{i}_{t_n} = \hat{i}_t - \hat{i}^n_t$. We can write $\tilde{g}_{t+1} = \hat{g}_{t+1}$ and $\tilde{\pi}_{h,t+1} = \hat{\pi}_{h,t+1}$ since $\hat{g}^n_{t+1} = \hat{\pi}^n_{h,t+1} = 0$. Finally, $\hat{q}_t$ and $\hat{i}_t$ denote natural level of output and nominal interest rate, respectively, and captures the equilibrium level of output and interest rates in the absence of nominal rigidities, which can be algebraically expressed as follows:

$$\hat{q}^{n}_{t} = \frac{(1+\phi)}{(\lambda_\theta+\phi)}\hat{a}_t - \frac{(\lambda+\lambda_\theta)}{(\lambda_\theta+\phi)}\hat{c}^{*}_t \tag{5}$$

$$\hat{i}^{n}_{t} = \lambda_\theta\left(E_t\left\{\hat{q}^{n}_{t+1}\right\} - \hat{q}^{n}_{t}\right) + \lambda_\theta\theta \;\; \varpi - 1 \;\; p_{c*} - 1 \;\; \hat{c}^{*}_t \tag{6}$$

where a_t is the log of technology process, A_t

5.1.2 Firms Behaviour and Price Setting

Identically monopolistic firms produce differentiated output as a function of labour units and linear technological shock. Capital is assumed absent for simplicity, such that the j[th] firm's production function can be written as follows:

$$Q_t(j) = A_t N_t(j) \tag{7}$$

Aside the constraint of facing different demand curves, firms also face sticky prices. Consistent with Calvo (1983), it is assumed that a fraction $1-\rho$ of the firms can set a new price in each period. Thus, a fraction ρ measures the degree of nominal rigidities, and shows the number of firms that keep its price unchanged. In other words, in each period, every firm may set a new price with probability $1-\rho$ and this probability is independent of the time interval of the previous price setting. Consequently, $1/1-\rho$ shows average duration that prices are fixed.

In order to introduce inflation persistence in the model that leads to the hybrid new Keynesian Phillips curve, backward looking behavior in price setting process is included in the spirit of Gali & Gertler (1999). In that regard, two types of firms in the economy are assumed. A fraction of $1-\zeta$ (the price setters), who change their prices each period with probability $1-\rho$ behave optimally as in the standard Calvo model. The remaining fraction (ζ), when setting their prices, prefers to take into account backward looking (rule of thumb) behaviour.

The price, $p^{b}_{h,t}$, set by a rule of thumb price setters, can be written as in Gali & Gertler (1999):

$$p_{h,t}^{b} = P_{h,t-1}^{*} \frac{P_{h,t-1}}{P_{h,t-2}} \tag{8}$$

where $P_{h,t-1}^{*} = \left(P_{h,t-1}^{f}\right)^{1-\zeta}\left(P_{h,t-1}^{b}\right)^{\zeta}$ depicts the aggregate prices chosen in period t-1 by both optimizing (forward looking, $P_{h,t-1}^{f}$) and rule of thumb (backward looking, $P_{h,t-1}^{b}$) price setting firms. Therefore, the rule of thumb price setters take cognizance of lagged inflation rate $\left(\pi_{h,t-1} = \frac{P_{h,t-1}}{P_{h,t-2}}\right)$ as well as aggregate price ($P_{h,t-1}^{*}$) occuring in period t-1, when they reset their prices contemporaneously. The existence of backward looking firms in addition to forward looking firms allows us to obtain a log-linearised open economy hybrid Phillips curve in terms of deviations from steady state as follows:

$$\hat{\pi}_{h,t} = \sigma^{b}\hat{\pi}_{h,t-1} + \sigma^{f}\mathrm{E}_{t}\left\{\hat{\pi}_{h,t-1}\right\} + \psi\hat{m}c_{t} + \varepsilon_{t}^{\pi} \tag{9}$$

$$\hat{mc}_t = \lambda_\theta + \phi \left(\hat{q}_t - \hat{q}_t^{n}\right) - \lambda_\theta \hat{g}_t + \hat{\tau}_t \tag{10}$$

where $\sigma^{b} = \frac{\zeta}{\rho + \zeta\left(1 - \rho\left(1 - \beta\right)\right)}$, $\sigma^{f} = \frac{\beta\rho}{\rho + \zeta\left(1 - \rho\left(1 - \beta\right)\right)}$, and

$$\psi = \frac{\left(1 - \beta\rho\right)\left(1 - \rho\right)\left(1 - \zeta\right)}{\rho + \zeta\left(1 - \rho\left(1 - \beta\right)\right)},$$

$\hat{mc}_t$ denotes real marginal cost and $\tau_t = -\ln\left(1 - \Upsilon_t / Q_t\right)$ is a log-linearized tax rate. ε_{t}^{π} represents a cost push (mark- up) shock included in the Phillips curve (Smets & Wouters, 2003, 2007; Beetsma & Jensen, 2004; Ireland, 2004; and Fragetta & Kirsanova, 2010).

In Smets & Wouters (2003) and Fragetta & Kirsanova (2010), it was assumed that cost push shock is independent and identically-distributed (i.i.d.) shock. From equation (10), government spending and income tax as well as output gap directly drive the real marginal cost process and thus, indirectly affect inflation through equation (9). The slope coefficient ψ in the hybrid phillips curve shows the sensitivity of domestic inflation with respect to real marginal cost. In addition to current real marginal cost, future expected inflation and past inflation, reflecting inflation inertia, enter the current domestic inflation equation. The structural reduced form parameters σ^b, $\sigma^f$and ψ are defined in terms of three deep parameters of the model, ζ; ρ and β. When the degree of backwardness, ζ, is equal to zero, one can obtain a forward looking open economy Phillips curve. However, when ζ is different from zero, a hybrid Phillips curve is found. Another interesting feature depends on the value of discount factor, β. When β = 1, the sum of σ^b and σ^f will be 1. Also, the total value of these components will be between σ^f (when σ^f = 0) and 1 (when σ^f = 1). Given that the value of discount factor is very close to 1, Amato & Laubach (2003), state that σ^b and σ^f could be viewed as the relative weights on lagged and lead inflation, respectively. A higher inflation inertia portends that the share of rule of thumb price setting firms increases. In addition, the sensitivity of current domestic inflation to current real marginal cost is undermined if the number of rule of thumb price setters increases and there is a high degree of sticky prices.

5.1.3 The Monetary Policy Rule

A simple Taylor-type interest-rule in the tradition of Smets & Wouters (2003, 2007), is defined as a function of inflation and output as follows:

$$\hat{i}_t = \rho_i \left(\hat{i}_{t-1} - \hat{i}^n_{t-1}\right) + 1 - \rho_i \left[i_\pi \hat{\pi}_{h,t} + i_q \left(\hat{q}_t - \hat{q}^n_t\right)\right] + \hat{i}^n_t + \varepsilon^i_t \qquad (11)$$

where $\hat{i}^n_t$ represents natural level of nominal interest rate and ρ_i $0 \leq \rho_i \leq 1$ interest rate smoothing coefficient and ε^i_t is an i.i.d. interest rate shock, which can be interpreted as the non-systematic part of the monetary policy. Parameters i_π and i_q are central bank's preference about inflation and output gap. Since the main objective of any central bank is to achieve price stability, the preference on the parameter i_π should be higher.

The rule suggests that central banks adjust nominal interest rates in response to deviation of inflation from its steady state value and deviation of output from its natural level. Additionally, Central Banks also take cognizance of the past value of nominal interest rates (when $\rho_i \neq 0$) when they reset their current nominal interest rates. The high value for the degree of interest rate smoothing reduces the contemporary responsiveness of the nominal interest rates to inflation and output gap.

5.2 Log-linearised Model and Description

This section describes the log-linearised version of the model. The model is specified in gap and rate-of-change terms, so that all the variables are rendered stationary. The model contains thirteen (13) equations as specified in equations (16)-(28) below:

$$y_t = \beta_1 y_{t+1} + (1-\beta_1) y_{t-1} + \beta_2 (i_t - pi_{t+1}) + \beta_6 (ner_t - pi_{t+1} + p_f) + \beta_7 yf + \beta_{10} g_{t-1} + \upsilon_{1t} \quad (16)$$

$$pi_t = \beta_3 pi_{t+1} + (1-\beta_3) pi_{t-1} + \beta_4 y_{t-1} - \beta_5 (po_t + (ner_{t+1} - ner_{t-1})) - \beta_8 ner + \beta_9 ms_t + v_{2t} \quad (17)$$

$$i_t = \alpha_1 mpr_{t-1} + (1-\alpha_1)\left[ie + pi_{t+1} + \alpha_2 pi + \varpi_1 y + \varpi_2 ner_t\right] + \upsilon_{3t} \quad (18)$$

$$\mathrm{g}_t = \rho_1 \mathrm{g}_{t-1} + (1-\rho_1)\mathrm{g}_{t+1} - \rho_2 ner_t + \rho_3 y_t + \rho_4 p_o + \rho_5 pi + \upsilon_{4t} \quad (19)$$

$$ner_t = \tau_1 ner_{t+1} + \tau_2 y_t - \tau_3 res_t - \tau_4 (i - rsf) + \upsilon_{5t} \quad (20)$$

$$p_{ft} = \tau_6 p_{ft-1} + \upsilon_{6t} \quad (21)$$

$$\mathrm{rsf}_t = \tau_7 rsf_{t-1} + \upsilon_{7t} \quad (22)$$

$$po_t = \tau_8 po_{t-1} + \upsilon_{8t} \quad (23)$$

$$ms_t = \tau_{10} ms_{t-1} + \upsilon_{9t} \quad (24)$$

$$yf_t = \tau_{11} yf_{t-1} + \upsilon_{10t} \quad (25)$$

$$ie_t = \tau_{12} ie_{t-1} + \upsilon_{11t} \quad (26)$$

$$res_t = \tau_{13} res_{t-1} + \upsilon_{12t} \quad (27)$$

$$mpr_t = \tau_{14} mpr_{t-1} + \upsilon_{13t} \quad (28)$$

Where y_t represents the output gap in period *t*; *yf* is the foreign output gap in period *t; ms_t* is money stock in period *t*, *pf* captures foreign price level in period *t; ner_t* is the nominal exchange rate in period *t; pi_t* represents inflation rate in period *t*; i is the domestic maximum lending rate in period t; rsf is the foreign short-term interest rate in period *t*; po_t represents crude oil price (bonny light) in period *t*; *res* represents the foreign exchange reserves at period t, *t-i* represents the lagged of relevant variables; *t+i* stands for the lead of relevant variables; and $\beta, \alpha, \rho, \varpi, \mu$ are all parameters to be estimated

Equation 16 specifies the aggregate demand function as an enriched version of the standard new-Keynesian Euler equation for consumption, which is theoretically linked to household utility optimization. The output gap is considered to have both backward and forward looking components. The lag (yg_{t-1}) and lead (yg_{t+1}) of output gap capture the level of habit formation in the economy. The inclusion of real interest rate is to reflect the role of financial wealth itself as a driver of the business cycle. Nigeria is a small open economy and, consequently, the real exchange rate is included to define degree of openness and the pass-through effect on the output gap through the prices of imports and exports. Foreign output gap (*yf*) is added as a determinant of export demand.

Equation 17 is a modified new Keynesian Philips curve capturing the aggregate supply in the economy. The equation shows that inflation rate is influenced not only by past inflation but also by future inflation, demand pressures, naira price of oil, nominal exchange rate and money supply. The inclusion of the backward component of the output gap reflects the short-run trade-off between output and inflation (sacrifice ratio). The inclusion of the exchange rate attempts to capture the exchange rate pass-through to domestic prices due to the openness of the economy. In order to reflect the peculiarities of Nigeria as an oil-exporting and import-dependent economy, domestic inflation is modeled to also depend on oil price. Money supply is introduced to anchor the role of money in driving domestic prices in Nigeria.

Equation 18 is the monetary policy rule of the central bank and is specified as a modified Taylor's rule. From the equation, monetary authorities react immediately to the changes in the nominal exchange rate, inflation and output gaps. In Nigeria, the central bank does not only want to stabilize inflation and output, but also to ensure that the exchange rate is stable within a band. Theoretically, Svensson (2000) shows that exchange rate affects consumer prices directly via the domestic currency price of imported final goods and indirectly through imported intermediate goods, which will eventually affect the cost of domestically produced goods. Consequently, stabilizing the exchange rate becomes critical in ensuring price stability.

The equation also includes a policy neutral rate (equilibrium interest rate plus the expected inflation). The coefficient $\left(1-\alpha_1\right)$ is the smoothing parameter that tells how central banks smooth interest rates to maintain financial stability (Cukierman (1992)), to improve on credibility by minimizing policy reversal (Goodhart (1999)) or reflect central bank's cautious attitude to information and model uncertainty (Clarida, Gali, and Gertler (1999)).

Equation 19 specifies the expenditure function of the government, which is determined by its own lead and lag values, nominal exchange rate, the output gap, the price of oil and domestic inflation. The coefficient of the past and future values ($\rho+\left(1-\rho_1\right)=1$) attempts to capture the persistence in expenditure, while the inclusion of the nominal exchange rate is the constraint imposed by the naira value of the exchange rate given the dependency of the budget on oil revenue. Evidence point out that government expenditure is highly correlated with the international price of oil in Nigeria (Sanusi, 2011). Thus, the international price of oil is an important variable in the budget constraint of the government. The coefficient of the output gap indicates how much preference the government reveals for output stabilization contemporaneously, while that of inflation measures the variability of expenditure subject to changes in domestic inflation.
Equation 20 is the uncovered interest rate parity (UIP) for an open economy, like Nigeria. Given the degree of openness of the Nigerian economy, it is plausible to assume that interest rate parity condition holds in Nigeria. Thus, nominal exchange rate depends on its own lead values. Reserves and interest rate differential are included in the equation to measure the effect of the country risk premium on the exchange rate. These variables also measure foreign investors' perception about the Nigerian economy (Garcia, 2010). Output gap measures the impact of output expansion in the tradable sectors of the economy on nominal exchange rate. Hitherto, fluctuations in the naira exchange rate have been associated with the Dutch disease syndrome.

Equations 21, 22, 23, 24, 25, 26 and 27 are foreign price (US CPI), foreign interest rate (US short term deposit rate), oil price, money supply, foreign output gap, equilibrium interest rate and reserves, respectively. These variables are exogenously determined but are assumed to be generated by an autoregressive process of order 1 (AR,1).

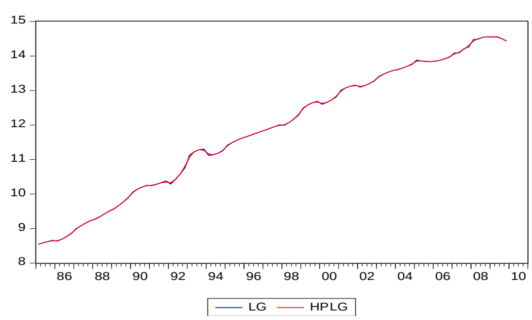
Chapter Six
Confronting The Model With The Data

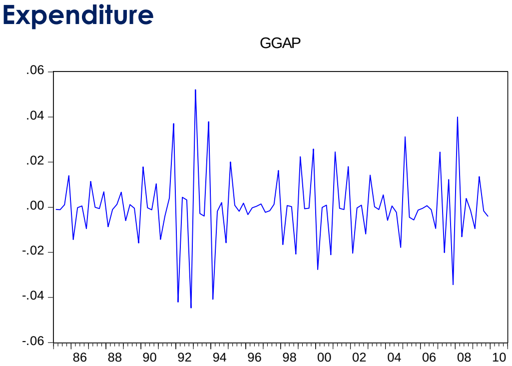
6.1 Data

In the estimation of the model parameters, quarterly data spanning 1985:Q1 to 2009:Q4 is employed on twelve macroeconomic indicators: domestic output (y); foreign output, proxied by the US GDP (yf); domestic headline inflation (pi); domestic interest rate (i); total government expenditure (g); nominal exchange rate (ner); price of oil, bonny light (po); external reserves (res); foreign prices, proxied by the US inflation (pf); foreign interest rate (rsf); broad money supply (m2); and monetary policy rate (mpr).

Given that the model is estimated in gap form, the gap variables are derived by taking the difference of the log of the actual and equilibrium values as shown in Figures 6.1-6.12. Before proceeding with the estimation, data was pre-processed to clean out the data and eliminate all sources of noise including outliers and trend non-stationary in the series. This is necessary to ensure that the model converges around the steady state. A Hodrick Prescott (1997) filter[2] was used to de-trend the series and derive equilibrium values which allows for additional constraints to be added to the minimization problem. Ultimately, this transformation of the data permits the resulting equilibrium value not to converge to the actual observed data at the end of the sample period.

Figure 6.1: Log of Actual and Potential, and the Gap of Government Expenditure





[2] Empirically, through an iterative process, this study found that a λ =1600 is not an appropriate smoothing parameter for Nigerian data, hence, a λ =0.25 performed better.

Figure 6.2: Log of Actual and Potential, and the Gap of Output

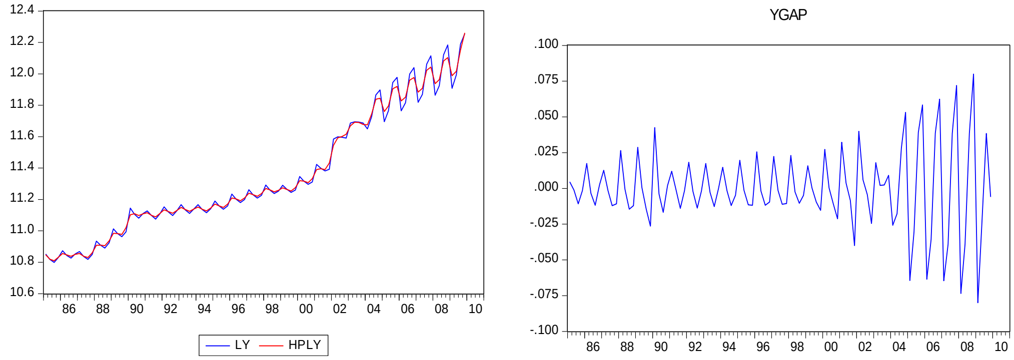


Figure 6.3: Log of Actual and Potential, and the Gap of External Reserves

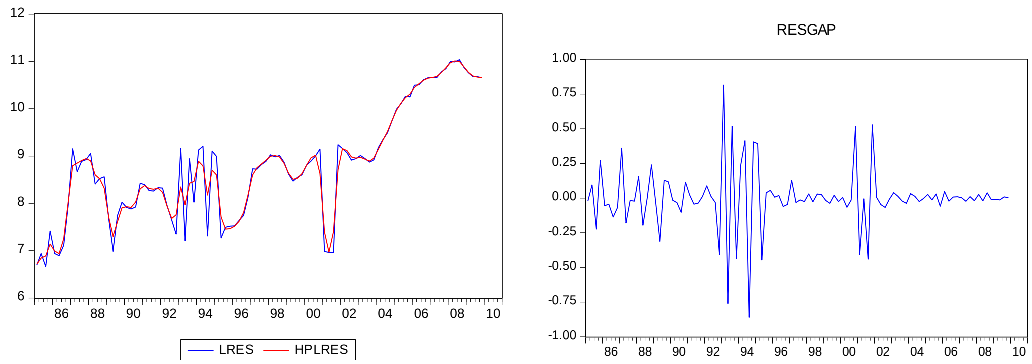


Figure 6.4: Actual and Equilibrium, and the Gap of Nominal Interest Rate

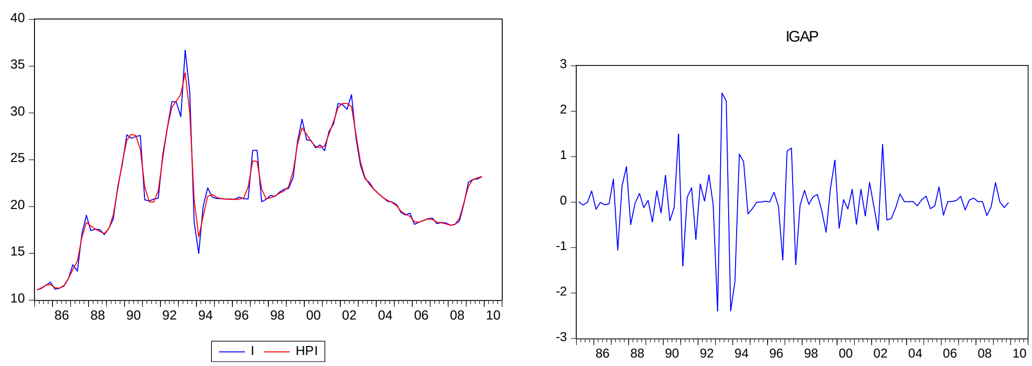


Figure 6.5: Log of Actual and Equilibrium, and the Gap of Broad Money Supply

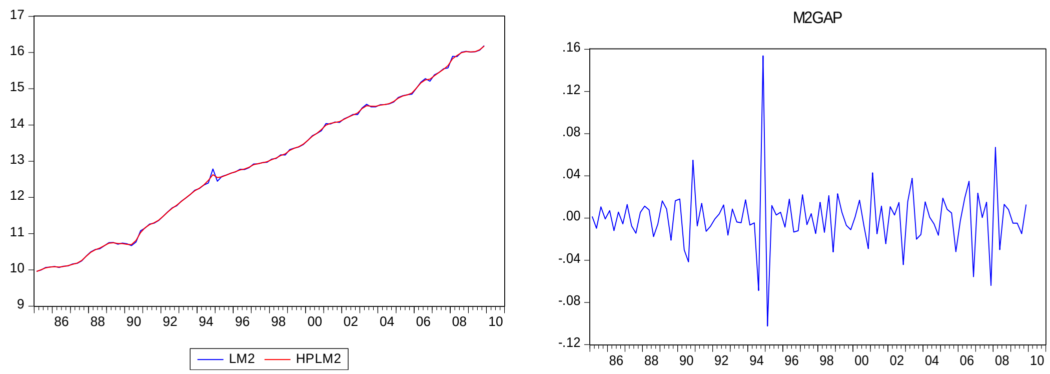


Figure 6.6: Log of Actual and Potential, and the Gap of Nominal Exchange Rate

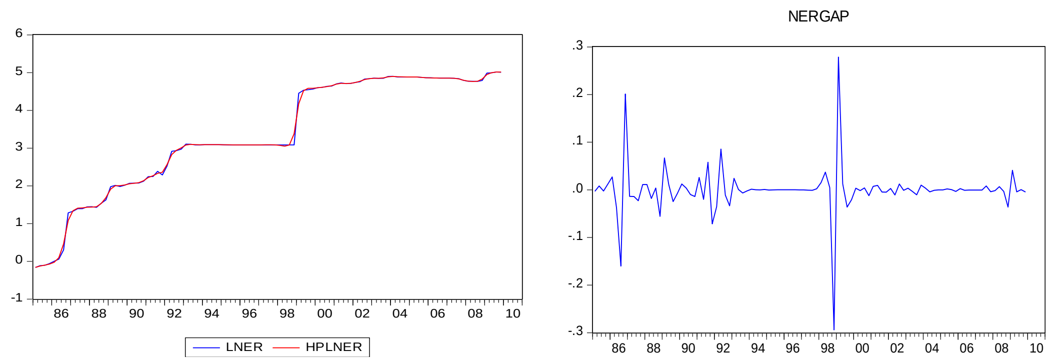


Figure 6.7: Log of Actual and Equilibrium, and the Gap of Foreign Output (USGDP)

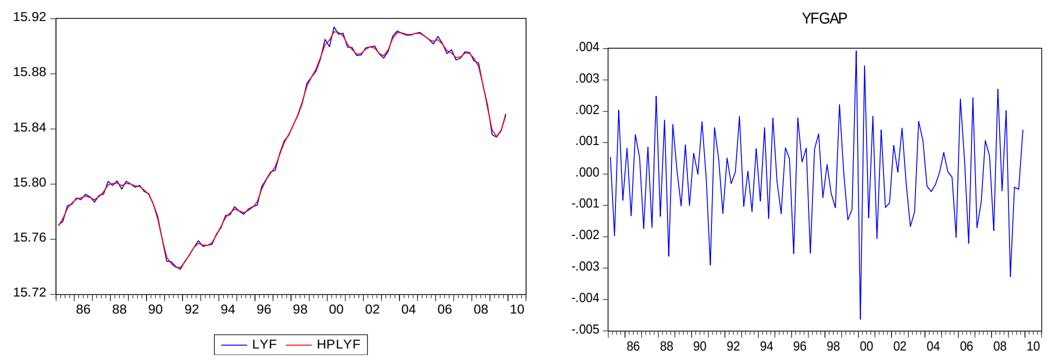


Figure 6.8: Actual and Equilibrium, and the Gap of Inflation Rate

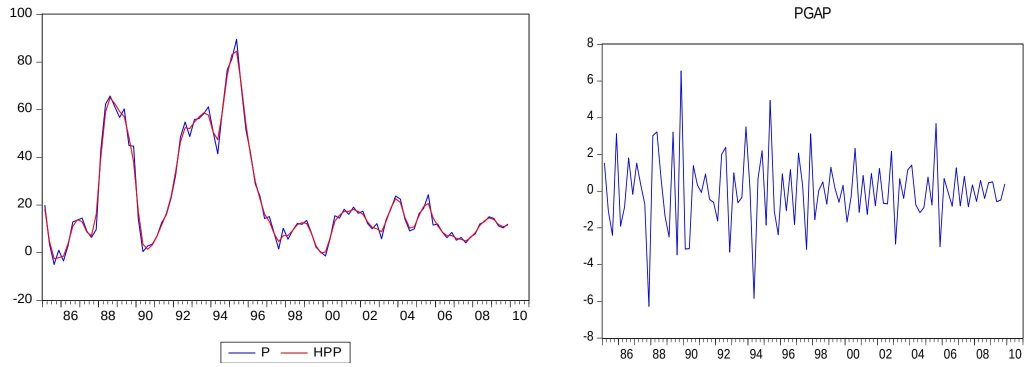


Figure 6.9: Actual and Potential, and the Gap of Monetary Policy Rate (MPR)

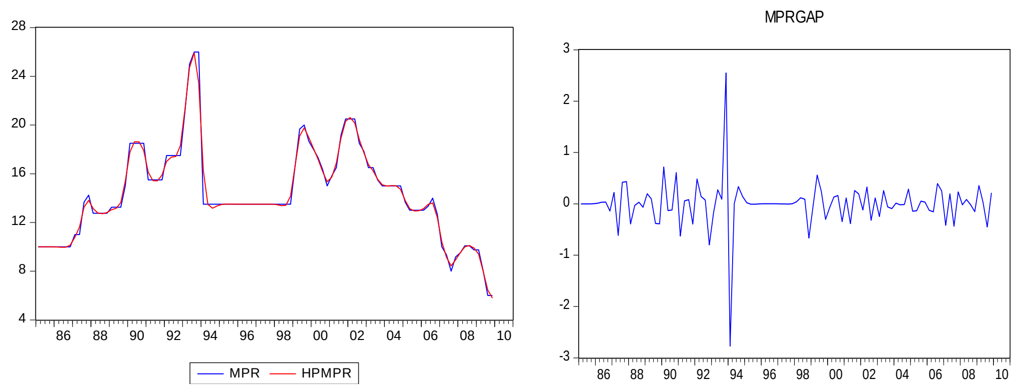


Figure 6.10: Actual and Potential Foreign, and the Gap of Interest Rate

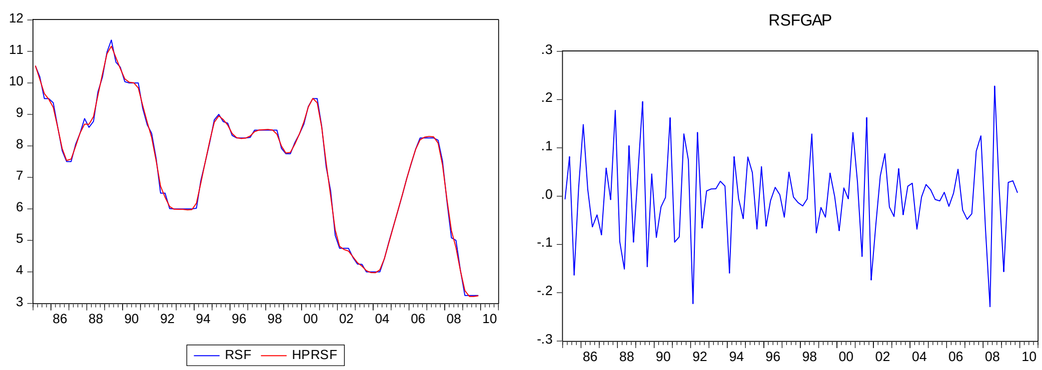


Figure 6.11: Actual and Equilibrium, and the Gap of Oil Price

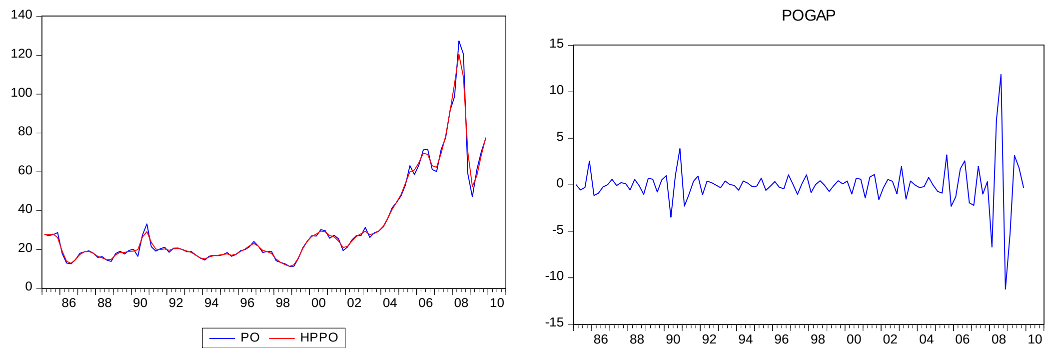
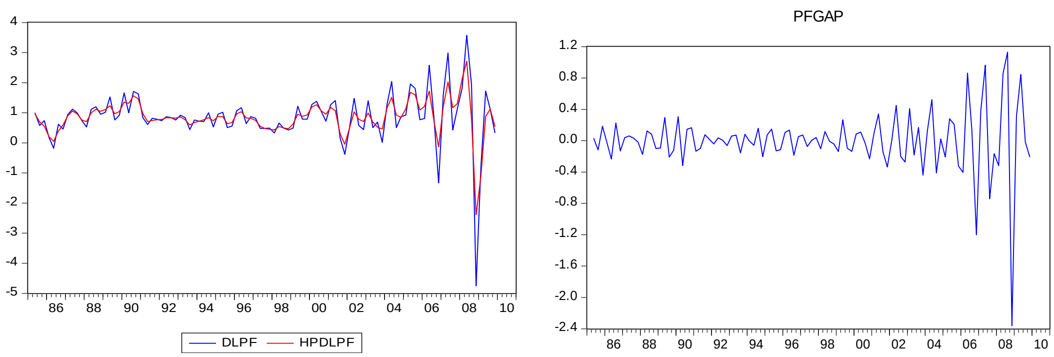


Figure 6.12: Actual and Potential, and the Gap of Foreign Prices



6.2 Calibration

6.3 Prior

According to the Schorfiede (2000), priors can be gleaned from personal introspection to reflect strongly held beliefs about the validity of economic theories. Priors also reflect researcher confidence about the likely location of structural parameter of the model. In practice, priors are chosen based on observation, facts and from existing empirical literature. In that regard

Table 6.1: Prior of the Estimated Parameters

Parameter	Description	Density	Mean	Std Deviation
β_1	Measures output gap persistence	Beta	0.20	0.0500
β_2	Marginal condition index	gamma	0.40	0.0500
β_3	Inflation expectation	Beta	0.30	0.0500
$1-\beta_3$	Measures Inflation persistence	Beta	0.30	0.0500
β_4	Measures sacrifice ratio	Beta	0.30	0.0500
β_5	Measures impact of oil price (bonny light) on inflation	gamma	0.20	0.0500
β_6	Measures marginal condition index	gamma	0.25	0.0500
β_7	Measures the impact of foreign demand on domestic output	Beta	0.50	0.0500
β_8	Measures exchange rate pass-through to price	Beta	0.25	0.0500
β_9	Measures the impact of money supply on output	gamma	0.50	0.0500
β_{10}	Measures impact of government expenditure on output	gamma	0.20	0.0500
α_1	Measures policy persistence	Beta	0.20	0.0500
α_2	Measures the weight put on inflation by policy makers	Beta	1.50	0.0500
ϖ_1	Measures the weight put on output gap by policy makers	gamma	0.50	0.0500
ϖ_2	Measures the weight put on exchange rate by policy makers	gamma	0.25	0.0500
ρ_1	Measures government expenditure persistence	gamma	1.00	0.1300
ρ_2	Measures impact of exchange rate on government expenditure	gamma	0.30	0.0120
ρ_3	Measures impact of output gap on government expenditure	gamma	0.25	0.2300
ρ_4	Measures impact of oil price on government expenditure	gamma	0.20	0.0120
ρ_5	Measures impact of inflation on government expenditure	gamma	0.30	0.2300
τ_1	Measures exchange rate expectation	gamma	0.50	0.0500

τ_2	Measures the impact of output gap on nominal exchange rate	gamma	0.20	0.0500
τ_3	Measures the impact of external reserves on nominal exchange rate	gamma	0.20	0.0500
τ_4	Measures the impact of interest rate differential on nominal exchange rate	gamma	0.50	0.0500
τ_6	Measures the AR(1) of foreign (USA) price	gamma	0.40	0.0500
τ_7	Measures the AR(1) of foreign interest rate	gamma	0.50	0.0500
τ_8	Measures the AR(1) of oil price	Beta	0.45	0.0500
τ_{10}	Measures the AR(1) of money supply	Beta	0.55	0.0500
τ_{11}	Measures the AR(1) of US GDP	Beta	0.60	0.0500
τ_{12}	Measures the AR(1) of equilibrium interest rate	gamma	0.50	0.0500
τ_{13}	Measures the AR(1) of external reserves	gamma	0.60	0.0500
τ_{14}	Measures the AR(1) of monetary policy rate	gamma	0.50	0.0500

The main challenge of finding the parameter's prior for the estimation exercise is the lack of published studies that use a DSGE modelling framework involving Nigeria's data that can serve as a reference. There are only two known published study that applies this modeling framework to the Nigeria's data – Garcia (2010) and Adebiyi and Mordi (2010). Both authors estimated small open economy DSGE model for Nigeria using Bayesian estimation technique. The information from these estimates is useful in guiding us to set the priors for most of the parameters in this exercise (Table 6.1).

6.4 Posterior Estimates

Following the Bayesian estimation technique, which combines the suitable priors with the likelihood, we obtained an analytically-intractable posterior density. In order to sample from the posterior, random walk MH algorithm is used to generate 150,000 draws from the posteriors. The Estimation results are reported in Table 6.2 showing the distribution used, the prior mean, the prior standard deviation, and the confidence interval.

Table 6.2: Prior and Posterior Estimates of Parameters

Parameter	Density	Prior Mean	Posterior Mean	Standard Deviation	Confidence Interval at 90%	
β_1	Beta	0.20	0.06	0.05	0.05	0.07
β_2	Gamma	0.40	0.43	0.05	0.41	0.45
β_3	Beta	0.30	0.38	0.05	0.36	0.41
β_4	Beta	0.30	0.32	0.05	0.31	0.33
β_5	Gamma	0.20	0.32	0.05	0.30	0.34
β_6	Gamma	0.25	0.28	0.05	0.27	0.30
β_7	Beta	0.50	0.46	0.05	0.44	0.47
β_8	Beta	0.25	0.25	0.05	0.24	0.26
β_9	Gamma	0.50	0.42	0.05	0.40	0.44
β_{10}	Gamma	0.20	0.11	0.05	0.10	0.12
α_1	Beta	0.20	0.43	0.05	0.39	0.48
α_2	Beta	1.50	1.45	0.05	1.44	1.46
ϖ_1	Gamma	0.50	0.53	0.05	0.53	0.54
ϖ_2	Gamma	0.25	0.28	0.05	0.26	0.30
ρ_1	Gamma	1.00	1.25	0.13	1.21	1.32
ρ_2	Gamma	0.30	0.31	0.01	0.31	0.32
ρ_3	Gamma	0.25	0.02	0.23	0.00	0.04
ρ_4	Gamma	0.20	0.21	0.01	0.21	0.21
ρ_5	Gamma	0.30	0.03	0.23	0.00	0.06
τ_1	Gamma	0.50	0.53	0.05	0.51	0.54
τ_2	Gamma	0.20	0.08	0.05	0.07	0.09
τ_3	Gamma	0.20	0.21	0.05	0.18	0.24
τ_4	Gamma	0.50	0.54	0.05	0.52	0.56
τ_6	Gamma	0.40	0.37	0.05	0.34	0.39
τ_7	Gamma	0.50	0.46	0.05	0.44	0.48
τ_8	Beta	0.45	0.43	0.05	0.41	0.45

τ_{10}	Beta	0.55	0.52	0.05	0.50	0.53
τ_{11}	Beta	0.60	0.57	0.05	0.56	0.58
τ_{12}	Gamma	0.50	0.50	0.05	0.48	0.53
τ_{13}	Gamma	0.60	0.70	0.05	0.69	0.72
τ_{14}	Gamma	0.50	0.40	0.05	0.38	0.42

* Metropolis-Hastings sampling algorithm based on 150000 draws with 63% acceptation rate.

Table 6.14 reveals that the data is informative as the posterior means are different from the prior means. Starting with the output gap equation, the habit parameter ($1-\beta_1$), which is estimated to be 0.94 is higher than the assumed prior mean of 0.8 and higher than the value of 0.72 obtained by Adebiyi and Mordi (2010). The estimate obtained appears to be highly data driven, indicating a quite high persistence of Nigerian households' consumption. The posteriors of the parameters of output gap are quite distinct from the assumed priors, indicating that the estimates draw important information from the data.

In the hybrid Phillip equation, the prior and posterior estimations show that the data provide useful information in explaining inflation behavior in Nigeria. The behavior of the economy depends critically on the value of β_3. The posterior estimates of Calvo price stickiness provide reasonable notion about frequencies of price change which is the probability of not changing price in a given quarters. The estimated values of $\beta_3 = 0.38$ for forward-looking and $[1-\beta_3] = 0.62$ for backward-looking indicates the proportion of firms that do not re-optimize their prices in a given quarters. Also, relatively lower value of $\beta_3 = 0.38$ shows domestic firms re-optimize their prices in every two quarters. These staggered price coefficients imply that the average duration of price contracts is around two quarters[3]. This finding is consistent with 0.382 obtained by Adebiyi and Mordi (2010) and the 0.57 obtained by Garcia (2009). It also establishes the hypothesis that the values of forward-looking inflation expectation must be significantly below 0.50 to produce results that is consistent with data (Berg, Karam and Laxton, 2006).

[3] This is obtained as $\dfrac{1}{1-\beta_3}$

For monetary policy to have an impact on inflation, the coefficients on the output and exchange rate gaps must be greater than zero. This assertion is established with the coefficients of output (β_2 = 0.43) and exchange rate (β_8 = 0.25) and this gives the CBN an important tool to control inflation through output gap. Also, the impact of the exchange rate on prices (β_8 = 0.25) indicating that the exchange rate pass-through into consumer prices is 25 per cent, which is very high.

Oil price has significant impact on inflation with a posterior value of β_5 = 0.32, which is greater than the prior values of 0.20. It implies that a 1 percent increase in oil price would lead to 0.32 percent rise in inflation rate the following period. The output cost of disinflation, which is the sacrifice ratio, estimated to be is 1.32[4].

The literature on interest rate parity reveals that more robust policies should assume a much smaller value of μ_1 (below 0.5), because it might be imprudent to rely so heavily on these forward-looking linkages in the face of uncertainty (Isard and Laxton, 1998; Berg, Karam and Laxton, 2006). The estimated coefficient in Table 6.14 (μ_1 = 0.284) satisfies this requirement.

The posterior estimates of the Central Bank of Nigeria monetary policy reaction function provide a reasonable description of monetary policy design in Nigeria during the sample period. Using the Taylor-type monetary policy reaction function as a benchmark, the monetary authority follows an active monetary policy (α_2 = 1.45) and demonstrates some concerns for output gap (ϖ_1 = 0.53) and exchange rate gap (ϖ_2 =0.28). The estimated values of monetary policy reaction function are approximately close to Taylor rule, which is an indication that monetary policy rule in Nigeria appears to follow Taylor-type. It also reveals that in the long run, central bank is more concern with output stabilization compared with price stability.

The posterior mean of exchange rate (ϖ_2) 0.28 is higher than its prior mean, which implies that the model does not totally pin down the data. It also indicates that monetary authority takes cognizance of exchange rate behaviour when

[4] Sacrifice ratio is defined as the cumulative output losses associated with a permanent one percentage point decline in inflation. This is obtained by summing up the lag ($[1-\beta_3] = 0.62$), and lead (β_3 = 0.28) terms of inflation and the coefficient on the output gap (β_4 =0.32)

determining the monetary policy rate. For example, if nominal exchange rate is appreciated by 1 per cent, maximum interest rate will decline by 0.28 percentage point.

The posterior estimate on the lag of interest rate parameter (α_1) is 0.43 higher than the prior of 0.20 indicating a smoothing path for the short-term interest rate. However, this estimate is lower than 0.623 obtained by Adebiyi and Mordi (2010). The overall results of reaction function show the effectiveness of monetary policy design in Nigeria with price stability as its primary objective consistent with the economic growth objectives.

With regards to the persistence parameters of the AR(1) process, all of the parameters, except the parameter of equilibrium interest rate (ie), show a posterior mean smaller than the mean of the prior. This indicates that the persistence of the shocks are smaller than our prior beliefs.

Turning to the estimated standard deviations, it is possible to conclude that the most volatile shock considered in the model is the equilibrium exchange rate (ie) (16.53), while the least volatile are foreign output (US GDP) (0.00) and broad money supply (m2) (0.03). For most of these parameters results seem to be driven to a reasonable extent by the data.

6.5 Viability of the Estimation

Statistical integrity of the maximum likelihood and the Bayesian estimation procedures and results is examined using a set of visual diagnostic tests. Figure 6.13 illustrates the historical and smoothed variables and shocks for each model. The horizontal axis in each plot denotes the length of the sample period. Visual inspection supports the consistency of the expected path of the shocks with the realized estimates of the innovations indicated by the clustering of the smoothed shocks estimates around zero.

Figure 6.13: Historical and Smoothed Variables and Shocks

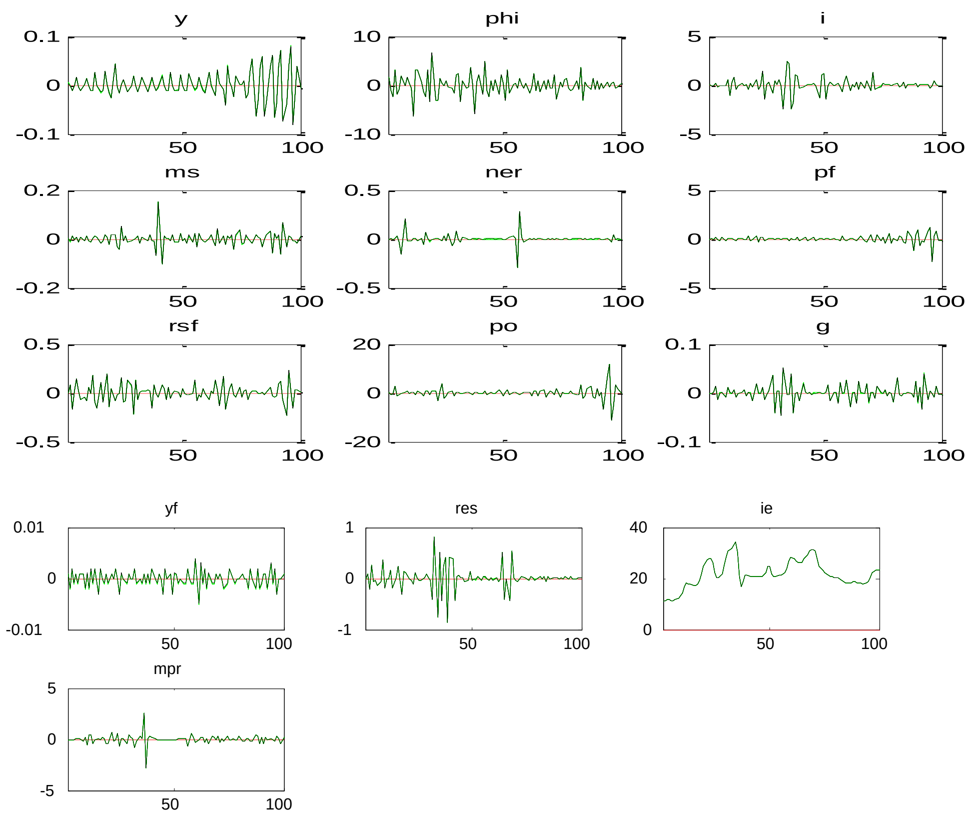
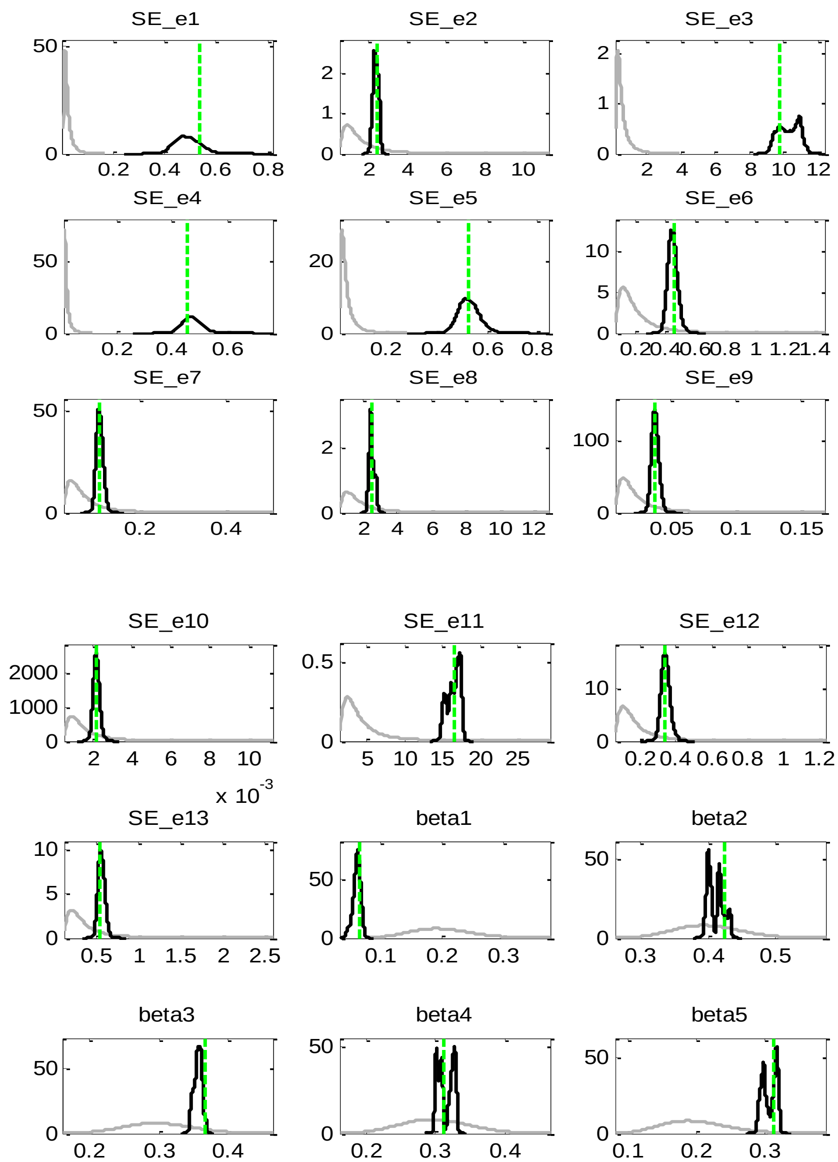
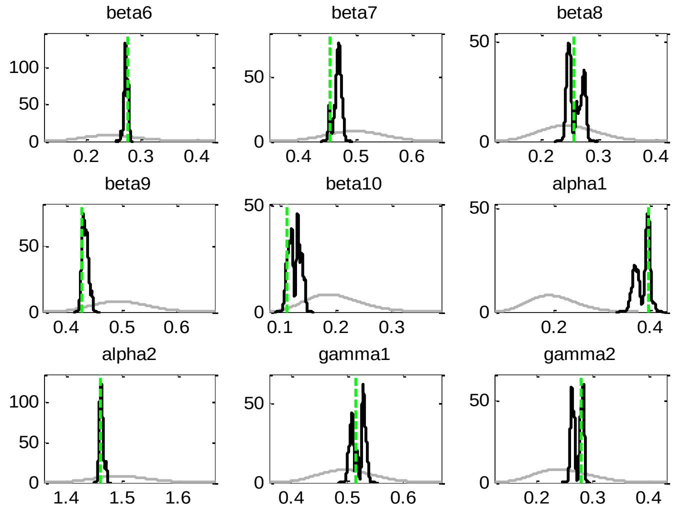
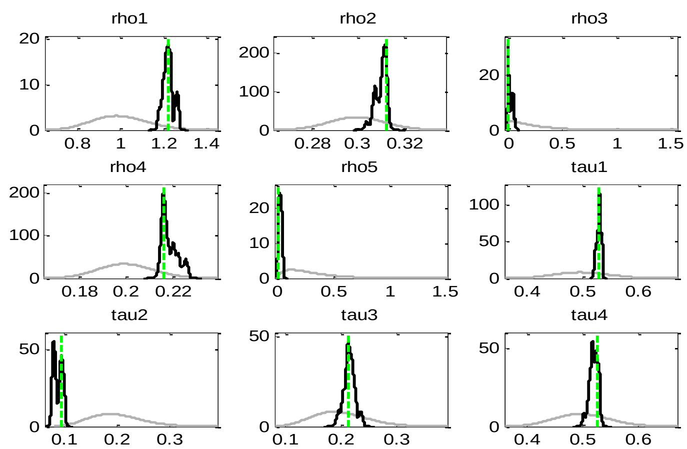


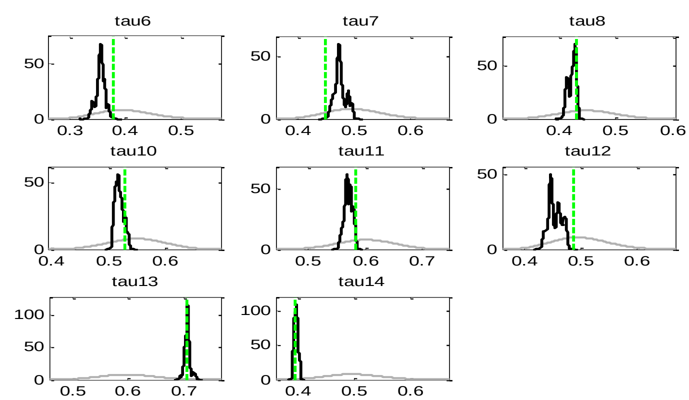
Figure 6.14 juxtaposes the prior (grey) and posterior (black) distributions for the parameters of the models. The vertical green line in each chart identifies the posterior mode from the numerical optimization simulations. With only a few exceptions, the optimization mode is usually similar to the posterior mode. This suggests that both the data and the selected priors are informative about the parameters, which in turn substantiates the plausibility of our estimates. In addition, excluding the uniform priors, the prior and posterior distributions are fairly close. The plotted posterior distributions do not appear to deviate substantially from normality.

Figure 6.14: Prior and Posterior Distributions



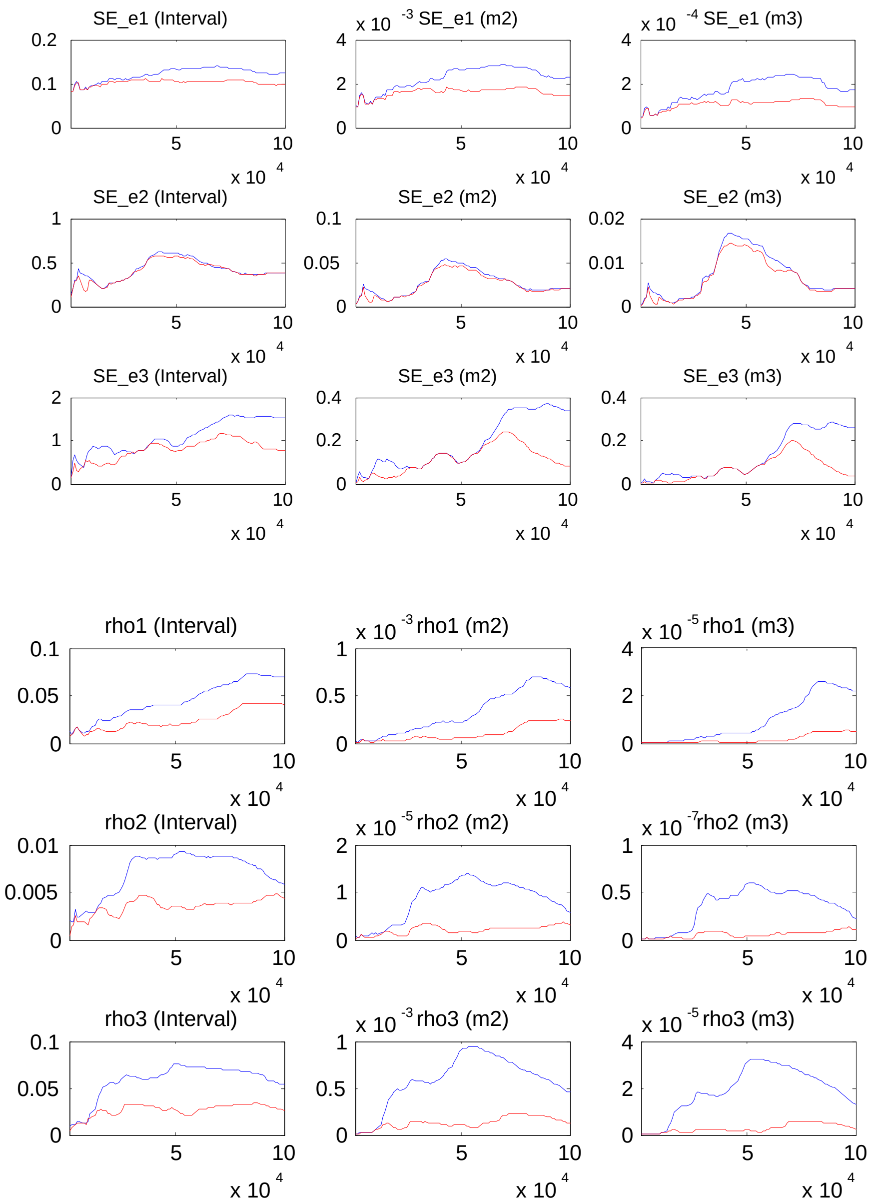

beta6
beta7
beta8
beta9
beta10
alpha1
alpha2
gamma1
gamma2

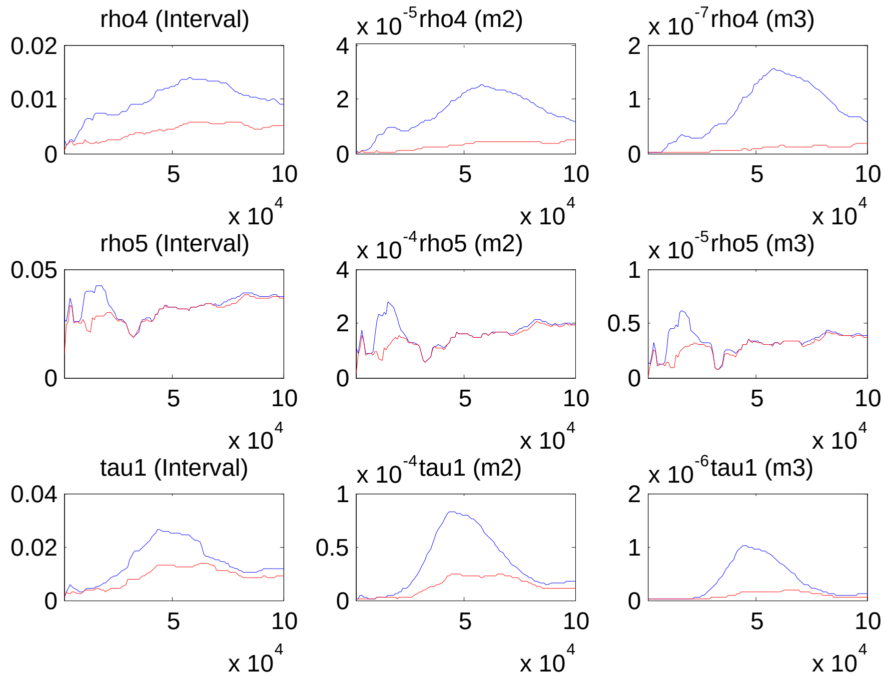

rho1
rho2
rho3
rho4
rho5
tau1
tau2
tau3
tau4

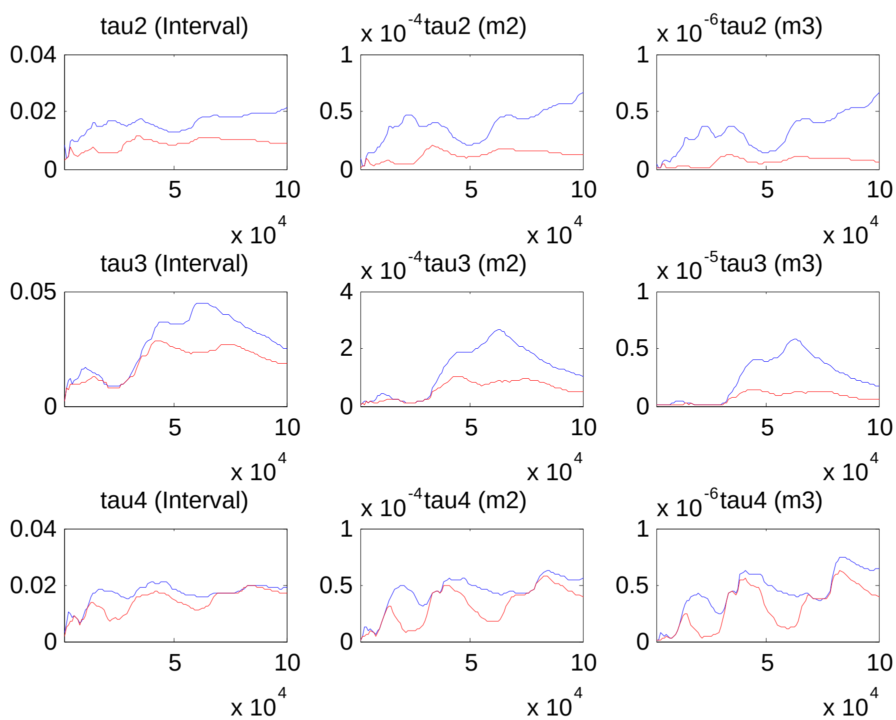

tau6
tau7
tau8
tau10
tau11
tau12
tau13
tau14

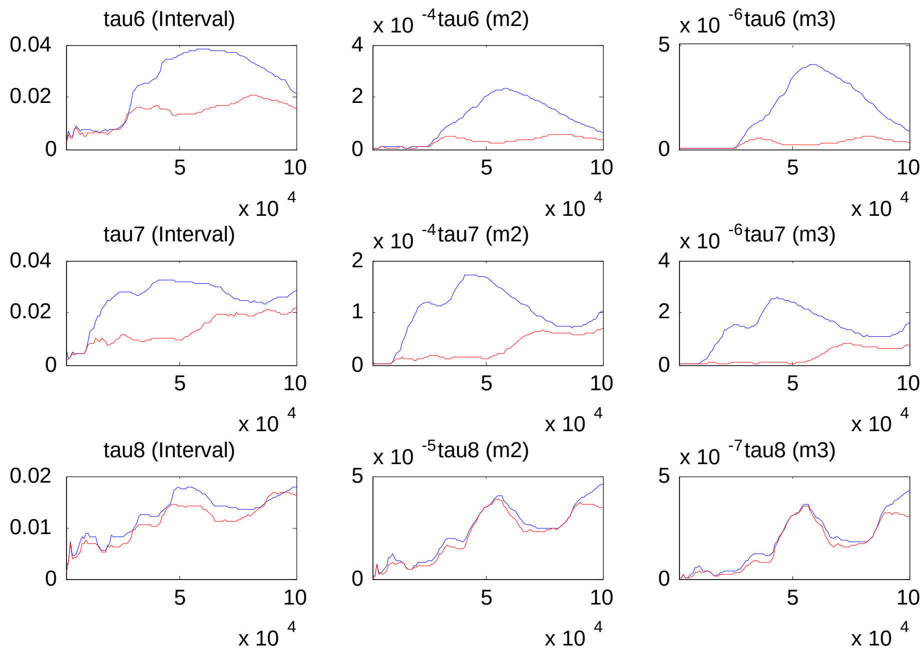
The sensibility of the MH simulations is investigated using the univariate Monte Carlo Markov Chain (MCMC) diagnostics test. Figure 6.15 display the univariate MCMC diagnostics for the coefficients of the models. The sensibility of the MH algorithm requires that the simulations are similar within and across the chains. Both lines should display little variability and eventually converge (Griffoli 2007). Figure 6.15 shows that the moments for all the parameters of the model seem stable and converge smoothly.

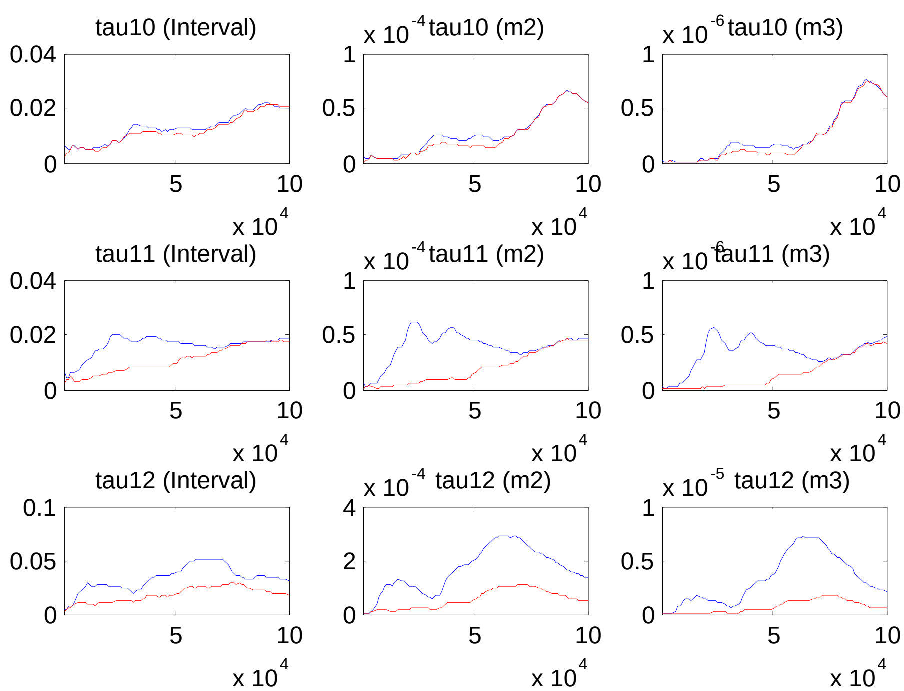
Figure 6.15: Univariate Diagnostics

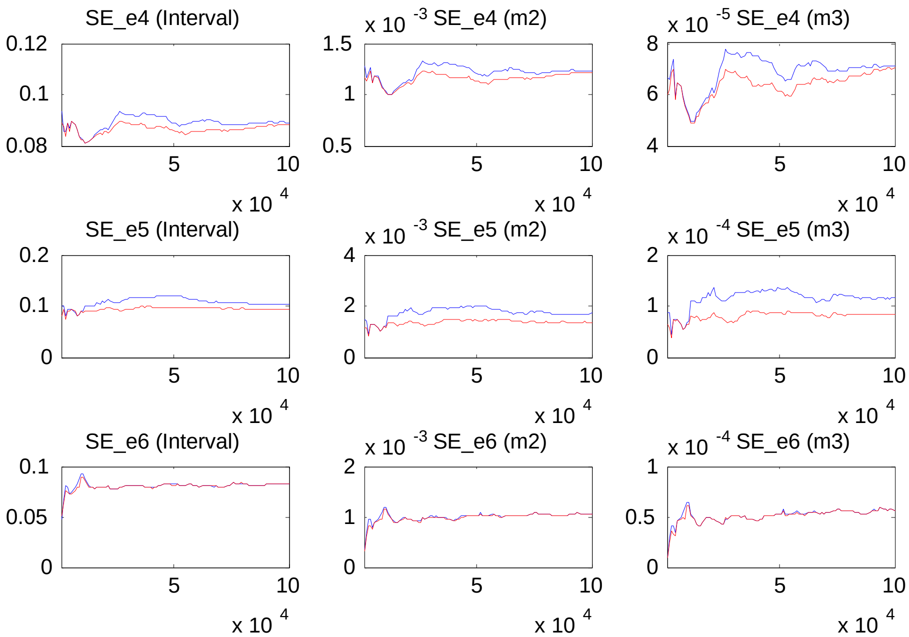


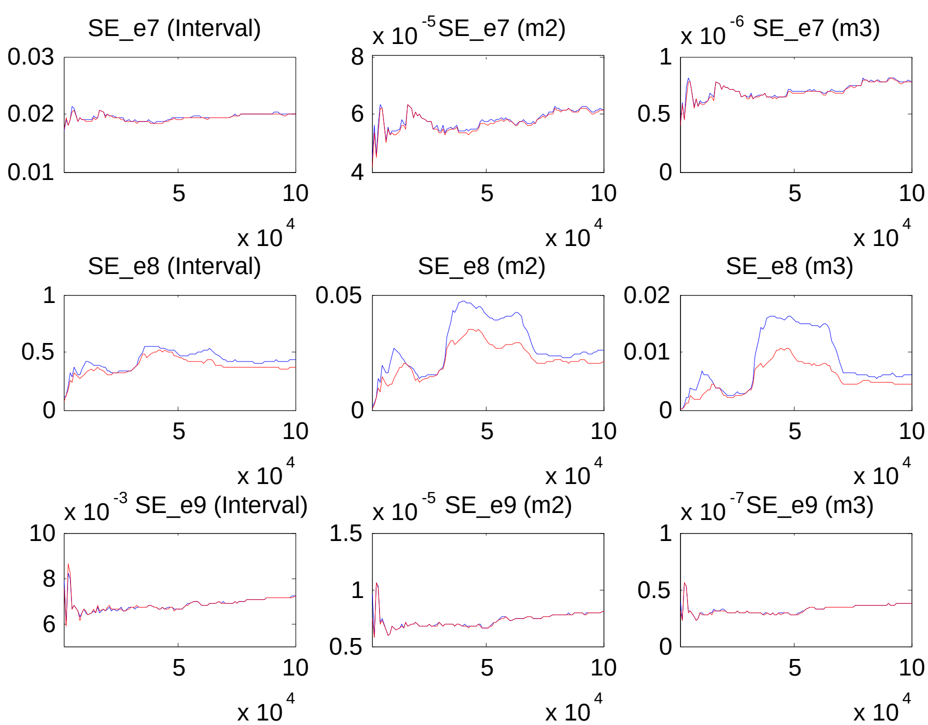

rho4 (Interval)
x 10^-5 rho4 (m2)
x 10^-7 rho4 (m3)
rho5 (Interval)
x 10^-4 rho5 (m2)
x 10^-5 rho5 (m3)
tau1 (Interval)
x 10^-4 tau1 (m2)
x 10^-6 tau1 (m3)
x 10^4

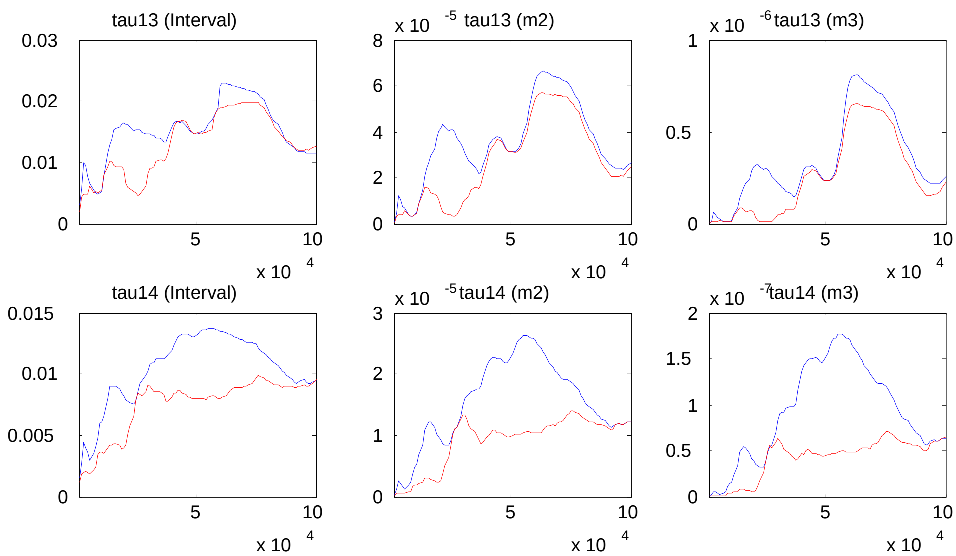

tau2 (Interval)
x 10^-4 tau2 (m2)
x 10^-6 tau2 (m3)
tau3 (Interval)
x 10^-4 tau3 (m2)
x 10^-5 tau3 (m3)
tau4 (Interval)
x 10^-4 tau4 (m2)
x 10^-6 tau4 (m3)
x 10^4

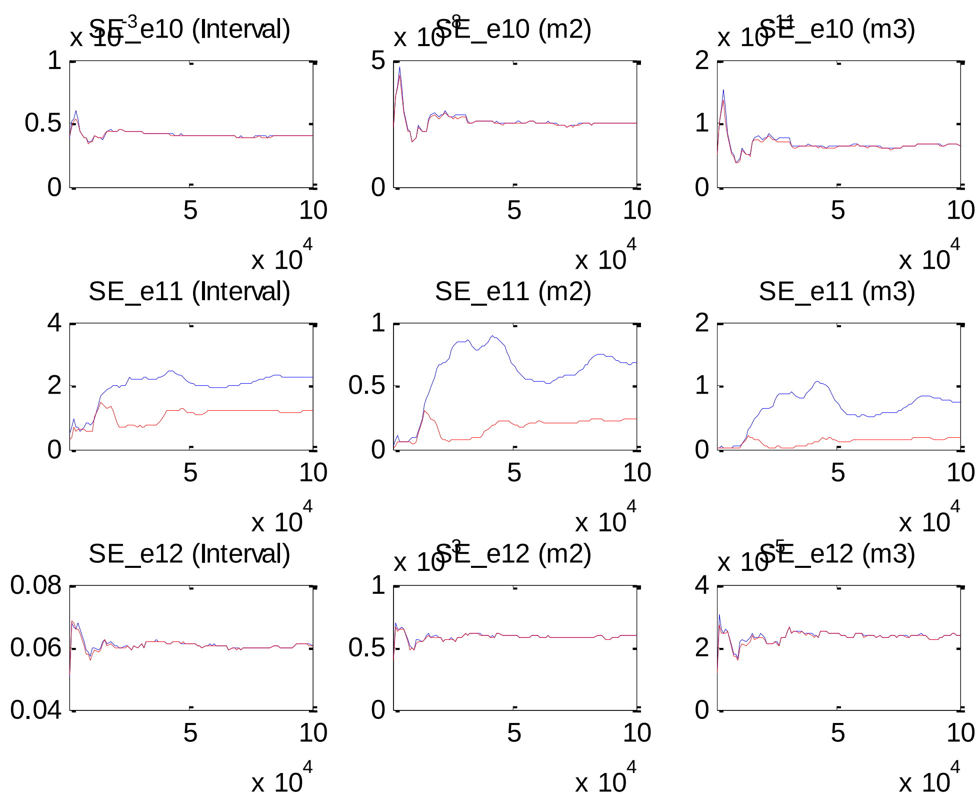

tau6 (Interval)
tau6 (m2)
tau6 (m3)
tau7 (Interval)
tau7 (m2)
tau7 (m3)
tau8 (Interval)
tau8 (m2)
tau8 (m3)

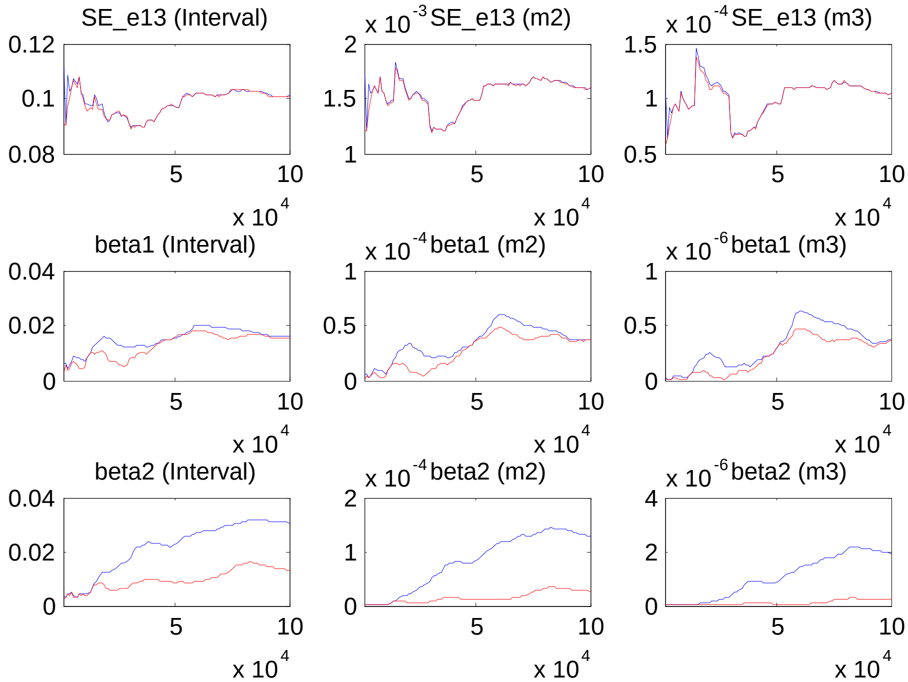

tau10 (Interval)
tau10 (m2)
tau10 (m3)
tau11 (Interval)
tau11 (m2)
tau11 (m3)
tau12 (Interval)
tau12 (m2)
tau12 (m3)

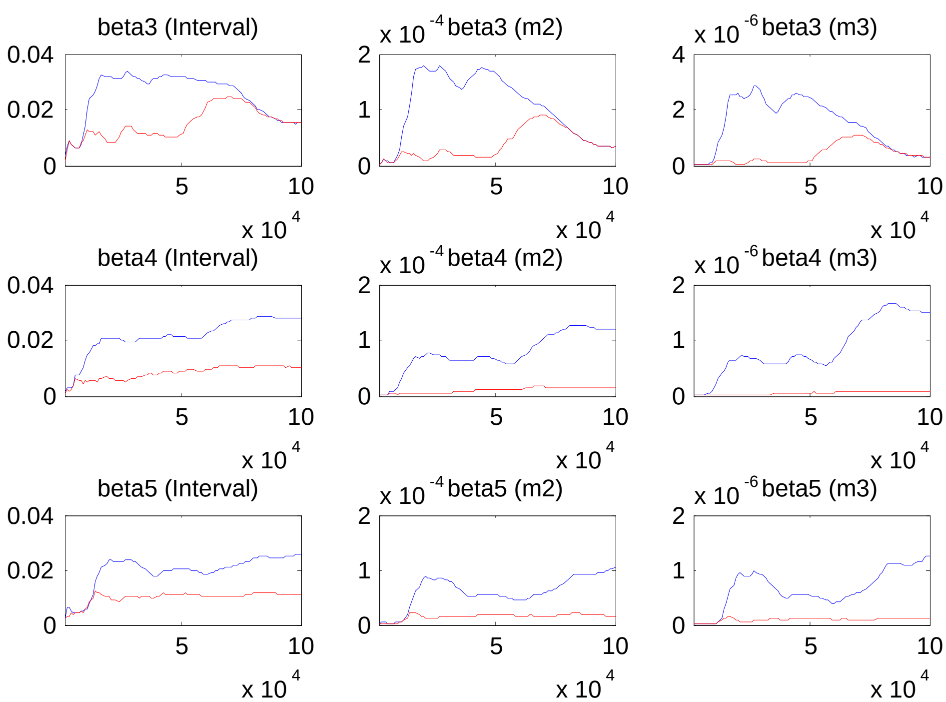

SE_e4 (Interval)
x 10 -3 SE_e4 (m2)
x 10 -5 SE_e4 (m3)
SE_e5 (Interval)
x 10 -3 SE_e5 (m2)
x 10 -4 SE_e5 (m3)
SE_e6 (Interval)
x 10 -3 SE_e6 (m2)
x 10 -4 SE_e6 (m3)
x 10 4

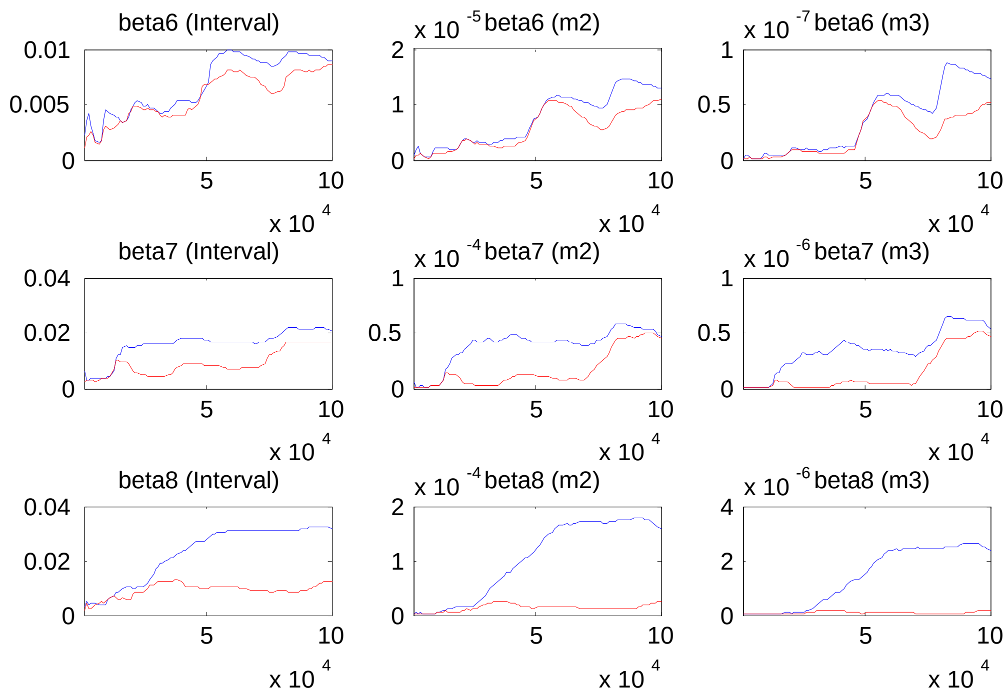

SE_e7 (Interval)
x 10 -5 SE_e7 (m2)
x 10 -6 SE_e7 (m3)
SE_e8 (Interval)
SE_e8 (m2)
SE_e8 (m3)
x 10 -3 SE_e9 (Interval)
x 10 -5 SE_e9 (m2)
x 10 -7 SE_e9 (m3)
x 10 4

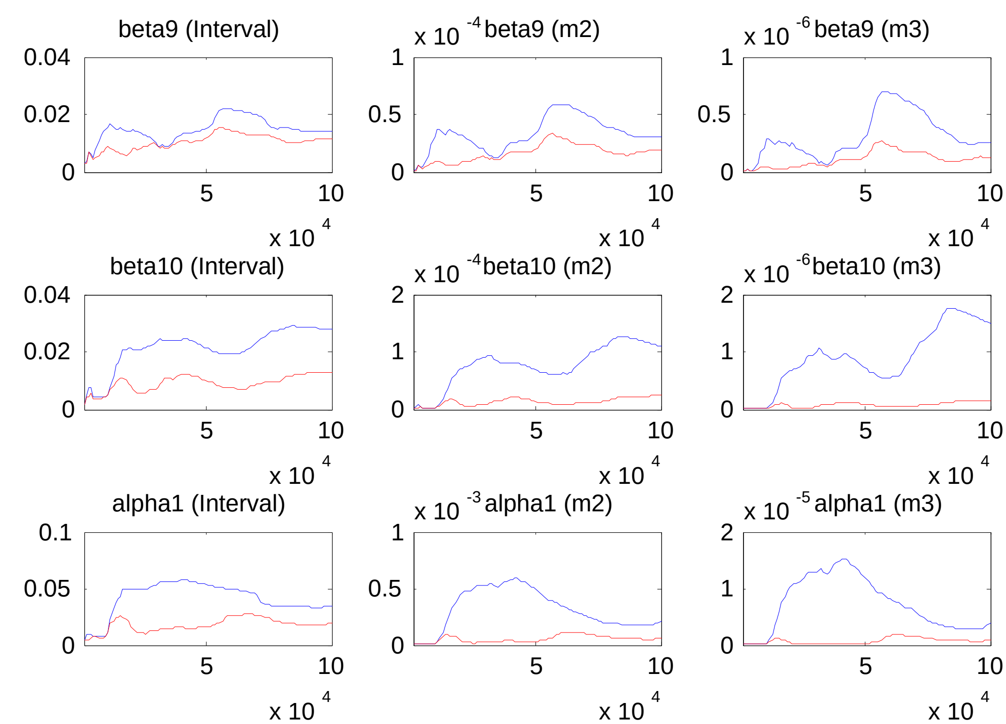

tau13 (Interval)
tau13 (m2)
tau13 (m3)
tau14 (Interval)
tau14 (m2)
tau14 (m3)

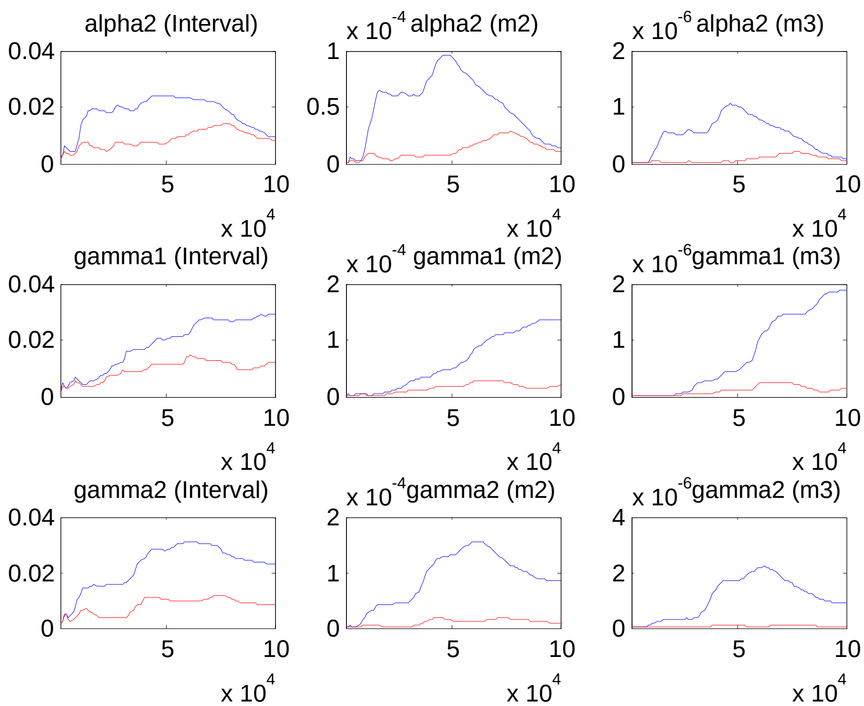

SE_e10 (Interval)
SE_e10 (m2)
SE_e10 (m3)
SE_e11 (Interval)
SE_e11 (m2)
SE_e11 (m3)
SE_e12 (Interval)
SE_e12 (m2)
SE_e12 (m3)


SE_e13 (Interval)
x 10^-3 SE_e13 (m2)
x 10^-4 SE_e13 (m3)
beta1 (Interval)
x 10^-4 beta1 (m2)
x 10^-6 beta1 (m3)
beta2 (Interval)
x 10^-4 beta2 (m2)
x 10^-6 beta2 (m3)


beta3 (Interval)
x 10^-4 beta3 (m2)
x 10^-6 beta3 (m3)
beta4 (Interval)
x 10^-4 beta4 (m2)
x 10^-6 beta4 (m3)
beta5 (Interval)
x 10^-4 beta5 (m2)
x 10^-6 beta5 (m3)

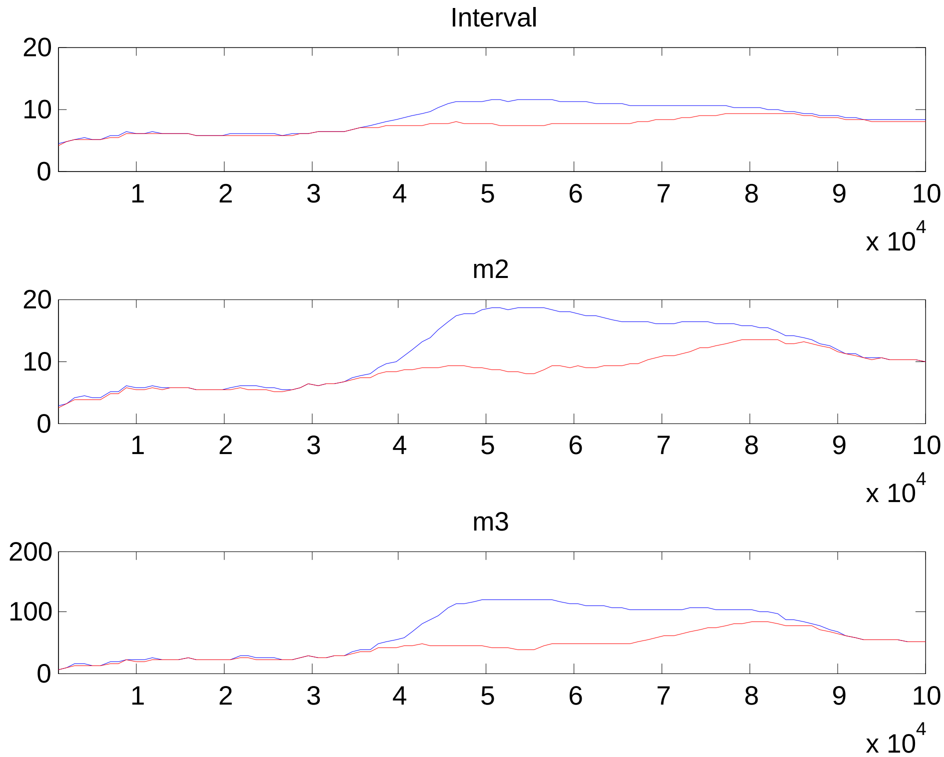

beta6 (Interval)
x 10 -5 beta6 (m2)
x 10 -7 beta6 (m3)
beta7 (Interval)
x 10 -4 beta7 (m2)
x 10 -6 beta7 (m3)
beta8 (Interval)
x 10 -4 beta8 (m2)
x 10 -6 beta8 (m3)
x 10 4


beta9 (Interval)
x 10 -4 beta9 (m2)
x 10 -6 beta9 (m3)
beta10 (Interval)
x 10 -4 beta10 (m2)
x 10 -6 beta10 (m3)
alpha1 (Interval)
x 10 -3 alpha1 (m2)
x 10 -5 alpha1 (m3)
x 10 4



The multivariate MCMC diagnostic tests are demonstrated in Figure 6.16. As for the MH sampling algorithm, a diagnosis of the overall convergence is summarised in three graphs, with each graph representing specific convergence measures and having two distinct lines that represent the results within and between chains. Those measures are related to the analysis of the parameters mean (interval), variance (m2) and third moment (m3). Convergence requires that both lines, for each of the three measures, become relatively constant and converge to each other. The chart supports the stability and convergence of the MH solver for all the models.

Figure 6.16: Multivariate Diagnostics



6.6 Sensitivity of the Results

To assess the sensitivity of the results to priors, changes were made in two ways and the model was re-estimated for each of the changes. Results concerning two particular cases are presented in Tables 6.3 and 6.4, for illustrative purposes. In scenario I, Table 6.4, all prior means and standard deviations were raised by 10 per cent. Comparing the obtained results with those of the benchmark model in Table 6.2, it is glaring that although estimates changed for the majority of the parameters, the change was not significant.

Table 6.3: Sensitivity Analysis: Increasing the Priors and Standard Deviation by 10%

Parameter	Density	Prior Mean	Posterior Mean	Standard Deviation	Confidence Interval at 90%	
β_1	beta	0.22	0.06	0.06	0.05	0.08
β_2	gamma	0.44	0.42	0.06	0.42	0.43
β_3	beta	0.33	0.37	0.06	0.36	0.38
β_4	beta	0.33	0.31	0.06	0.31	0.31
β_5	gamma	0.22	0.32	0.06	0.31	0.33
β_6	gamma	0.28	0.28	0.06	0.27	0.28
β_7	beta	0.55	0.45	0.06	0.45	0.46
β_8	beta	0.28	0.26	0.06	0.24	0.27
β_9	gamma	0.55	0.43	0.06	0.43	0.44
β_{10}	gamma	0.22	0.11	0.06	0.10	0.11
α_1	beta	0.22	0.40	0.06	0.39	0.42
α_2	beta	1.65	1.46	0.06	1.45	1.47
ϖ_1	gamma	0.55	0.52	0.06	0.51	0.52
ϖ_2	gamma	0.28	0.28	0.06	0.27	0.28
ρ_1	gamma	1.00	1.22	0.14	1.21	1.24
ρ_2	gamma	0.33	0.31	0.01	0.31	0.32
ρ_3	gamma	0.28	0.02	0.25	0.00	0.04
ρ_4	gamma	0.22	0.22	0.01	0.21	0.22
ρ_5	gamma	0.33	0.02	0.25	0.00	0.04
τ_1	gamma	0.55	0.53	0.06	0.53	0.53
τ_2	gamma	0.22	0.10	0.06	0.09	0.11
τ_3	gamma	0.22	0.22	0.06	0.21	0.23
τ_4	gamma	0.55	0.53	0.06	0.52	0.55
τ_6	gamma	0.44	0.38	0.06	0.37	0.40
τ_7	gamma	0.55	0.45	0.06	0.45	0.46
τ_8	beta	0.50	0.43	0.06	0.43	0.43

τ_{10}	beta	0.61	0.53	0.06	0.52	0.54
τ_{11}	beta	0.66	0.58	0.06	0.57	0.59
τ_{12}	gamma	0.55	0.48	0.06	0.47	0.49
τ_{13}	gamma	0.66	0.71	0.06	0.70	0.72
τ_{14}	gamma	0.55	0.50	0.06	0.39	0.40

In scenario II, Table 6.4, the prior means were kept constant while prior standard deviations were raised considerably, by 50 per cent. Although results exhibit a more substantial change than in scenario I, the overall conclusions remained broadly the same as the ones of the benchmark model. It can be concluded therefore that for reasonable changes in the values of the priors mean and standard deviation, the overall quantitative results are quite robust and therefore, the posterior means are generally reliable and stable. The model thus satisfies the Blanchard-Kahn condition.

Table 6.4: Sensitivity Analysis: Increasing the Standard Deviation by 50%

Parameter	Density	Prior Mean	Posterior Mean	Standard Deviation	Confidence Interval at 90%	
β_1	beta	0.20	0.05	0.08	0.04	0.06
β_2	gamma	0.40	0.42	0.08	0.42	0.43
β_3	beta	0.30	0.37	0.08	0.36	0.38
β_4	beta	0.30	0.32	0.08	0.31	0.33
β_5	gamma	0.20	0.33	0.08	0.32	0.33
β_6	gamma	0.25	0.28	0.08	0.27	0.28
β_7	beta	0.50	0.46	0.08	0.45	0.46
β_8	beta	0.25	0.26	0.08	0.25	0.27
β_9	gamma	0.50	0.43	0.08	0.41	0.44
β_{10}	gamma	0.20	0.11	0.08	0.10	0.12
α_1	beta	0.20	0.42	0.08	0.41	0.42
α_2	beta	1.50	1.46	0.08	1.45	1.47
ϖ_1	gamma	0.50	0.51	0.08	0.50	0.52
ϖ_2	gamma	0.25	0.28	0.08	0.27	0.28
ρ_1	gamma	1.00	1.22	0.20	1.19	1.26

ρ_2	gamma	0.30	0.31	0.02	0.31	0.32
ρ_3	gamma	0.25	0.00	0.35	0.00	0.01
ρ_4	gamma	0.20	0.22	0.01	0.22	0.22
ρ_5	gamma	0.30	0.01	0.35	0.00	0.02
τ_1	gamma	0.50	0.53	0.08	0.52	0.53
τ_2	gamma	0.20	0.10	0.08	0.09	0.11
τ_3	gamma	0.20	0.22	0.08	0.21	0.23
τ_4	gamma	0.50	0.54	0.08	0.53	0.54
τ_6	gamma	0.40	0.37	0.08	0.36	0.38
τ_7	gamma	0.50	0.45	0.08	0.44	0.45
τ_8	beta	0.45	0.43	0.08	0.42	0.43
τ_{10}	beta	0.55	0.53	0.08	0.53	0.54
τ_{11}	beta	0.60	0.58	0.08	0.57	0.58
τ_{12}	gamma	0.50	0.48	0.08	0.46	0.50
τ_{13}	gamma	0.60	0.71	0.08	0.71	0.72
τ_{14}	gamma	0.50	0.39	0.08	0.39	0.39

6.7 Model Properties: Impulse Response Analysis

In this section of the paper, we examine how shocks relative to the steady states propagate. We examine impulse response functions of different shocks as shown in Figures 6.17 – 6.22 and Table 6.5.

Table 6.5: Summary Results of Impulse Response Functions

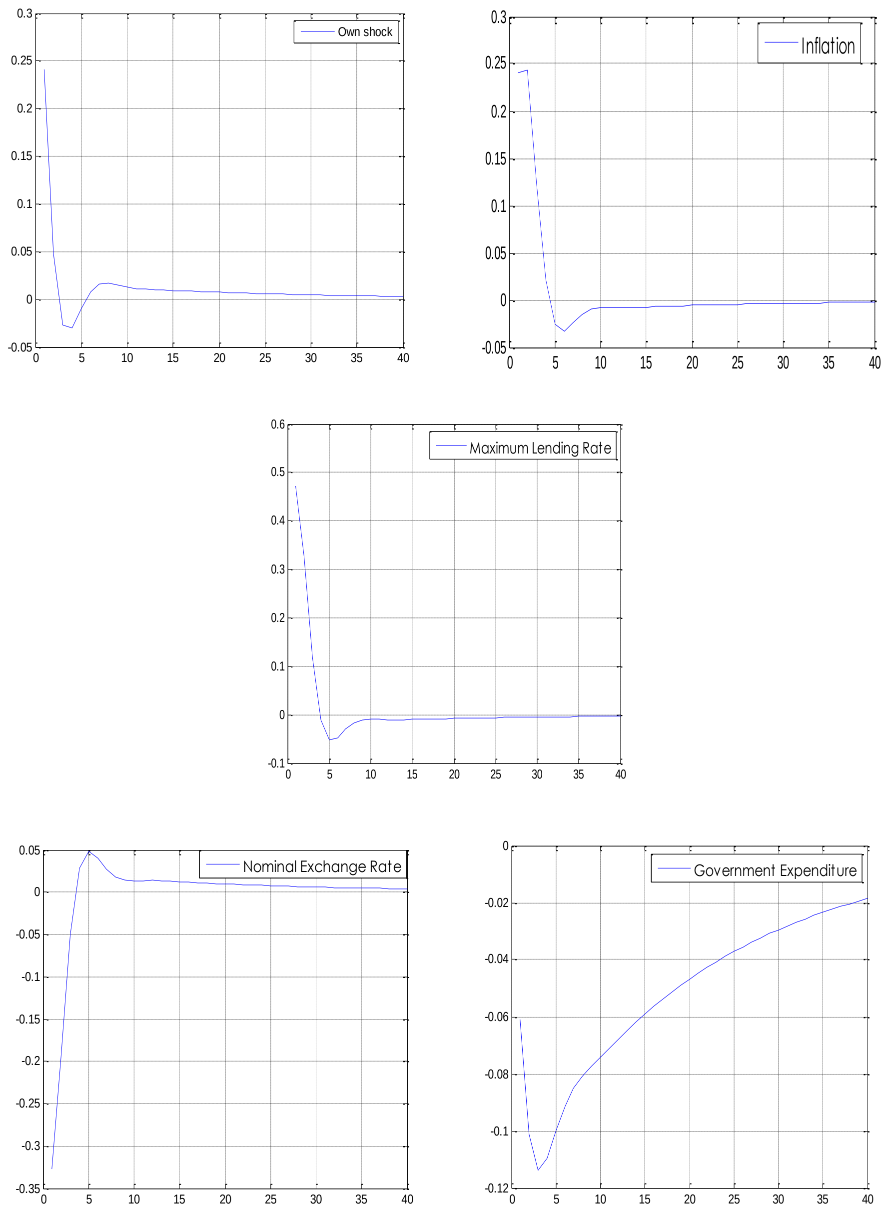
Periods	Output Gap	Inflation	Interest Rate	Nominal Exchange Rate	Government
	Aggregate Demand Shocks				
1	0.249	0.249	0.499	-0.348	-0.057
3	-0.030	0.119	0.111	-0.044	-0.108
7	0.017	-0.024	-0.029	0.026	-0.080
8	0.017	-0.015	-0.016	0.018	-0.075
	Aggregate Supply Shock				
1	-1.341	2.764	2.399	-1.112	-0.322
3	-0.472	-0.509	-1.032	0.755	-0.162
7	0.055	0.021	0.065	-0.047	-0.029
8	0.018	0.036	0.055	-0.032	-0.034
	Monetary Policy Shocks				
1	0.011	-0.017	-0.046	0.012	0.006
3	-0.014	-0.116	-0.072	0.054	0.002
7	0.006	0.007	0.016	-0.012	0.007
8	0.000	0.007	0.011	-0.007	0.006
	Oil Price Shocks				
1	0.556	-1.008	-1.023	0.497	0.536
3	0.360	0.132	0.497	-0.477	0.725
7	-0.119	0.110	0.123	-0.134	0.553
8	-0.104	0.072	0.085	-0.110	0.527
	External Reserves				
1	-0.028	0.017	0.001	-0.080	-0.020
3	-0.002	-0.042	-0.056	-0.005	-0.028
7	0.008	-0.009	-0.010	-0.002	-0.031
8	0.006	-0.007	-0.008	0.001	-0.031
	Nominal Exchange Rate Shock				
1	0.079	0.031	0.133	0.376	0.106
3	-0.079	0.081	0.050	-0.022	0.060
7	-0.005	0.000	0.005	-0.011	0.060
8	-0.006	0.008	0.013	-0.015	0.057

6.6.1 Response to Unanticipated Temporary Shock of 1% to Aggregate Demand

An aggregate demand shock can be in the form of an increase in government expenditure or a cut in taxes. A positive demand shock raised output by about 0.25 per cent higher than its potential in the first quarter, falling about 0.03 per cent below its steady state equilibrium in the third quarter. This raised inflation about 0.25 per cent and almost doubled the interest rate gap as the monetary authority tightens monetary policy stance leading to a 0.348 per cent appreciation of the nominal exchange rate in the first quarter. As a result of the combined effects of nominal appreciation of the exchange rate and high interest rate, output gap is dampened by 0.03 per cent in the third quarter.

Output gap became positive rising about 0.017 per cent apiece in the seventh and eight quarter but remaining persistent with long-term effects before return to its steady states.

Figure 6.17: Impulse Responses to Aggregate Demand Shocks

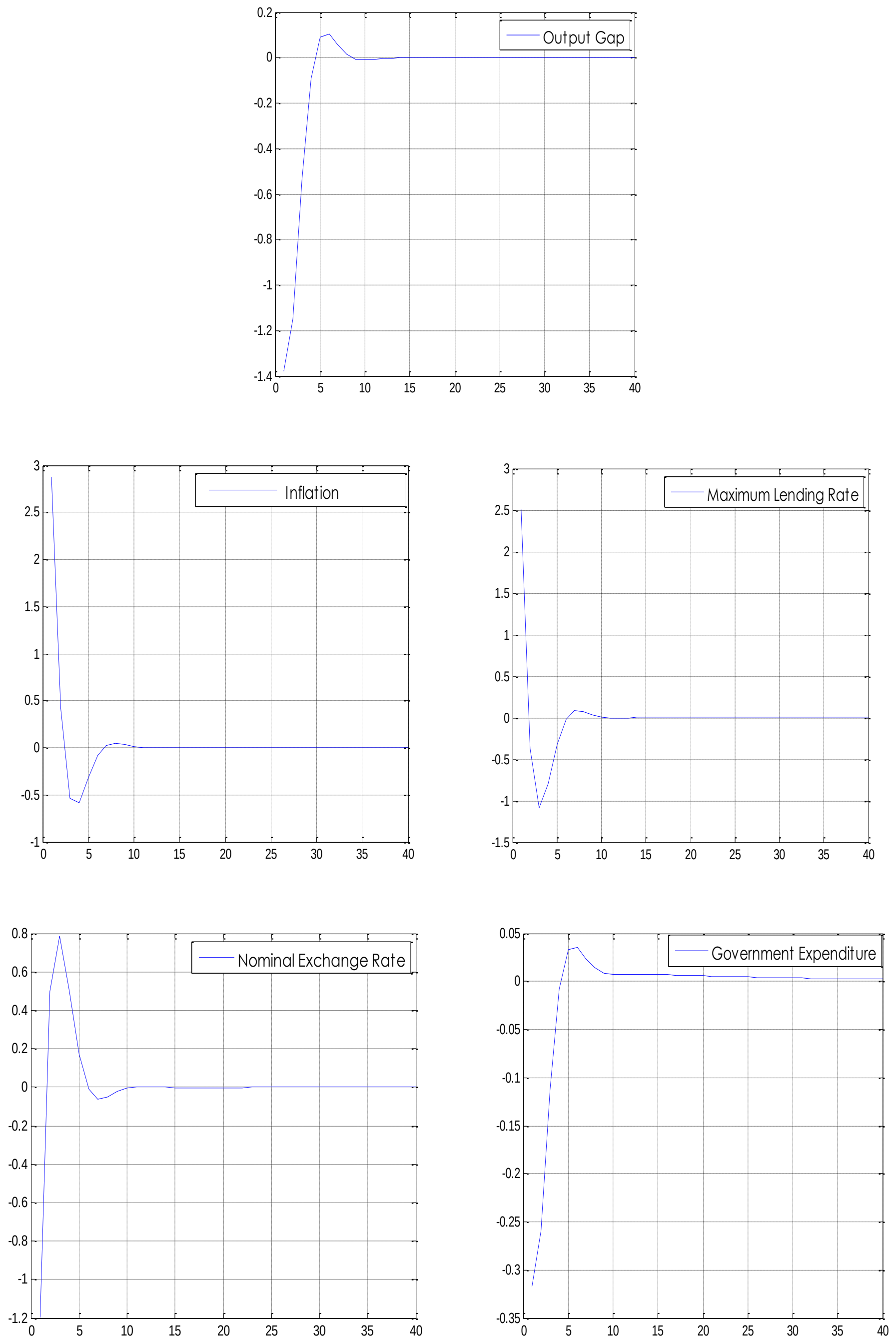


Source: Own estimates

6.6.2 Response to Unanticipated Temporary Shock of 1% to inflation

A positive supply shock pushed output below its potential level by 1.34 and 0.47 per cent, respectively, in the first and third quarter. Thereafter, output gap edged up by 0.055 per cent in the seventh quarter to become positive thereafter, returns to steady state. This result points out that supply shocks produce short-term effects, while demand shock lingered with long-term effects. Given that supply shock led to temporal supply adjustment problems, it pushed interest rates and inflation upward by 2.76 and 2.39 per cent, respectively, in the first quarter. Interest and inflation rates turned negative in third quarter with a fall of 0.51 and 1.0 per cent, respectively. Nominal exchange rate appreciates in the first quarter and in response, government expenditure falls by 0.057 and 0.108 in the first and third quarter. But as output picks-up above its trend levels in response to positive supply shocks as firms adjusted to new technologies, there is a 0.036 and 0.055 per cent increase in interest and inflation rates, respectively, in the eight quarter. The appreciation in the nominal exchange rate by 0.032 per cent, however, led to reduced government expenditure by 0.034 per cent in the eight quarter. This result affirmed the strong correlation between the monetization of foreign exchange earnings, exchange rate and government expenditure. The variables eventually decayed to equilibrium in the medium to long-run.

Figure 6.18: Impulse Responses to Supply Shocks

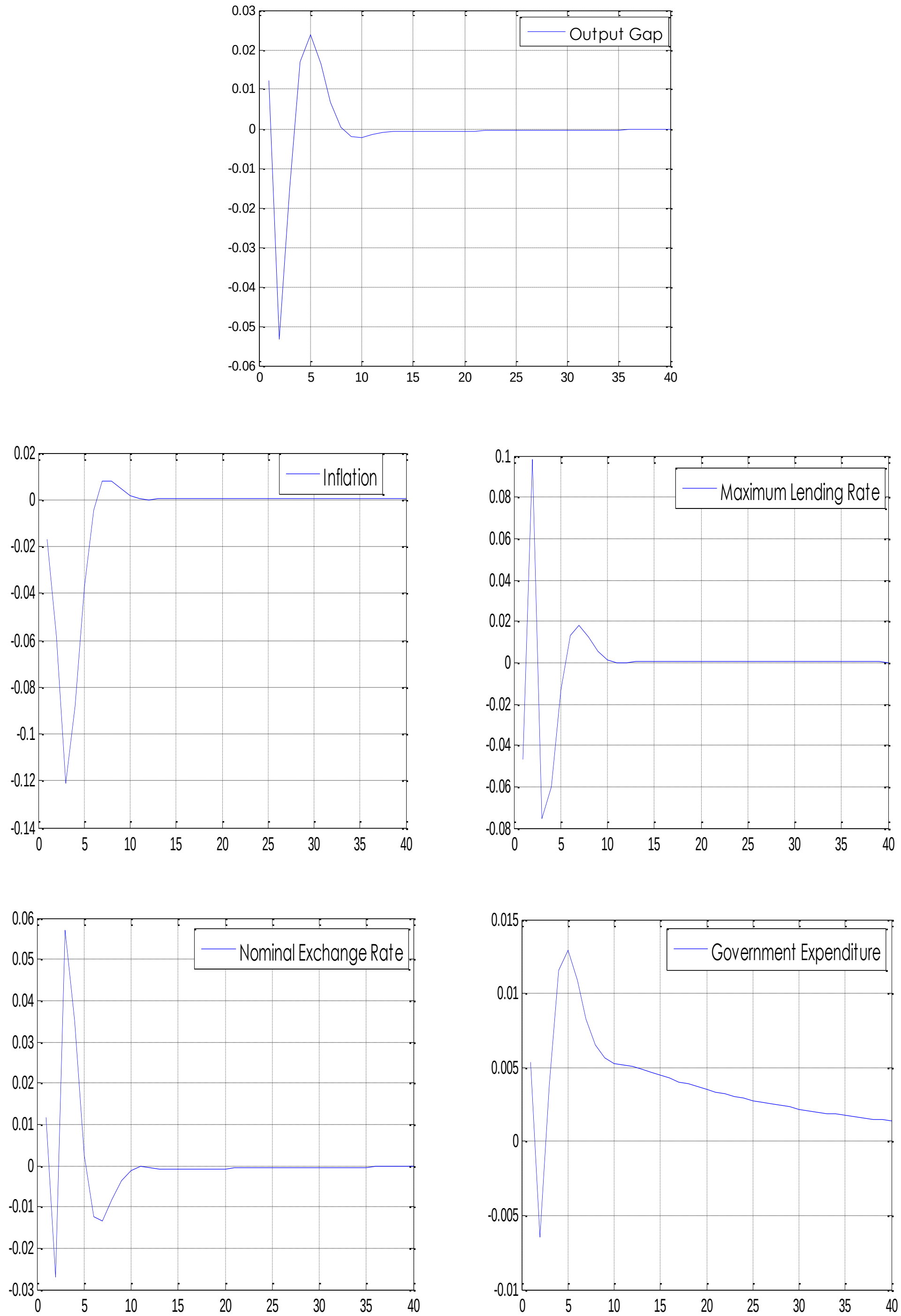


Source: Own estimates

6.6.3 Response to Unanticipated Temporary Shock of 1% to Monetary Policy Rate

A positive monetary policy shock reduced interest rate in the first and third quarters, respectively, by 0.046 and 0.072 per cent and a positive impacted on the output gap of 0.011 per cent in the first quarter. Inflation, similarly, nosedived by 0.017 and 0.116 per cent in the first and third quarter. Nominal exchange rate, however, remained under pressure depreciating by 0.054 per cent in the first three quarters (persistence in imports, foreign exchange supply bottlenecks and the size of the government budget at the three tiers are some of the preponderant factors), oscillating between different magnitudes of depreciation and appreciation within ten quarters. Government expenditure correlated with upward trend movements in all prices and the output gap. It showed that monetary policy is essentially pro-cyclical. These results reasonably captured the effectiveness of monetary policy as it showed to achieve its basic objectives, with some nominal tradeoffs, in terms of output decline and exchange rate appreciation. In the medium to long-run all the variables died off to their equilibrium levels.

Figure 6.19: Policy Rate Shocks

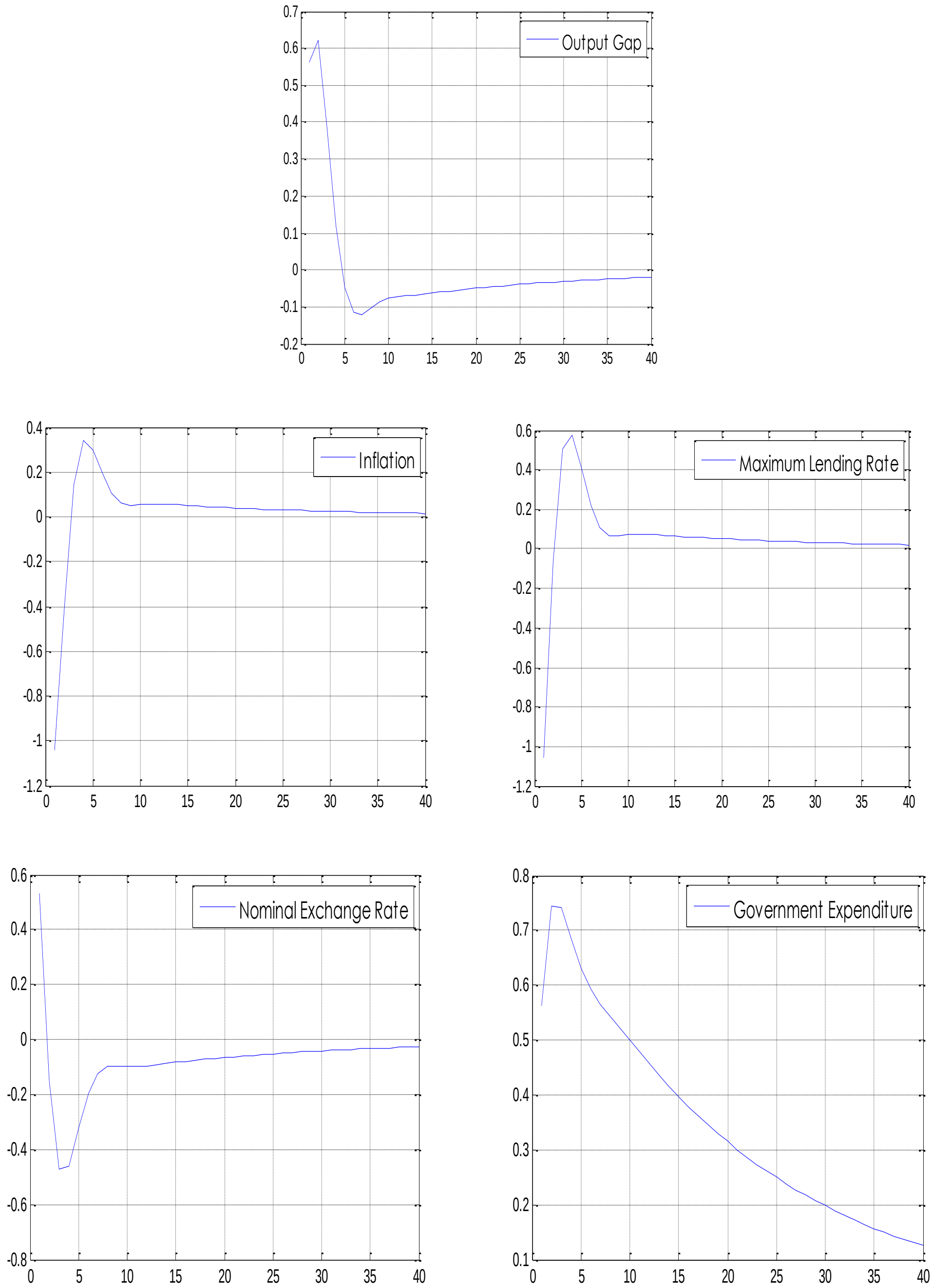


Source: Own estimates

6.6.4 Response to Unanticipated Temporary Shock of 1% to Oil Price

There existed a positive contemporaneous correlation between oil price shocks, output gap and government expenditure. The oil price shock reduced inflation and interest rate by 1.01 and 1.02 per cent, respectively, in the first quarter, rising to 0.132 and 0.5 per cent in the third quarter and remaining positive up to the eight quarter and thereafter returning asymptotically to its steady state. We find first quarter depreciation in the nominal exchange rate of almost 0.5 per cent and a compensating smoothing of 0.48, 0.134 and 0.11 in the third, seventh and eight quarters, respectively, to return exchange rate to steady state equilibrium. Government expenditure response to oil price windfalls appear to be persistent over eight quarters averaging about 0.59 per cent. The return to equilibrium after the shock is sluggish and persistent for output gap, inflation, interest rate, exchange rate and government expenditure. In the medium to long-run all the variables returned the steady states.

Figure 6.20: Oil Price Shocks

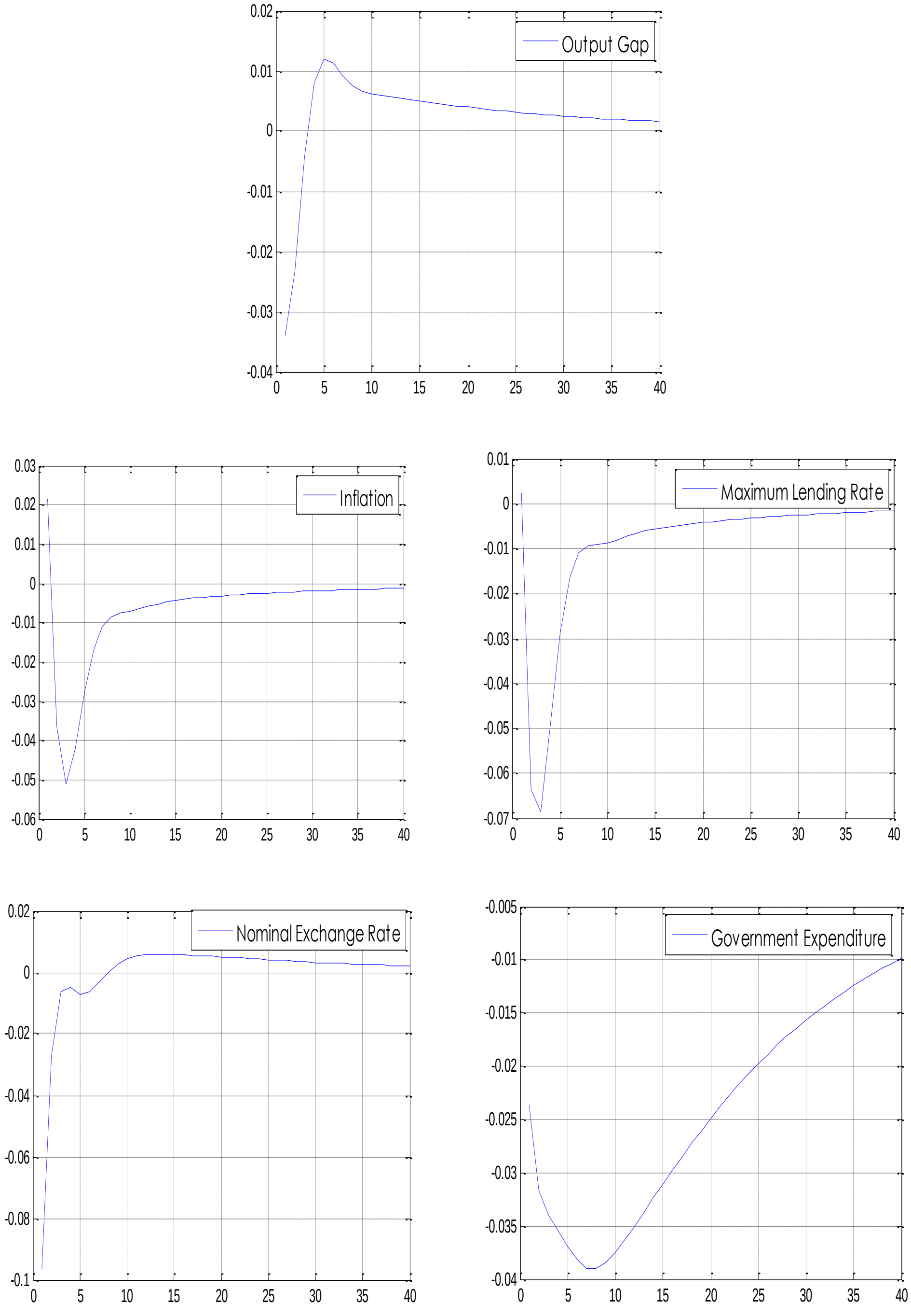


Source: Own estimates

6.6.5 Response to Unanticipated Temporary Shock of 1% to External Reserves

A positive external reserve shocks appreciated the exchange rate by 0.08 in the first quarter and 0.01 and 0.002 per cent in the third and seventh quarters, respectively. In response to the nominal exchange rate appreciation, output gap declined by 0.028 and 0.002 per cent in the first and third quarters, but with the moderation in exchange rate appreciation and a reversal to a depreciation of about 0.001 in the eight quarter, output expanded by 0.008 and 0.006 per cent in the seventh and eight quarters, respectively. Government expenditure similarly, declined approximately by an average of 0.028 per cent over the eight quarter period. A combination of these developments, almost immediately mount pressures on domestic inflation and interest rates. Inflation and interest rates rose about 0.017 and 0.001 per cent in quarter one, falling thereafter, by 0.019 and 0.025 per cent on the average over the eight quarter periods. In the medium to long-run all the variables returned steady state equilibrium.

Figure 6.21: External Reserves Shocks

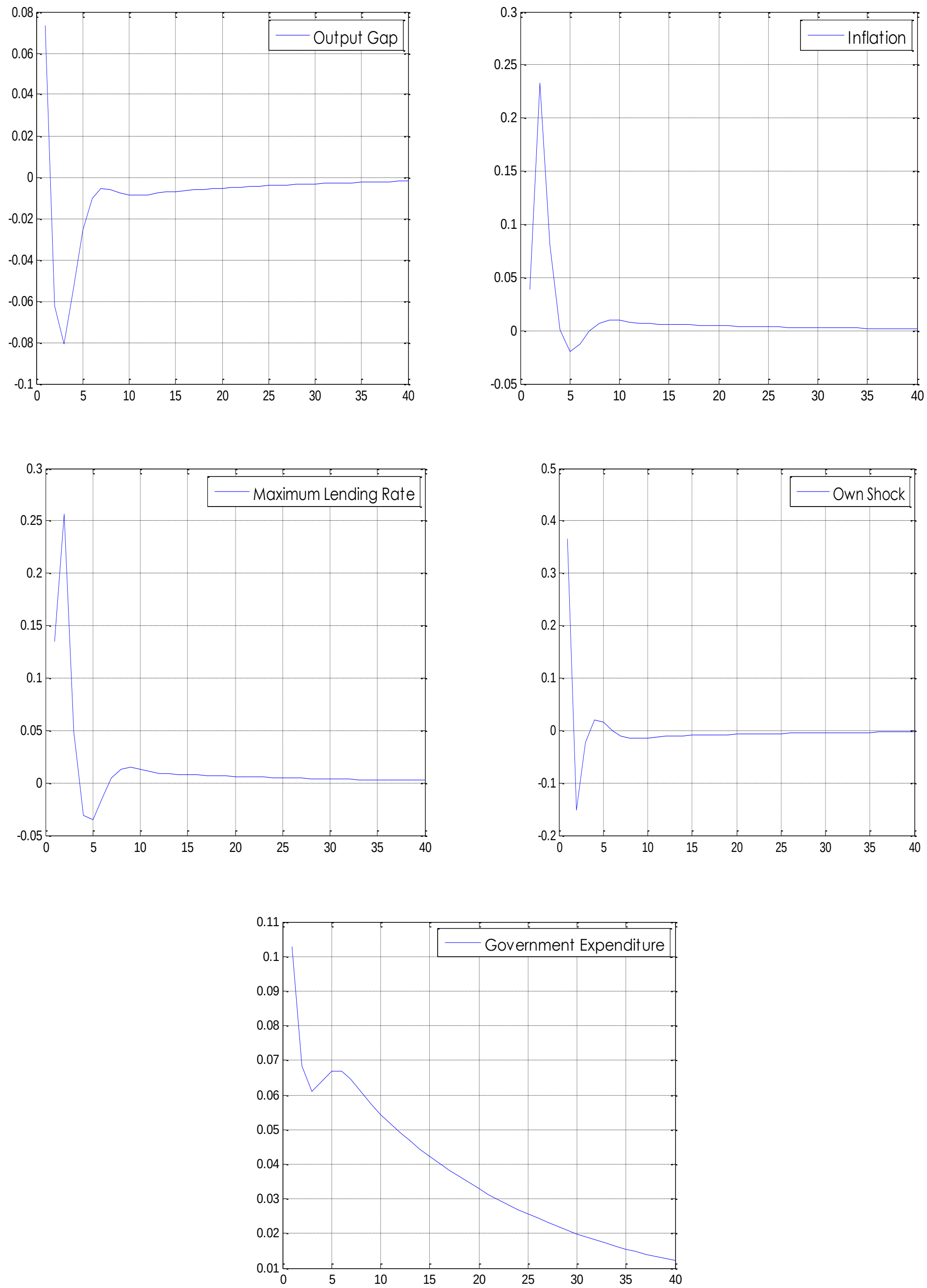


Source: Own estimates

6.6.6 Response to Unanticipated Temporary Shock of 1% to Nominal Exchange Rate

Figure 6.22 showed that a positive shock to the nominal exchange rate could lead to a 0.376 per cent increase in the nominal exchange rate in quarter one and an immediate real interest rate tightening of up to 0.133 per cent due to a 0.031 per cent surge in inflation, thus, confirming the existence of exchange rate pass-through in the Nigerian economy. In response output rises by 0.079 per cent in the first quarter, but declined on the average by 0.03 per cent following a 0.016 appreciation of the exchange rate on the average over the five quarter period. Government expenditure remained positive in a delayed response to the appreciation of the exchange rate, but plausibly, the higher interest rate would be attractive enough to fund government spending from the domestic debt market. The model showed a peak for the nominal interest rate, which implied that the Central Bank of Nigeria reacted strongly to an exchange rate shock at the very beginning of the adjustment period. In the medium to long-run all the variables returned steady state equilibrium.

Figure 6.22: Nominal Exchange Rate Shocks



Source: Own estimates

6.7 Forecast Error Variance Decomposition

This section analyses the relative contribution of each structural shock to the volatility of some key endogenous observable variables as reported in Table 6.6 Some of these shocks include aggregate demand shock (which also include an explicit government expenditure shock), aggregate supply shock, interest rate shock, monetary policy shock, oil price shocks, among others.

From the results, interest rate shocks accounted for about 43 per cent of output gap fluctuations, while shocks to the equilibrium interest rate made a relative contribution of 38.5 per cent over the sample horizon. Aggregate demand shocks also explained approximately 14.6 per cent and a 3.5 per cent arising from shocks to oil price.

Equilibrium interest rate shocks explained 60 per cent of the volatility in inflation gap, while a shocks to interest rate account for 29.3 per cent fluctuations in inflation gap. The intuition of this finding could be gleaned from the view that economic agents seek to compensate for any distortions that placed a risk on their investments.

Interest rate and equilibrium interest rate shocks were the major shocks explaining fluctuations in interest rate and nominal exchange rate gaps. Interest rate shocks accounted for 56 and 46 per cent of the fluctuations in its own shocks and exchange rates, respectively. Similarly, shocks to equilibrium interest rate, contributed 33 and 40 per cent of the volatility in interest and exchange rates, respectively. Domestic supply shocks were able to explain between 8 to 9 per cent of interest rate and nominal exchange rate fluctuations.

Oil price shocks explained 54 per cent of the variance forecast error of government expenditure, while government expenditure and equilibrium interest rate shocks contributed, 14.3 and 18.4 per cent of the fluctuations in government expenditure, respectively. The relative contribution of monetary policy shocks were rather small in explaining the fluctuations in most of the variables and could plausibly be dampened due to domestic supply and interest rate shocks.

Table 6.6: Variance Decomposition (% of Variation Accounted by Different Shocks)

	Aggregate Demand	Aggregate Supply	Interest Rate	Nomina l Exchange Rate	Government Expenditure
Aggregate Demand Shock (e1)	0.39	0.17	0.47	0.75	1.92
Aggregate Supply Shock (e2)	14.56	8.80	8.23	8.99	2.27
Interest Rate Shock (e3)	42.88	29.32	55.94	45.92	7.66
Government Expenditure (e4)	0.16	0.03	0.05	0.27	14.28
Nominal Exchange Rate Shock (e5)	0.08	0.06	0.09	0.58	0.78
Foreign Price Shock (e6)	0.01	0.02	0.04	0.08	0.30
Foreign Interest Rate Shock (e7)	0.00	0.00	0.00	0.01	0.04
Oil Price Shock (e8)	3.35	1.31	1.77	3.34	54.06
Money Supply Shock (e9)	0.00	0.00	0.00	0.00	0.00
Foreign Output Shock (e10)	0.00	0.00	0.00	0.00	0.00
Equilibrium Interest Rate Shock (e11)	38.53	60.26	33.36	40.00	18.41
External Reserve Shock (e12)	0.01	0.01	0.01	0.03	0.25
Monetary Policy Rate Shock (e13)	0.02	0.02	0.02	0.02	0.01

Source: Own estimates

Chapter Seven
Conclusion and Directions for Further Study

7.1 Conclusion

An analysis of a central bank's behaviour in formulating monetary policy is of considerable interest to both academic and non-academic researchers. In the quest to gain further insight on this issue, non-policy makers tend to raise questions regarding the behaviour of a central bank with respect to the formulation of monetary policy.

In the quest to gain further insight on this issue, a DSGE model using Bayesian estimation technique is employed with Nigerian data spanning the period 1985q1 - 2009q4. The model was based on the standard New Keynesian framework comprising three rational economic agents -- households, firms and the monetary authority. Overall, the log-linearised version of the model contained five main equations -- an output gap (aggregate demand), inflation (aggregate supply), a monetary policy rule (Taylor-type rule), an uncovered interest rate parity condition (to capture the small open economy nature of the Nigerian economy) and government expenditure. In specifying the equations, attention was paid to the peculiarities of the Nigerian economy with particular reference to its dependence on the oil sector.

As a guide to the empirical exercise, model parameters were initially calibrated according to the Bayesian technique based on expert knowledge, understanding of the Nigerian economy, sound economic theory, country experiences with relatively the same economic structure as Nigeria and value judgement. Subsequently the model was taking to the data and the following results were obtained. First, the results reveal that the data is informative as the posterior mean is different from the prior mean. Second, the habit persistence parameter was high and data driven. This implied the high persistence of households' consumption behavior in Nigeria. Third, in the Phillip curve equation, the Calvo price stickiness was established for Nigeria, which indicated that firms in Nigeria tend to change their prices frequently (every two quarters). Fourth, the estimate of the exchange rate pass through to prices was 0.25 per quarter. Fifth, the output cost of disinflation (the sacrifice ratio) was estimated to be 1.32, which was quite high. The implication of this was that the Central Bank had, over the estimation period, paid more attention to output stabilization rather than price stability in the conduct of monetary policy.

Analysis of the impulse response functions showed that a positive supply shock pushes output below its potential level in the initial quarter becoming positive thereafter and last for about four quarters prior to returning to steady states. This result pointed out that supply shocks produced short-term effects, while demand shock led to long-term effects. A positive monetary policy shock reduced interest rate with a positive impact on the output gap. There existed a positive contemporaneous correlation between oil price shocks, output gap and government expenditure. A positive external reserve shock reduced output gap, but almost immediately mount pressures on domestic inflation and interest rates.

The results of the variance decomposition indicated that interest rate shocks accounted for about 43 per cent of output gap fluctuations, while shocks to the equilibrium interest rate made a relative contribution of 38.5 per cent over the sample horizon. Aggregate demand shocks also explained approximately 14.6 per cent and a 3.5 per cent arising from shock to oil price. Oil price shock explained 54 per cent of the variance forecast error of government expenditure, while government expenditure and equilibrium interest rate shocks contributed, 14.3 and 18.4 per cent of the fluctuations in government expenditure, respectively. The relative contribution of monetary policy shocks were rather small in explaining the fluctuations in most of the variables and could plausibly be dampened due to domestic supply and interest rate shocks.

7.2 Directions for Future Study

In the course of the study, the following challenges were identified:

- There is need to use alternative priors to reflect the changes in the structure and fundamentals of the economy.

- The transformation of data using other filtering techniques apart from the Hodrick-Prescott filter should be considered since it is subject to several preconditions and assumptions.

- The estimated model is a snapshot of the characteristics of the Nigerian economy. However, the absence of the fiscal reaction function may not completely reflect the structure of the Nigerian economy. In this regard, it will be difficult to analyse the impact of a shock in key fiscal variables such as taxes.

- Since foreign variables are estimated using autoregressive of order one (AR,1), further studies should estimate these variables outside the model to reflect the true impact of the foreign sector on the economy.

REFERENCES

Abel, A. (1990), 'Asset Prices Under Habit Formation and Catching up with the Joneses', *The American Economic Review*, Volume 80 (2)

Adam C., S. O. Connell, E. Buffie, and C. Pattillo(2009) Monetary Policy Rules for Managing Aid Surges in Africa. *Review of Development Economics*, Vol. 13, No. 3: 464.490.

Adebiyi, M.A. and C.N.O. Mordi (2010). Estimating Small Scale Macroeconometric Model (SSMM) For Nigeria: A Dynamic Stochastic General Equilibrium (DSGE) Approach. *Central Bank of Nigeria Occasional Paper*, No 39, pp. 1-45

Adolfson, M., S. Laséen , J. Lindé, and M. Villani, (2007) Bayesian estimation of an open economy DSGE model. *Journal of International Economics*, 72: 481.511.

Adolfson, M., S. Laseén, J. Lindé and M. Villani, (2005). "Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through", *SVERIGES RIKSBANK Working Paper Series,* No. 179.

Alege, Philip O. (2008). "Macroeconomic Policies and Business Cycle in Nigeria: 1970-2004", *An unpublished PhD Dissertation*, Department of Economics and Development Studies, Covenant University, Ota

Almeida, V. (2009). "Bayesian Estimation of a DSGE Model for the Portuguese Economy", Masters Thesis, Economic Research Department, Banco de Portugal.

Amato, J. D. & T. Laubach, (2003). Rule-of-Thumb Behaviour and Monetary Policy. *European Economic Review*, 47(5), 791-831.

An, S. and F. Schorfheide, 2005, Bayesian Analysis of DSGE models, *CEPR Working Paper* 5207.

Arrow, K. J. and G. Debreu (1954) "The Existence of an Equilibrium for a Competitive Economy" *Econometrica*, vol. XXII, 265-90

Beetsma, R. M. W. J. and H. Jensen, (2004). Mark-up Fluctations and Fiscal Policy Stabilisation in a Monetary Union. *Journal of Macroeconomics*, 26(2), 357-376.

Berg, A., Karam P. and D. Laxton (2006). A Practical Model-Based Approach to Monetary Policy Analysis- Overview. *IMF Working paper, WP/06/80*, pp1-43.

Berg, A., J. Gottschalk, R. Portillo, and L. Zanna (2010): The Macroeconomics of Medium-Term Aid Scaling-Up Scenarios. *IMF Working Paper*, WP/10/160.

Burriel, P., J. Fernandez-Villaverde and J. F. Rubio-Ramirez (2009). "A DSGE Model for the Spanish Economy", MEDEA

Calvo, G. A. (1983). Staggered Prices in a Utility Maximizing Framework. *Journal of Monetary Economics,* 12(3), 383-398.

Canova, F (2007). *Methods for Applied Macroeconomic Research*. Princeton University Press.

Carabenciov, I., I. Ermolaev, C. Freedman, M. Juillard, O. Kamenik, D. Korshunov, D. Laxton and J. Laxton, (2008). "A Small Quarterly Multi-Country Projection Model. *IMF Working Paper*, UP/08/279.

CBN "Banking Supervision Annual Report" (Various Issues)

CBN "Annual Report and Statement of Accounts" (Various Issues)

Mordi, C.N.O, A. Englama and B.S. Adebusuyi (eds)(2010). "*The Changing Structure of the Nigerian Economy", Central Bank of Nigeria, 2nd Edition.*

CBN (2009). "Statistical Bulletin", Volume 20, December.

CBN (2009), *CBN Briefs,* Research Department Series 2008/09

Christiano, L. J., M. Eichenbaum and C. Evans, (2005). "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy", *Journal of Political Economy* 113, no. 1:1–45.

Clarida, R., J. Gali and M. Gertler (1999): The Science of Monetary policy: A New Keynesian Perspective, *Journal of Economic Literature*, 37(4), 1661.

Colantoni, Luca (2007) Monetary Transmission in Estonia: The Interest Rate Channel, Mimeo.

Coletti, D. and S. Murchison (2002). Models in Policy-Making. *Bank of Canada Review*, Summer, pp 19-26.

Cukierman, A. (1992): *Central Bank Strategy, Credibility, and Independence: Theory and Evidence*. MIT Press.

Dagher, J., J. Gottschalk and R.Portillo (2010) Oil windfalls in Ghana: A DSGE Approach. *IMF Working Paper* WP/10/116.

Debreu, G.(1959) '*Theory of Value: An Axiomatic Analysis of Economic Equilibrium*, New Haven and London, Yale University Press.

DeJong, D. and C. Dave (2007) '*Structural Macroeconometrics*, Princeton University Press.

Dervis, K., J. de Melo and S. Robinson (1982) 'General Equilibrium Models for Development Policy, Washington D. C., A World Bank Research Publication.

Diebold, F. X. (1998) "The Past, Present and Future of Macroeconomic Forecasting." *Journal of Economic Perspectives* 12(2): 175-192.

Dixon, P. B. and B. R. Parmenter (1996) 'Computable General Equilibrium Modelling for Policy Analysis and Forecasting, in Amman, H. M., D. A. Kendrick and J. Rust (eds) (1996), *Handbook of Computational Economics*, I, Elsevier Science B. V.

Erceg, C. J., D. W. Henderson, and, A. T. Levin (2000), 'Optimal Monetary Policy with Staggered Wage and Price Contracts,' *Journal of Monetary Economics*, Volume 46

Fragetta, M. and T. Kirsanova (2010). Strategic Monetary and Fiscal Policy Interactions: An Empirical Investigation. European Economic Review, 54(7), 855-879.

Gali, J. and M. Gertler (1999). In.ation Dynamics: A Structural Econometric Analysis. *Journal of Monetary Economics*, 44(2), 195-222.

Garcia, C.J. (2010). Is the Phillips Curve Useful for Monetary Policy in Nigeria?, *Central Bank of Nigeria* Occasional *Paper* 38, December, pp 1-36

Gelain P. and D. Kulikov (2009). "An Estimated General Equilibrium Model for Estonia"

Goodhart, C. A. (1989) Central Bankers and Uncertainty, *Bank of England Quarterly Bulletin*, February 1999.

Grassini, M. (2007) 'Rowing Along the Computable General Equilibrium Modelling Mainstream' *Studi e Note di Economia*, Anno XII, n-3

Griffoli, T. M. (2007), An Introduction to the Solution & Estimation of DSGE Models, *DYNARE User Guide*, Chapter 8, pp. 81-91.

Hara, N.; Ichiue, H.; Kojima, S; Nakamura, K, and T. Shirota (2009). Practical Use of Macroeconomic Models at Central Banks. *Bank of Japan Review,* January, Pp1-9.

Hendry, D. F. (2001) *Dynamic Econometrics*. Oxford: Oxford University Press.

Hodrick, R. and E. Prescott (1997), "Post-War US Business Cycles: An Empirical Investigation", *Journal of Money, Credit and Banking,* Vol. 29, No. 1.

Houssa, R., C. Otrok and R. Puslenghe (2009) A Model for Monetary Policy Analysis for Sub-Saharan Africa. Open Econ Rev. Springer Science + Business Media, LLC 2009.

Ioan , C., I. Ermolaev, C. Freedman, M. Juillard, O. Kamenik, D. Korshunov, D. Laxton, and J. Laxton (2008). A Small Quarterly Multi-Country Projection Model*, IMF Working Paper,* WP/08/279, pp. 1- 59.

Idowu, A. E. (2010). "Fiscal Operations and the Efficacy of Monetary Management in Nigeria, *CBN Bullion* Vol.34, No. 1, pp.

Ireland, P. N. (2004). Technology Shocks in the New Keynesian Model. *Review of Economics and Statistics*, 86(4), 923-936.

Jakab, Z., M. and B. Világi, (2007). "An Estimated DSGE model of a Hungarian Economy", Central Bank of Hungary.

Jayawickrama, A. (2007) 'Macroeconometric Modelling: What Do We Learn from the Past', *The Paradeniya Journal of Economics*, Volume 1, Number 1 and 2, June/December.

Klein, L. R. (1960) "Single Equation vs Equation System Methods of Estimation in Econometrics." *Econometrica* 28: 866-871.

Klein, L. R. (1993) "Carrying Forward the Tinbergen Initiative in Macroeconometrics." 55-73. In A. Knoester and A. H. E. M. Wellink (eds.) *Tinbergen Lectures on Economic Policy*. Amsterdam: North-Holland.

Klein, L. R. (2002) "An Essay on the Accuracy of Economic Prediction." 29-69. In K. Puttaswamaiah (ed.) *Paul Samuelson & the Foundations of Modern Economics*. New Brunswick and London: Transaction Publishers.

Klein, L. R. (1989) 'Development and prospects in macroeconometric modelling'. *Eastern Economic Journal*, 15(4), 287–304.

Kydland, F. and E. Prescott (1982),'Time to Build and Aggregate Fluctuations', Econometrica Volume 50(6)

Lendvai, J. and W. Roeger (2008) Estonia 1995 to 2007: Catching-up and Beyond. Mimeo

Lucas, R. E. (1976), "Econometric Policy Evaluation: A Critique," in K. Brunner and A. H. Meltzer eds., *The Phillips Curve and Labor Markets*, msterdam: North Holland, pp. 19-46.

McKenzie, L. W. (1981). "The Classical Theorem on Existence of Competitive Equilibrium", *Econometrica.*

Mankiw, N. G. (1989) "Real Business Cycles: A New Keynesian Perspective." *Journal of Economic Perspectives* 3 (Summer): 79-90.

National Planning Commission (2010). *Report of the Macroeconomic Framework Thematic Working Group* (MFTWG) (2010)

Olekah and J.K and R. Oyaromade (2007). Estimating A DSGE Model of the Nigerian Economy. Draft paper scheduled for presentation at the *12th African Econometric Society (AES) Conference* in Cape Town, South Africa, July 4-6, 2007.

Oni, S. A. (2010). "Overview of the Four Pillars of the Banking Reforms in Nigeria", *CBN Bullion*, vol. 34, no. 3, July – September, 2010.

Peiris, S. J. and M. Saxegaard (2007) An Estimated DSGE Model for Monetary Policy Analysis in Low-Income Countries. IMF Working Paper WP/07/282.

Pesaran, M. H. and R. P. Smith (1985) "Evaluation of Macroeconometric Models." *Economic Modelling* 2(2): 125- 134.

Pongsaparn (2008). "A Small Semi-Structural Model for Thailand: Constructions and Applications"; Modelling and Forecasting Team, Monetary Policy Group

Rotemberg, J. and M. Woodford (1995), 'Dynamic General Equilibrium Models with Imperfectly Competitive Product Market', *Natural Bureau of Economic Research* – Working Papers Series No. 4502

Sanusi, Lamido S., (2010). "The Banking Reforms in Nigeria: What Next After CBN's Intervention? Being a Keynote Address at the Businessday Conference, Federal Palace Hotel, Lagos, February 11.

Scarf, H. E. (1967), "On the Computation of Equilibrium Prices" in Fellner, W.J. (ed.), *Ten Economic Studies in the tradition of Irving Fischer*, New York, NY: Wiley

Sims, C. (2006). "Comment on Del Negro, Schorfheide, Smets and Wouters". Available at: http://sims.princeton.edu/yftp/DSSW806/DSseattleComment.pdf

Smets, F. and R. Wouters (2003). An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association*, 1(5), 1123-1175.

Smets, F. and R. Wouters (2007). Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. *American Economic Review*, 97(3), 586-606.

Soludo, C.C (2007). Governor's end of year address to staff of the CBN, 2007.

Steinbach, R., P. Mathuloe and B. Smit, (2009). "An Open Economy New Keynesian DSGE Model of the South African Economy", *South African Reserve Bank Working Paper*, WP/09/01.

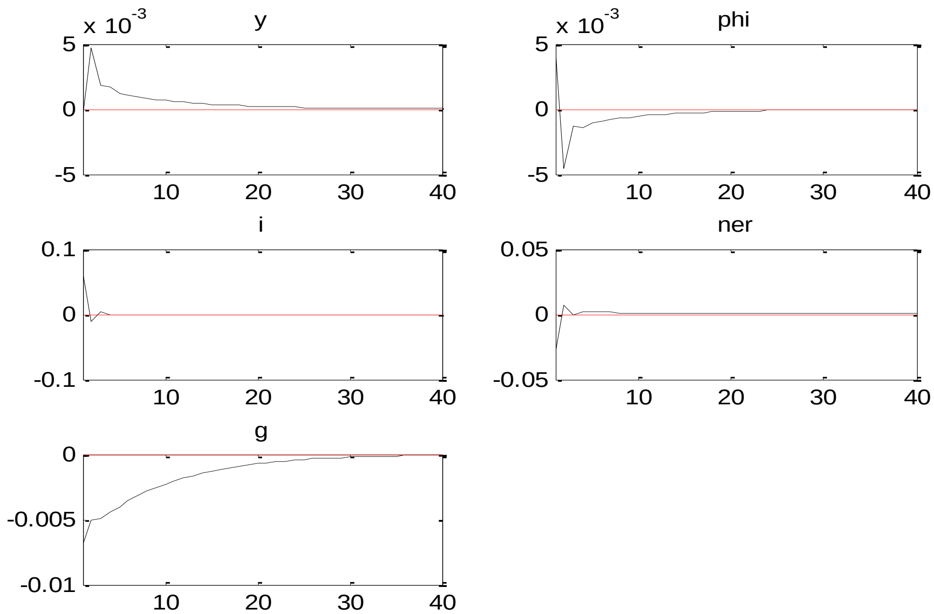
Tovar, C. E. (2009) 'DSGE Models and Central Banks', *The Open-Access, Open-Assessment E-Journal,* Volume 3, May.

Velupillai, K.V. (2006) "Algorithmic Foundations Of Computable General Equilibrium Theory", *Applied Mathematics and Computation* 179, pp. 360–69

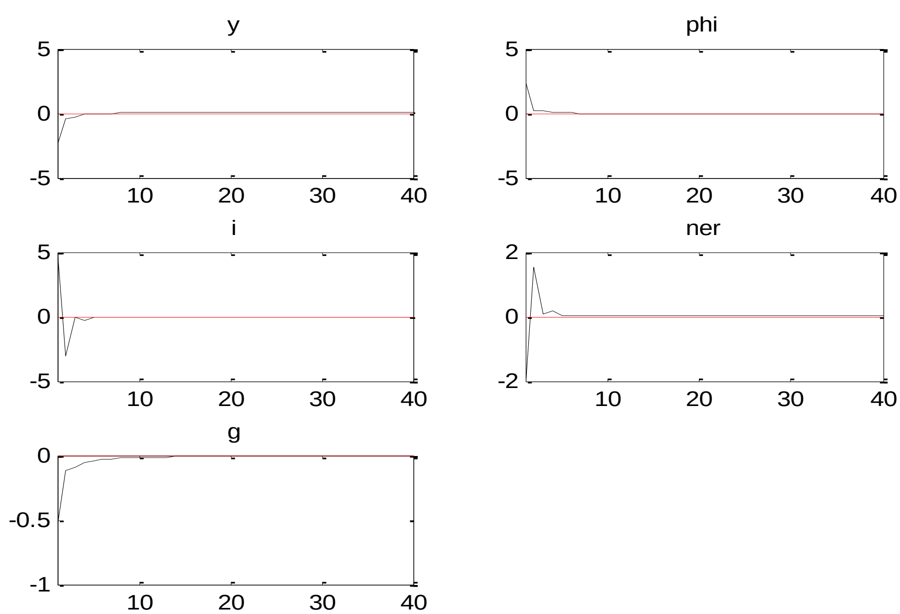
Walras, L. (1877, trans. 1954). *Elements of Pure Economics*. ISBN 0678060282 Scroll to chapter-preview links.

APPENDIX I: Orthogonalised Shocks

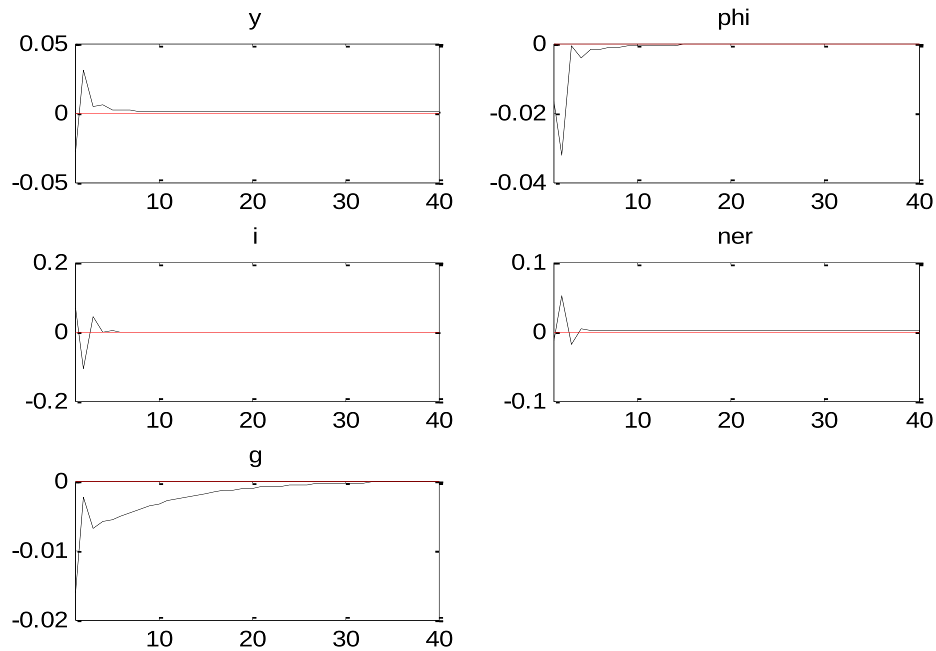
Orthogonalised Shock to Output Gap



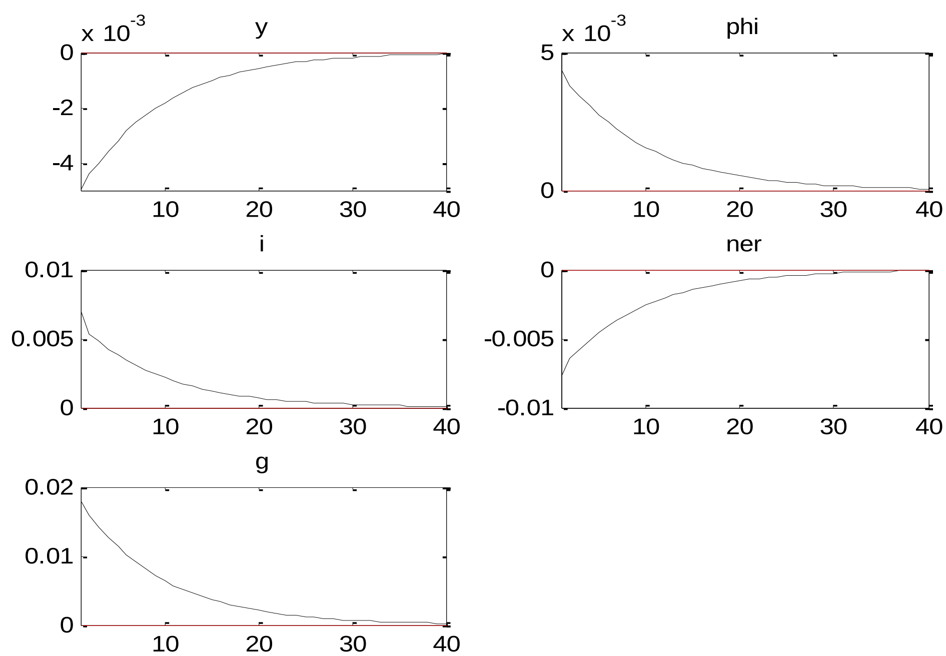
Orthogonalised Shock to Inflation



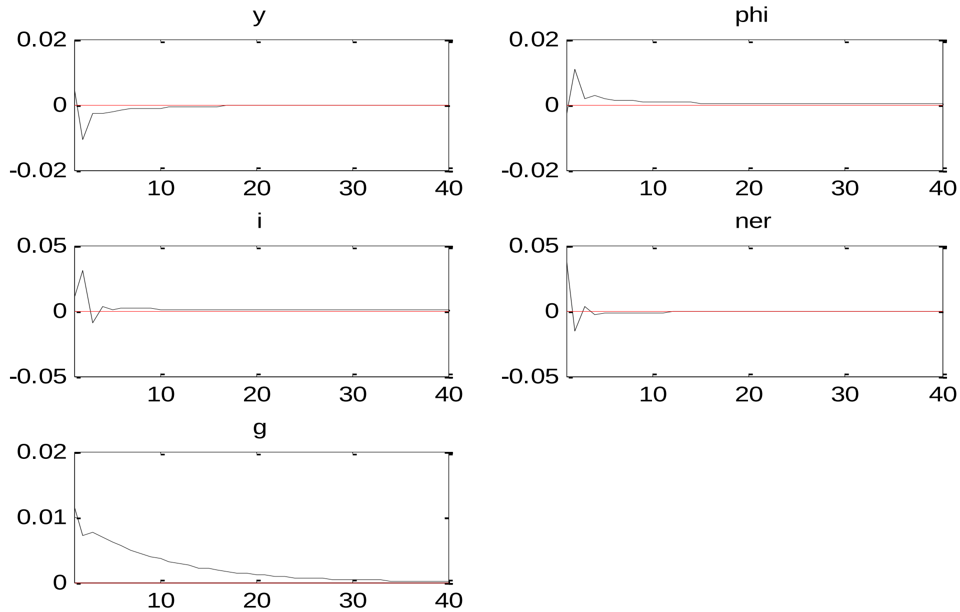
Orthogonalised Shock to Nominal Interest Rate



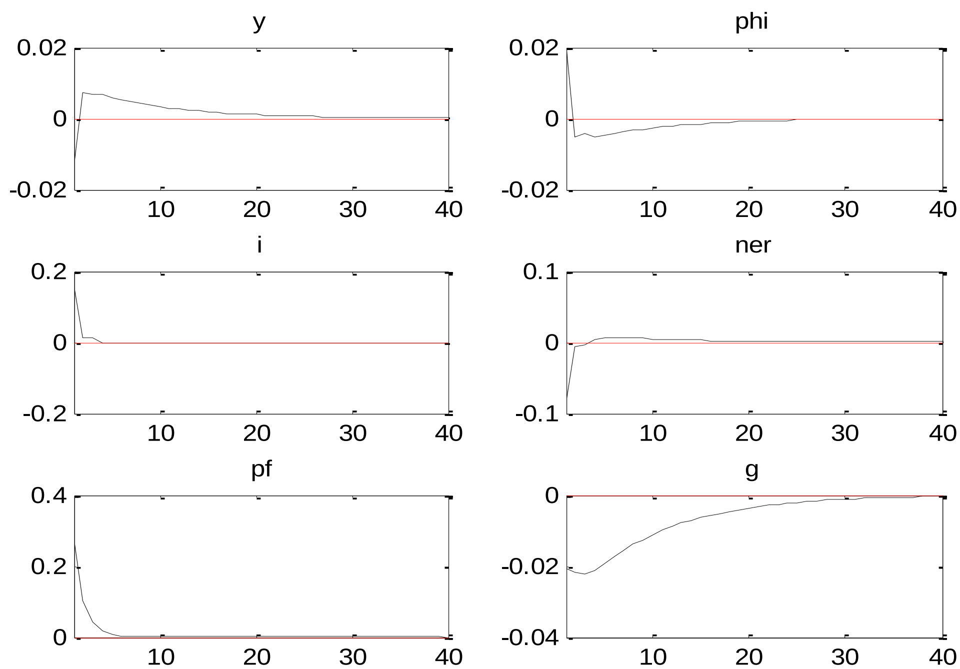
Orthogonalised Shock to Government Expenditure



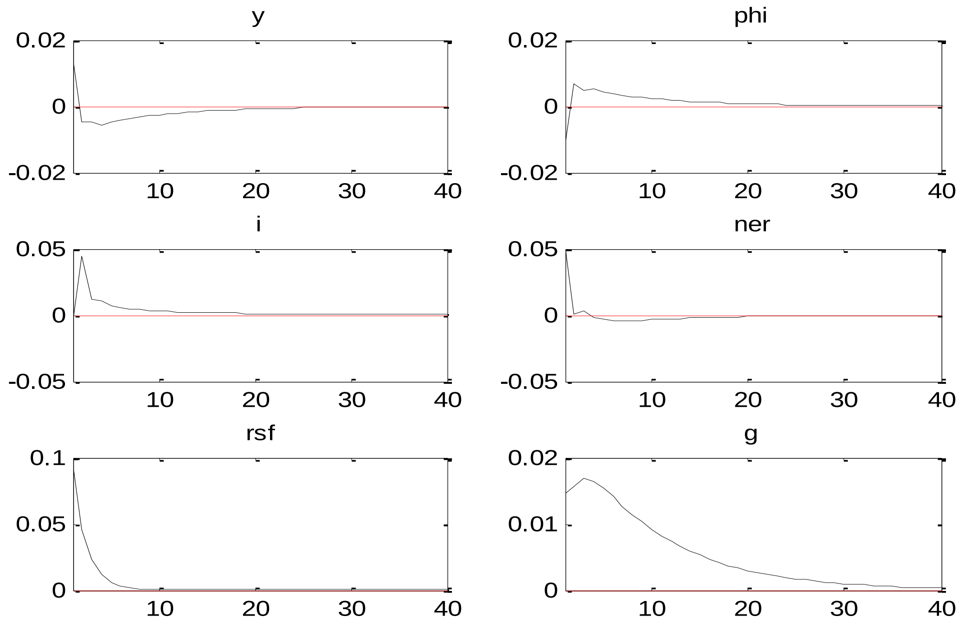
Orthogonalised Shock to Nominal Exchange Rate



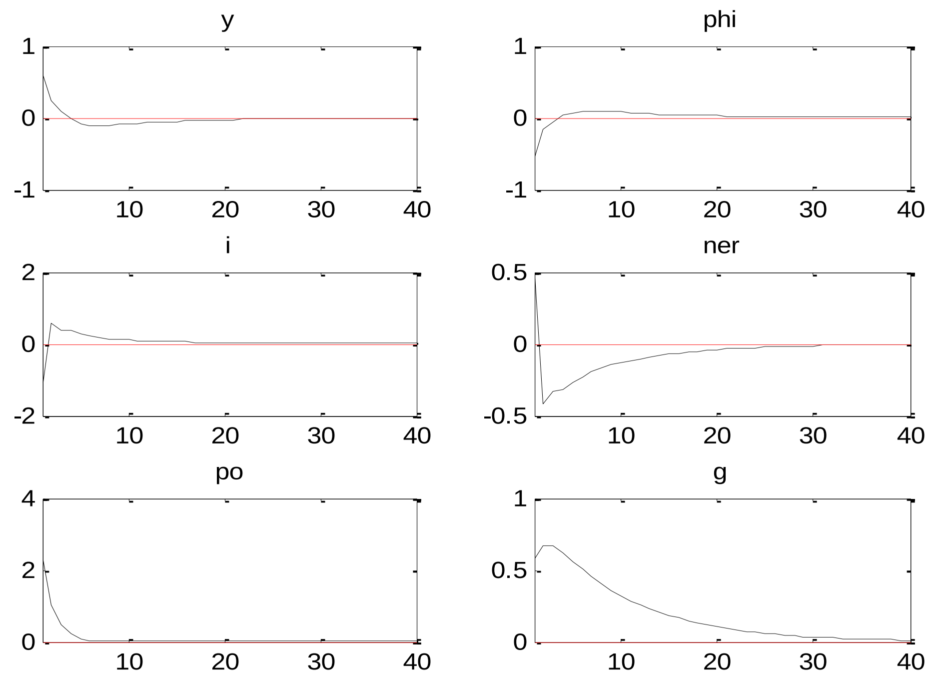
Orthogonalised Shock to Foreign Prices



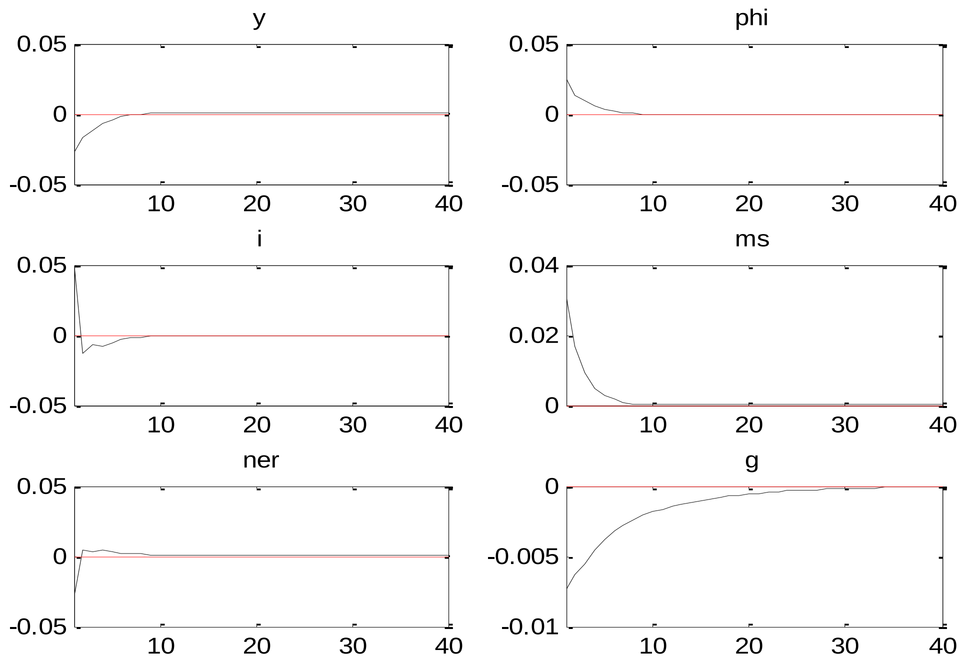
Orthogonalised Shock to Foreign Interest Rate



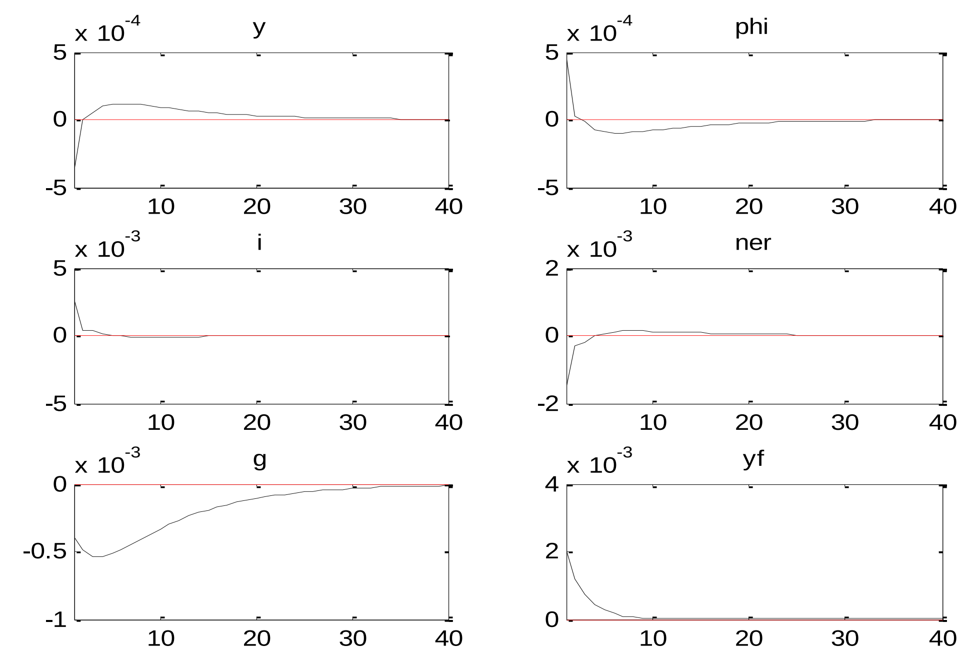
Orthogonalised Shock to Oil Price



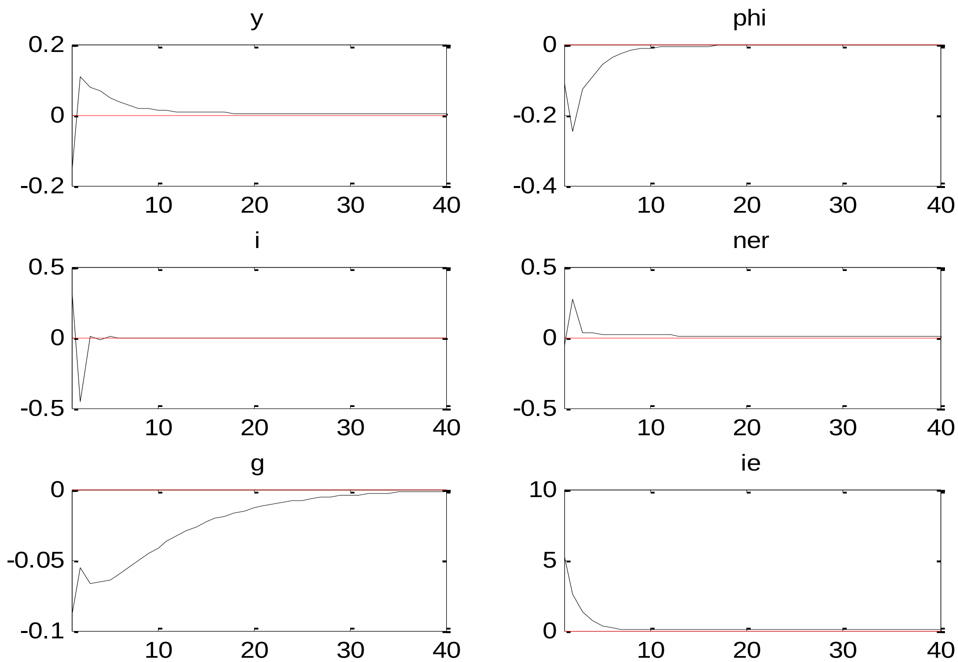
Orthogonalised Shock to Money Supply



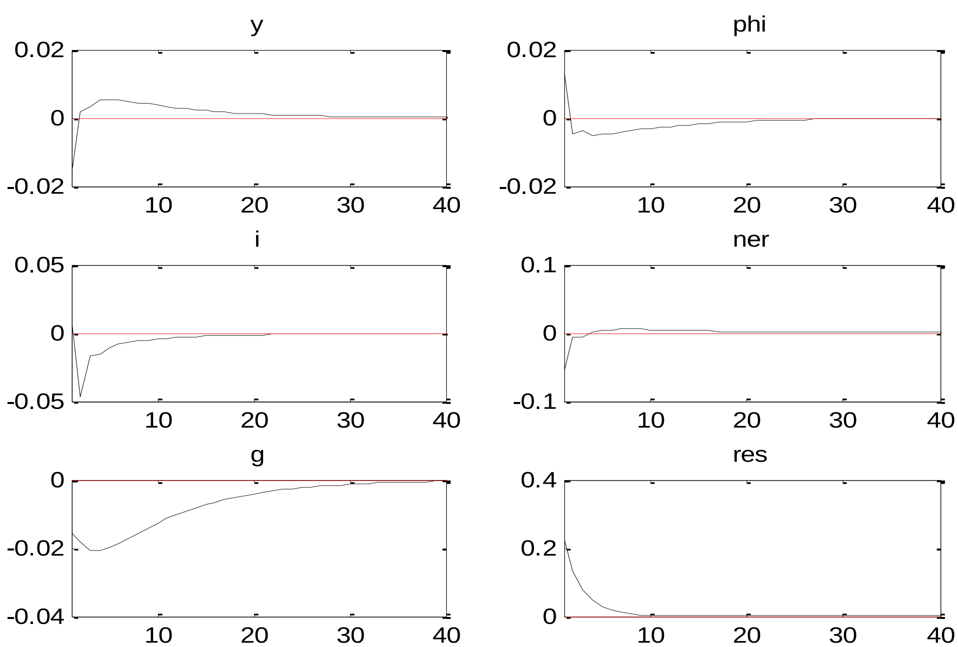
Orthogonalised Shock to Foreign Output



Orthogonalised Shock to Interest Rate Equilibrium



Orthogonalised Shock to Reserves



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