THAILAND’S MONETARY POLICY ANALYSIS:

A BAYESIAN ESTIMATION OF NK-DSGE MODELS

A Dissertation

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by

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To my dear parents

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ABSTRACT

This study applies Bayesian approach in estimating New-Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) models for Thailand, focusing on identifying and analyzing the impacts of monetary policy. The NK-DSGE models, designed to incorporate frictions observed in the real world, are capable of showing the non-neutral responses of real variables to a shock in short-term interest rate. In particular, the output, private consumption, and private investment expenditures display responses consistent with theoretical prediction and empirical findings from VAR models.

Unlike calibration which fixes the model parameters at specific values, Bayesian estimation allows for uncertainty in parameters' values through the use of priors and seeks to draw their posterior distributions. The posterior estimates of the behavioral parameters and structural shocks in the models provide insights of the economy as well as the characteristics of the monetary policy. With the calculation of marginal likelihood, we identify the set of model-improving frictions, and also compare the empirical performance of competing models for Thailand.

EXECUTIVE SUMMARY

Understanding how the monetary policy affects the economy is critical in policy formulation and assessment. In order to obtain such information, this study performs the Bayesian estimation of DSGE models for Thailand, emphasizing on analyzing the dynamic impacts of a monetary policy shock on a set of key macroeconomic variables.

The overarching framework by which we carry out the analysis is based on the New Keynesian family of the DSGE models. The NK-DSGE models are developed by taking into account the real world's imperfection and frictions, allowing for non-neutral responses of real variables to a monetary policy shock. Although price stickiness is regarded as an important source of monetary non-neutrality, we also study the inclusion of other forms of nominal and real frictions in the economy.

Our methodology relies on the Bayesian approach to parametize the DSGE models. Combining the data and the priors, the posterior estimates offer insights on the deep parameters inside households' and policymakers' decisions as well as the characteristics of the exogenous shocks. By calculating the marginal likelihood, which measures the model fit in terms of out-of-sample predictive power, the Bayesian approach also provides us with a basis for model comparison, allowing for sensitivity analysis and model fit test.

Our findings resonate a confirmation with theoretical prediction and empirical findings from VAR model. In particular, the output, private consumption, and private investment expenditures are shown to negatively respond to an increase in short-term interest rate, though with peak effects at different lags. Investment is identified as the most

responsive component of GDP to the monetary policy shock. Based on the marginal likelihood measure, we identify the list of frictions which improve the model performance. We also carry out forecast performance assessment and find that a medium-sized DSGE can compete with statistical BVAR models of different lags in explaining the dynamics of Thai data.

The brief outline of the following chapters is as follows. **Chapter 2** describes the economic structure and the conducts of monetary policy in Thailand, forming the contextual basis for understanding the rationales underlying the model specifications and the result interpretations in the subsequent chapters. **Chapter 3** presents our estimation of the parsimonious specification of a DSGE model following the work by Ireland (2004). With the only friction in terms of the price stickiness, we show that the monetary policy impact on real output is significant. Details of the Bayesian estimation and its advantages are also discussed.

To investigate a bigger picture and greater detail, **Chapter 4** uses a medium-sized DSGE model as proposed by Smets and Wouters (2007) with frictions in both nominal and real variables, including price and wage stickiness, habit formation in consumption, investment and capital utilization adjustment costs. Although the monetary policy shock is estimated to be small, its impacts on real variables as seen from the impulse response functions and variance decompositions cannot to be overlooked. Sensitivity analysis is performed to check the significance of the frictions and forecast performance comparison is also undertaken between the DSGE and BVAR models. **Chapter 5** offers the concluding remarks, drawing lessons learnt and recapitulating on the important findings.

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LIST OF ABBREVIATIONS

BOT: Bank of Thailand

BVAR: Bayesian Vector Autoregressive

DSGE: Dynamic Stochastic General Equilibrium

FRED: Federal Reserve Economic Data, St.Louis Fed

NESDB: National Economic and Social Development Board

NK: New Keynesian

NSO: National Statistical Office

RBC: Real Business Cycle

CHAPTER 1
INTRODUCTION

Monetary policy is an important macroeconomic policy tool with far-reaching impacts on the economy. Given its weighty implications, understanding the manners by which the monetary policy affects the intended variables is crucial in policy formulation and assessment. In this study, we explore the use of Bayesian methodology in estimating New-Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) models for Thailand, focusing particularly on identifying and analyzing the dynamic impacts of the monetary policy.

In particular, we aim to show the effect of the traditional interest rate channel on the key real variables, namely output, consumption, and investment. The estimation of the deep parameters inside the model structure also provides us with additional insights regarding the behavioral patterns and decision considerations of economic agents as well as the exogenous shocks.

In the simple yet powerful framework of IS-LM, the effect of an exogenous monetary policy shock takes place in a shift of the LM curve. The analysis pays attention to the results of the shock on the key variables: interest rate and output. Theoretically, an expansionary monetary policy shock, equivalently a rightward shift in LM curve, would entail a lower interest rate and a larger output. In a DSGE framework, where a larger set of variables interact based on behavioral equations, the intuition of monetary policy analysis remains mostly the same but with greater traceability and explanatory power.

NK-DSGE models have been recognized as a befitting tool for monetary policy analysis given their coherent theoretical framework to show the real impacts of monetary policy shock as well as their fit to data (Christiano et al, 2011). The strong theoretical support of DSGE models builds on the microeconomic foundation of general equilibrium framework where all economic agents in different sectors simultaneously optimize their decisions given respective constraints. The New-Keynesian family of DSGE models featuring a set of real world's imperfections is particularly apt to account for the non-neutrality of monetary policy, a conclusion contrary to the prediction of the RBC literature.

Our methodology, the Bayesian estimation, combines the structural model with the data and the initial beliefs regarding the parameters (priors). Unlike the calibration approach which fixes parameters at specific values, the Bayesian method allows for the uncertainties surrounding the parameters values and seeks to obtain their posterior distributions. It also provides a measure of model fit, in terms of the calculation of marginal likelihood, which allows researchers to compare different model specifications.

Based on the above framework, this dissertation focuses on the following questions: (1) To what extent monetary policy can influence the Thai real economy under the estimated NK-DSGE framework? (2) For Thailand, which kind of frictions is model-improving, which one is not, and to what extent? and lastly (3) How the forecast performance of the estimated DSGE model stands in comparison with statistical tools such as BVAR models? The answers to these three questions represent our contributions.

From the estimated NK-DSGE models in both chapters 3 and 4, we show that monetary policy has a non-neutral impact on the key macroeconomic variables. From the forecast error variance decompositions, interest rate shock accounts for between 7-11 percent of fluctuations in the real variables over the medium term. Impulse response analysis also shows the distinct responses among output and its components, in both magnitude and time dimension. Private investment is identified as the most responsive to monetary policy, with a decline threefold larger than that of the output and the longest lag of six quarters.

Frictions and rigidities are important ingredients of the NK models; however, which friction is important for the model and to what extent require a deeper investigation. We perform an exercise to identify the impacts of dropping individual friction on the model's performance. Exclusion of certain friction actually improves the model forecasting power. The results not only validate the choice of frictions included in the estimated model, but also offer valuable information for future model builders.

In order to stress the importance of model fit to data, this study provides the first formal comparison of forecast performance of the NK-DSGE models with that of Bayesian Vector Autoregressive (BVAR) for Thailand, along the same line with Smets and Wouters (2007). BVAR models, without imposing theoretical restrictions on the relationships among variables, are widely accepted as a leading statistical tool that offers superior description of the data. If the NK-DSGE specifications can compete with the BVAR, there is no need to compromise between sound theoretical restrictions and the model's predictive power.

The brief outline of the following chapters is as follows. **Chapter 2** describes the economic structure and the conducts of monetary policy in Thailand, forming the contextual basis for understanding the rationales underlying the model specifications and the result interpretations in the later chapters. **Chapter 3** presents our estimation of the parsimonious specification of a DSGE model based on the work by Ireland (2004). With the only friction in terms of sticky prices, we show that the monetary policy impact on real output is significant, and that there is an important role for additional frictions in the model. Details of the Bayesian estimation and its advantages are also discussed.

To investigate a bigger picture and greater detail, **Chapter 4** uses a medium-sized DSGE model as proposed by Smets and Wouters (2007) with a set of frictions in both nominal and real variables, including price and wage stickiness, habit formation in consumption, investment and capital utilization adjustment costs. Although the monetary policy shock is estimated to be small, its impacts on real variables in the model are important. Sensitivity analysis is performed to check the significance of the frictions and we also show that the DSGE model has a competitive forecast performance against different specifications of purely empirical BVAR models. The dissertation ends with **Chapter 5** which concludes by drawing lessons learnt and recapitulating on the important findings.

CHAPTER 2
THAILAND'S MACROECONOMIC OVERVIEW AND MONETARY POLICY

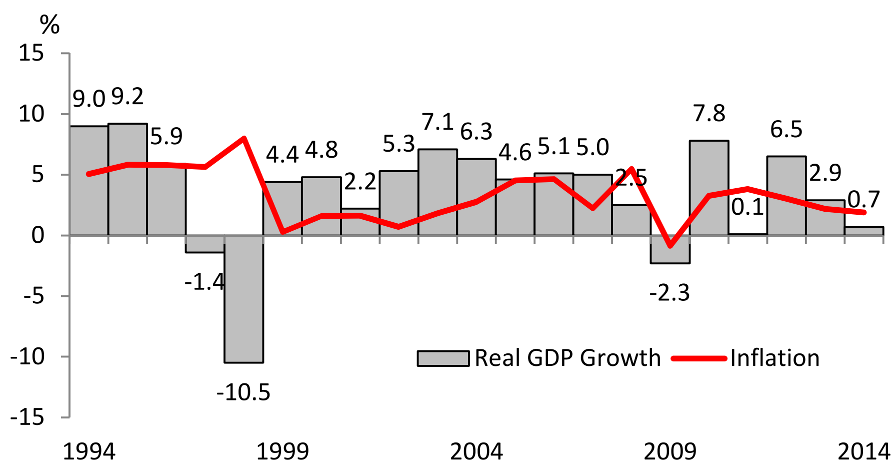
This chapter offers a portrayal of the country's economic development and structure as well as the overall framework of the monetary policy, forming an important building block to facilitate our analysis and result interpretations in the subsequent chapters. Section 1 takes a look at the breakdown of the Thai economy from both the production and expenditure sides, identifying the key components of the GDP. The behaviors of the other key macroeconomic variables such as price and wage are also examined. Section 2 narrates a brief history and current practice of the Bank of Thailand in navigating the monetary policy directions, focusing on its mission, target, and policy instrument.

1. Thai Economic Overview

The Thai economy has weathered through two major economic crises in the past twenty years. Figure 2-1 shows the development of real output and price level between 1994 and 2014. Before the Asian Financial Crisis in 1997, the Thai economy had enjoyed a period of amazing expansion, registering annual growth rates as high as 9 percent per year. The debacle of the bubble burst brought to light weaknesses in many sectors, resulting in a deep recession for the crisis years of 1997-1998, where the economy went through a major restructure and recovery. During 2000-2008, Thailand maintained an average growth of about 5 percent per year. The second economic distress came in 2009, resulting from the deteriorating impacts of the Global Financial (Subprime) Crisis, where the country observed a notable decline in exports and subdued confidence.

For the entire year of 2014, the nominal amount of GDP at current prices stood at 12.1 billion baht (or 0.35 billion USD at the exchange rate of 34baht/USD). In general, the inflation, defined as changes in headline Consumer Price Index (CPI), shows movements that are in tandem with the output fluctuations, except for during the period of 1997-1998, where the currency devaluation induced the rise in import prices which then transmitted into the domestic price levels. Over the two decades, the economy grows at 3.8 percent per year, and headline inflation at 2.6 percent per year.

Figure 2-1 Real GDP Growth and Headline Inflation (CPI)

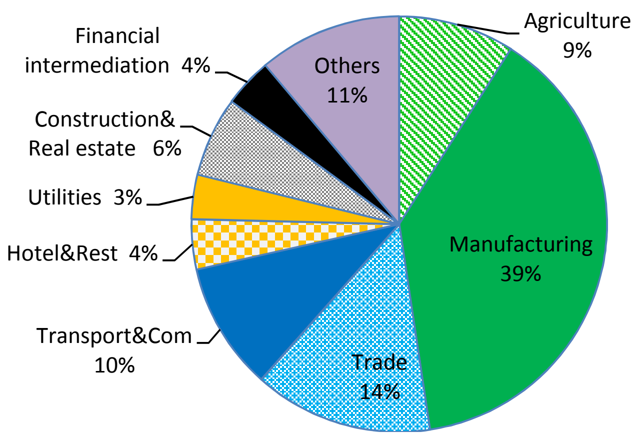


Source: FRED

Supply Perspective

In order to see the decomposition of the Thai economy, Figure 2-2 displays the average shares[1] of different industries relative to real GDP. From the production side, the Thai economy is characterized mainly by the manufacturing, agriculture, trade as well as transports and communication industries, together accounting for about three-quarter of total output. Hotels and restaurants, financial intermediation, construction and real estates, and utilities (electricity, water supply, gas, etc) contribute the additional 15 percent share of GDP. Others sector, which provides the rest of 10 percent share of GDP, consists mainly of other forms of services such as education, health care, and public administration. Within the manufacturing industry, which alone accounts for almost 40 percent share of GDP, the key outputs include electronic products, petroleum, textiles, and foods, as implied by the weights of the Manufacturing Production Index (MPI) published by the Bank of Thailand.

Figure 2-2 Decomposition of GDP by Industries



Source: NESDB

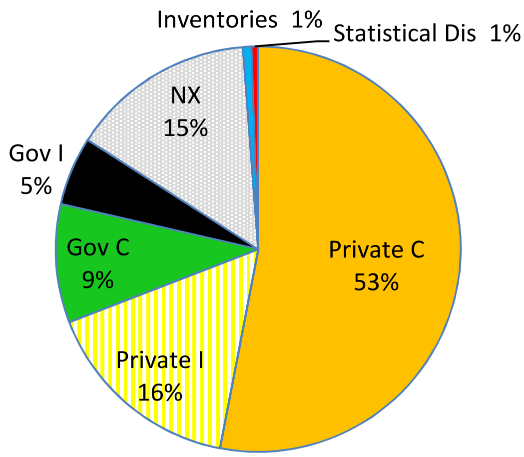
[1] The shares of GDP are calculated using the sample average between 2001 and 2014 of the GDP at constant (1988) prices.

Demand Perspective

Figure 2-3 shows the dissections of the Thai economy based on main expenditure components. Private consumption expenditure (PCE) is by far the largest GDP item, accounting for more than half of the total output. Combining the private consumption and investment spendings, the total share of private sector reaches almost 70 percent of GDP. The shares of public sector and the net exports, on the other hand, stand roughly the same at 15 percent of GDP respectively. Changes in inventories and Statistical discrepancies are negligible at 1 percent share each.

Within the PCE, the major components are non-durable consumption (food and non-food) and services, together representing about three-quarter of household consumption. On the other hand, durable and semi-durable consumptions account for the rest of 25 percent of PCE. (Dacharux, 2012)

Figure 2-3 Decomposition of GDP by Expenditures

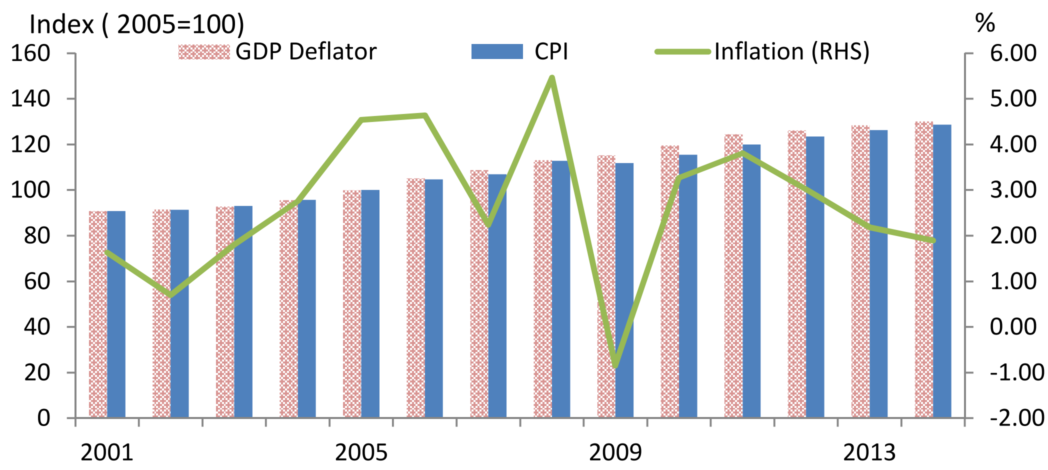


Source: NESDB

Prices

The most prevalent and well-understood measure of overall price level in Thailand is the Consumer Price Index (CPI), tracking the prices of key items in the consumer basket. Another important measure is the GDP deflator which is calculated as a ratio between nominal and real GDP. Despite the differences in components and compilation methods, the CPI and the GDP deflator trace almost exactly the same trend, as shown in the Figure 2-4. The headline inflation, calculated as the change in CPI, grows at the average rate of 2.6 percent during the period 2001-2014. Inflation hiked up in 2008 as a result of record-high oil price in the world market, before taking a deep plunge in 2009 as the adverse repercussion from the Subprime crisis slowed down the global economy. Since then, inflationary pressure remains low due to softened demand as well as the increase in oil supply from the innovation in shale oil production.

Figure 2-4 Prices and Monthly Wage for the Whole Kingdom



Source: NESDB, FRED

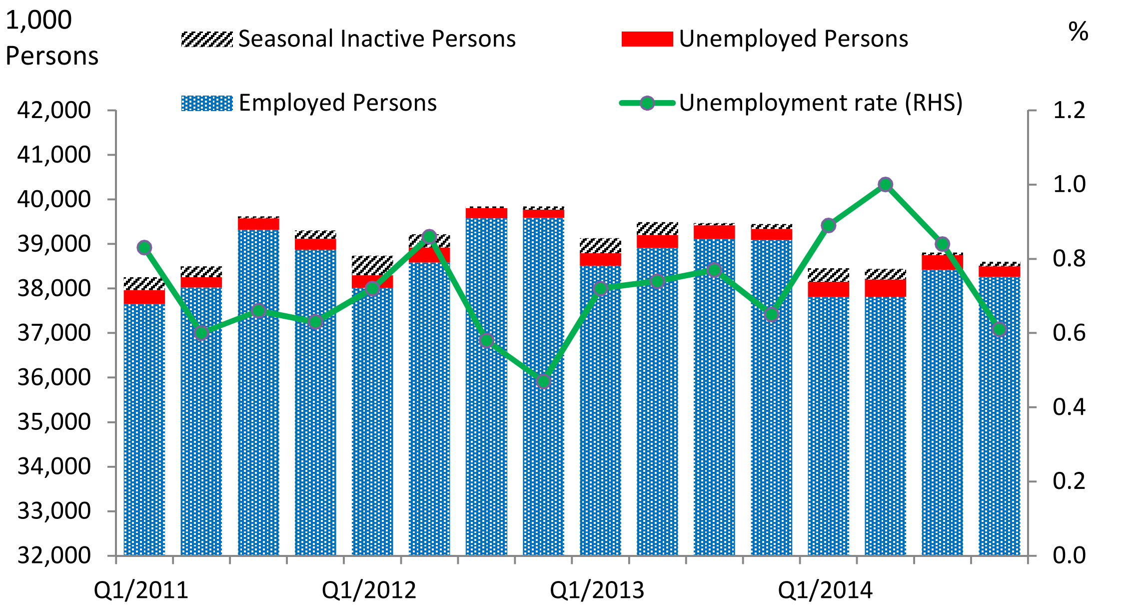
Labour Force

The National Statistical Office (NSO) carries out Labour Force Survey on a monthly basis. For the last quarter of 2014, Thailand had a total of 55 million persons aged 15 years old and over. A fraction of this number is not considered to be in the labour force due to their undertaking in non-professions such as study or household work.

Thai labour force, thus, stood at 38.5 million persons, of which 99.1 percent were employed. Among the employed persons, about 30 percent work in the agriculture sector, while the rest, about 25 million persons, work in the non-agriculture sector which includes manufacturing, trade, hotels and restaurants, and construction. This picture is consistent with the GDP by industries as shown above. On the other hand, at the end of 2014, there were 0.24 million unemployed persons, or approximately 0.6 percent of the labour force, as shown in Figure 2-5.

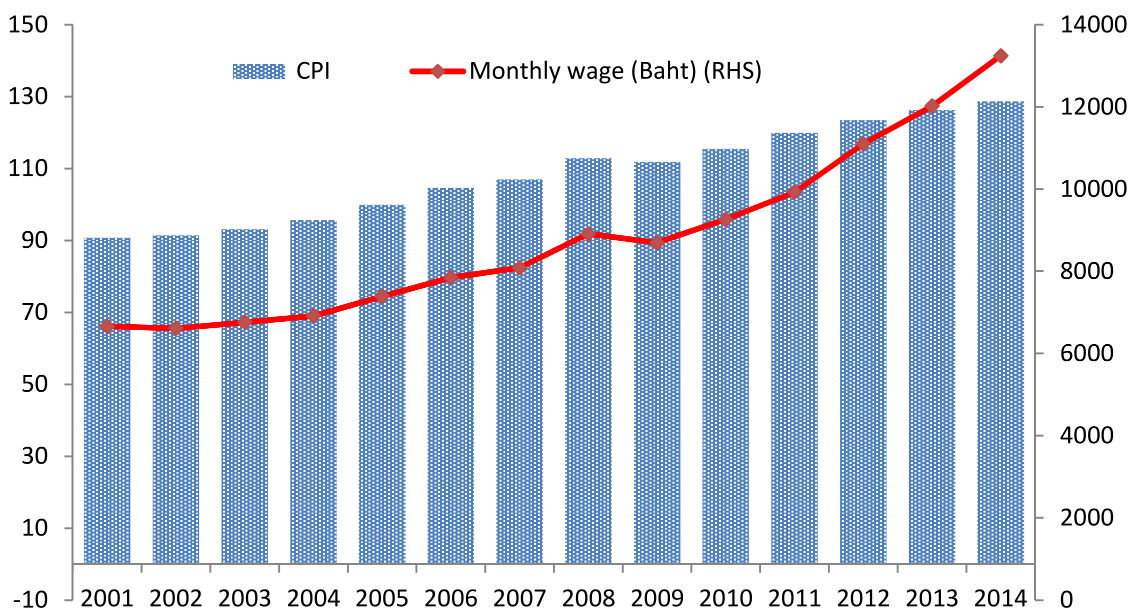
Figure 2-6 displays the development of the average monthly wage for the whole kingdom between 2001-2014. As evident from the figure, the average wage appears to well reflect the movement in price level, as indicated by the CPI. At the end of 2014, the monthly average wage stood at about 13,000 baht (or around 390 USD at the exchange rate 34 baht/USD).

Figure 2-5 Labour Force and Unemployment Rate



Source: Labour Force Survey, NSO and BOT

Figure 2-6 Monthly Wage for the Whole Kingdom and CPI



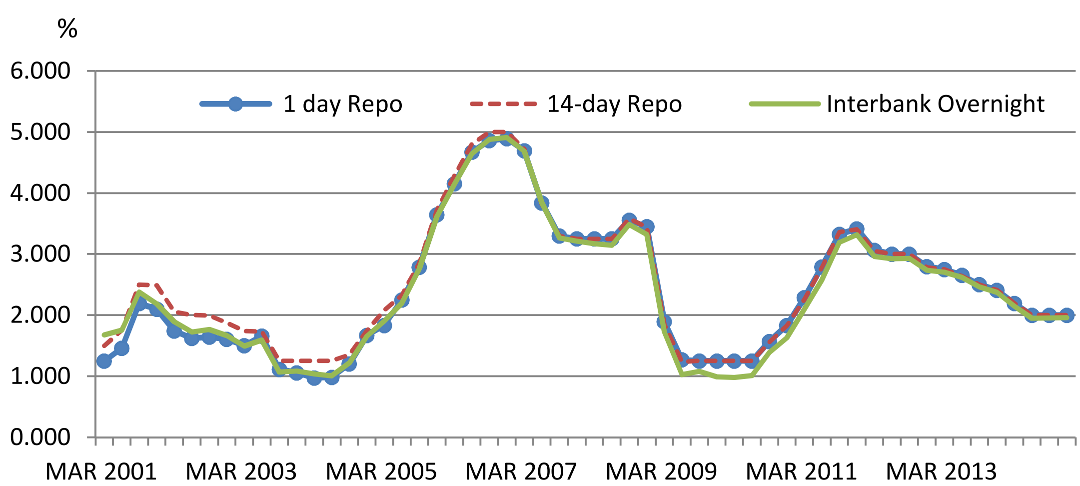
Source: Labour Force Survey, NSO and BOT

2. Monetary Policy

From the establishment in 1942 until the outbreak of the Asian Financial Crisis in 1997, the Bank of Thailand had used the pegged exchange rate regime, mainly to the value of US dollars. For the additional three years leading to the recovery from the crisis, under the International Monetary Fund (IMF) program, Thailand adopted the monetary (money supply) targeting to support the economic growth and stability objectives. It was not until May 2000 that the current regime of inflation targeting was in place.

Under the inflation targeting framework, the central bank has a clear mandate in maintaining price stability, translating into a mission of keeping headline inflation low and stable in the range of 2.5±1.5 percent on the annual basis. Any excessive deviation from this target in either direction would prompt the central bank to issue explanation to the general public to ensure its transparency and accountability in maneuvering one of the country's most important macroeconomic policies.

Figure 2-7 Policy Interest Rate and Other Money Market Rates



Source: BOT

The policy instrument for the monetary policy to achieve its target inflation is the 1-day repurchase (1-day Repo) rate, as shown in the Figure 2-5, a short-term money market interest rate that affects the commercial banks' cost of capital and influences the lending/deposit rates. The change in interest rates facing consumers and investors would then alter their decisions about current consumption and investment, leading to a change in aggregate demand and the overall price levels. This brief explanation outlines the traditional interest rate channel of the monetary policy's transmission mechanism. There are other transmission channels, including credit channel, asset price channel, exchange rate channel, and expectation channel. For more theoretical background and detail, please refer to Boivin et al (2011).

In order to formulate an appropriate monetary policy, the central bank needs to have a clear and correct understanding of the current economic conditions as well as the outlook to which the economy is heading. With this demand in policymaking process, the Bank of Thailand has employed a number of statistical and econometric models to assess and forecast the economy. These include the main workhorse BOTMM (Bank of Thailand Macroeconometric Model), an estimated semi-structural model, a calibrated DSGE model, among others. For further detail regarding these models, please refer to subsection 2.3 of the Chapter 3.

CHAPTER 3
BAYESIAN ESTIMATION OF A NEW-KEYNESIAN DSGE MODEL AND MONETARY POLICY IN THAILAND

1. Introduction

This chapter studies the use of Bayesian methods in estimating New-Keyesian Dynamic Stochastic General Equilibrium model for Thailand with the focus on the analysis of the monetary policy impacts on key macroeconomic variables. In the short-run, the impacts of monetary policy instrument, the short-term interest rates, on real variables are not neutral.

A large number of studies have been carried out in developing DSGE models that are representative of the actual economic and institutional characteristics. The DSGE models have evolved from the perfect world of Real Business Cycle to incorporate real world frictions such as those lags in adjusting prices and production capacities. Following Ireland (2004), our New Keynesian DSGE model is parsimonious, allowing for monopolistic competition in the economy and featuring a monetary authority which adopts a rule-based framework to decide the direction of monetary policy. The Bayesian approach, which gains increasing popularity and provides the basis for our estimation, is a useful tool to uncover the important information regarding the deep parameters in the DSGE models as well as the possibility of DSGE models' downsides such as misspecification.

A brief glance at the results shows that in the small NK-DSGE with only one source of nominal rigidity in terms of sticky prices, an increase in short-term interest rate induces output measures as well as inflation to decline. The non-neutrality of monetary policy impacts is further confirmed by the variance decomposition of the key endogenous variables. The Modified model with the inclusion of lagged variables performs better than the Baseline model which is purely forward-looking, indicating a significant role of additional frictions in the model.

After this brief introduction, the paper proceeds to review the key literature regarding the development of DSGE models as well as exploring the international evidence of DSGE models in monetary policymaking institutes including that of Thailand. Section 3 focuses on the Bayesian methods in estimating DSGE models before the specification of our DSGE model is described in the Section 4 with a particular attention on monopolistic competition and monetary policy. Section 5 shows the results and interpretations, and this chapter ends with Section 6 of concluding remarks.

2. Literature Review

This section introduces Dynamic Stochastic General Equilibrium (DSGE) models, relevant studies and widespread uses by policymaking institutions, as well as the particular role this class of models plays at the Bank of Thailand. DSGE framework has been developed along with the progress made in both Monetary Economics and Macroeconomics since 1970s (Walsh, 2003), starting from the theoretical foundation by Lucas (1972) for the role of money on real economy, to the trailblazing work on Real Business Cycle models by Kydland and Prescott (1982) that highlighted the importance of technology innovation, and to the additional frictions in the model economy that allow for the roles of money and other kinds of shocks in the New Keynesian DSGE framework.

2.1 DSGE Literature: A Brief Review

DSGE models were developed to bridge between aggregate macroeconomic data and economic principles, based on microfoundation especially the optimization which characterizes behaviors of different sectors in the model economy. Before the advent of DSGE models, researchers and policymakers relied on the traditional macroeconomic models, which consisted of relationship equations based on historic data without clear-cut theoretical linkage. Despite the fitness to data and forecast performance of these macroeconomic models, the lacking of Economics stories behind them could pose problems in explaining the results coherently.

DSGE literature started with Real Business Cycle (RBC) models before branching out to imitate more of the real world imperfections in New Keynesian lineage. The pioneering work in RBC by Kydland and Prescott (1982) combined Neoclassical growth and business cycle theories, together with multi-period assumption. This allowed the authors to demonstrate the powerful potential of a small dynamic model to recreate fluctuations similar to that observed in the actual data. This keystone work inspired a vast number of follower researchers, hugely contributing for the rise of the RBC models. As

King and Rebelo (1999) summarize, the RBC models are ones in which technology innovations, create and propagate economic fluctuations. In other words, only the ‘real’ shocks have impact on output. This class of models assumes a perfect world with flexible prices, perfectly functioning markets, zero friction, such that there is no effective role for monetary policy in affecting the economic outcomes. The only source of fluctuations in the economy comes from technology innovations or productivity shocks.

An alternative, contending perspective, that the world is less than perfect, came with the development of another branch of DSGE models, the New Keynesian. As Walsh (2003) summarize, there are 3 key components for what we term New Keynesian models: 1) Demand side: an expectational IS curve that represents the intertemporal decisions of the households based on Euler equation; 2) Supply side: monopolistic producers and sticky prices; and 3) Monetary policy to achieve a targeting objective. , New Keynesian DSGE models are basically RBC models with additional assumptions to mimic the real world’s institutions and imperfections.

Tovar (2008) summarize that the rigidities that are added to the RBC models often include frictions of both real and nominal natures. Real frictions are the persistence in output components such as the habit in consumption and capacity utilization in production. Nominal rigidities usually involve stickiness in prices and wages which may result from the presence of adjustment cost, contracts or market failures. Monetary policy institution is assumed to aim to achieve policy targets, bringing the economy close to the efficient level. Combining rigidities in the markets and the presence of monetary authority, the models generate fluctuations from various kinds of shocks, not limited solely to changes in productivity.

Monopolistic competition was first shown to have important impact on how the fluctuations propagate in the economy. Rotemberg and Woodford (1993) introduced a novel idea in DSGE modeling at the time by assuming that firms, instead of being price-takers in a market of perfect competition, produce differentiated goods and thus possess market power enough to set prices. This alteration of the traditional assumption resulted in the rising significance of mark-up shocks in driving the business cycle, compared to the exclusive role of technology shock in the standard RBC model.

However, DSGE models with monopolistic competition alone cannot tackle the pressing question of the impacts of monetary policy on real activity, especially the explanation for co-movement between output and inflation observed in data. Yun (1996) was one of the pioneering researchers to integrate a complete monetary policy analysis in a DSGE system. By deriving optimizing decisions for each sector, Yun's model incorporated not only the monopolistic competition and staggered multi-period Calvo-type price setting behavior which resulted in price stickiness, but also a representation of monetary policy through a money supply rule. This allowed him to demonstrate a significant impact of monetary policy shocks on the model economy under sticky prices, a result more in line with empirics, in contrast to the neutral role suggested by flexible-price models.

As pointed by Fernandez-Villaverde (2009), three requirements for non-neutrality of money in NK-DSGE models for monetary policy analysis lie in 1) monopolistic competition that induces price rigidity; 2) money in the utility function; and 3) monetary policy rule. In the perfect world of RBC, money is neutral. In order for DSGE model to recognize the role of shocks from sources other than technology, some forms of frictions must be added.

The work by Ireland (2004) provided an inspiration and basis for this study to construct a NK-DSGE for Thailand with analytical focus on the role of monetary policy shocks. In particular, the presence of sticky prices stemming from monopolistic producing firms and the monetary authority adopting a fixed feedback rule allowed Ireland to demonstrate the meaningful impacts of preference shocks, cost-push shocks, and monetary policy shocks, in addition to the traditional technology shocks in the RBC literature. Monetary policy shocks were shown be a key driver of variations in output growth and inflation. Based on the model's impulse responses, an interest rate hike of 21 basis points entailed a decline in output and inflation by 63 and 83 basis points, respectively. This powerful result corresponded to the work of Christiano et al (2005) which also documented a DSGE model with nominal rigidities in prices and wages, along with frictions in consumption and investment, produced fluctuations similar to the post-war US data. In particular, monetary policy was demonstrated to have dynamic impacts on the US economy, as apparent in the real variables showing hump-shaped responses to monetary policy disturbance.

2.2 DSGE for Monetary Authorities

We have seen that DSGE has been developed in such a manner that various kinds of shocks can be accounted for, and monetary policy shocks appear to be of particular attention. Now we turn the discussion to the acceptance of DSGE especially among the monetary policy institutes, together with the strengths and weaknesses that come with it. Tovar (2008) reviewed the use of DSGE models in central banks around the world to gain insights of the working of their respective economy. It was recognized that this class of model was popular among the monetary authorities in giving the policy decision framework a coherent theoretical support. Central banks in Canada, England, EU, Norway, Sweden, US, Chile, and Peru were among the adopters of DSGE models for analyzing the economy and policy impacts (Tovar, 2008; Del Negro and Schorfheide, 2006).

One of the widely cited works is by European Central Bank's Smets and Wouters (2003), who developed and estimated a NK-DSGE model for the Euro area. This comprehensive DSGE model featured a set of 10 shocks, ranging from supply and demand sides shocks to monetary policy shocks. Given an array of rigidities assumed for the economy, the model produced the dynamics as close to the real data as those provided by the less structured models such as VAR models, while given its identification of the structural shocks, it can serve as a tool for policy analysis. Another benefit of DSGE estimation in Smets and Wouters (2003) was that structural parameters can be obtained, for instances the extent of price rigidity or the elasticity governing the decision of labor hours. Both provided important insights for the Euro area economic dynamism, particularly the inflation persistence and adjustment in labor market. The DSGE model also allowed the authors to draw conclusions about the impacts of various structural shocks through the use of impulse response functions and variance decompositions.

Another use of the micro-founded, optimization-based DSGE model in monetary policy analysis was done by Erceg et al. (2006). At the Federal Reserve Board, the DSGE model, dubbed SIGMA, was developed to incorporate with two-country, open-economy assumptions. By including an array of shocks relevant and important in policy questions, the SIGMA can help analyze the impacts of changes in home country demand, foreign demand, risk premium, along with fiscal and monetary shocks. This was done in comparison with the results from the large-scale macroeconomic model (FRB/Global model), and in the short-run horizon both models perform consistently for most of the variables, except a few disparities in import prices and the output impact of foreign shocks. However, the DSGE type of model, as the authors argued, has an advantage in analyzing structural shocks over other types of macroeconomic model as in the DSGE framework transmission channels of all shocks are spelled out clearly.

Despite its strengths in coherent theoretical support and popularity among academic and policymakers, DSGE models are not without weakness. As Tovar (2008) critiqued, although DSGE models were developed in most central banks, they are not fully integrated into policy decision framework due to firstly the difficulty in communicating the model and its results among the policymakers as well as to the public given its technical complexity and detailed derivations. Secondly, DSGE models are highly stylized and definitions of variables are crucial, meaning that data manipulation is required, such as detrending, eliminations of structural breaks or outliers, among others. Thirdly, the forecast performance of DSGE models is also still lacking behind the class of less structured models such as VAR family. And lastly, there is debatable possibility of misspecification of DSGE type of models. The attack comes at the highly stylized structure of DSGE models with their strong assumptions about the economy. However, DSGE proponents, instead, argue that this class of model can deal nicely with misspecification given that it includes the definitions of shocks or disturbances in the system. Especially with the use of Bayesian techniques, employed in this paper, the concern over misspecification become of less importance. (More detailed discussion in the following section on Methodology)

2.3 DSGE Models for Thailand

At the Bank of Thailand, DSGE model assists policymakers in forecasting and analyzing the economy and impacts of policy changes. To inform the Monetary Policy Committee (MPC), three main types of economic models help to formulate understanding about the functioning of the economy and the impacts of policy decision[2].

The first is Bank of Thailand Macroeconometric Model or BOTMM, which is a large-scale system of equations representing Thai economy in 4 main sectors: real, financial, external, and public sectors. Although, these relationship equations in and between sectors are "guided by theory", they are not directly derived from optimization principle. Since expectation is not explicitly taken into account in this type of models, the parameters are subject to Lucas Critique and thus unbefitting to analyze policy changes. The BOTMM is estimated by error-correction method. The second is the Small Semi-Structural model, a parsimonious model of behavioral equations describing Thai and foreign economies. This second model positions itself between the empirical BOTMM and the structural DSGE

[2] This subsection is based on the explanation provided on www.bot.or.th.

models, providing "a good blend of theories and empirics" in a simple and tractable manner (Pongsaparn, 2008). The model is estimated using Bayesian method, allowing for specifications of prior distributions and shocks; however, since the structure is not derived from optimizing problems, this second model does not estimate the deep parameters which govern the economic agents' behaviors.

The third model is an elaborate New Keynesian DSGE developed by Tanboon (2008). This microfounded DSGE model systematically incorporates important characteristics of the Thai economy, replicating the real world that has sticky prices and wages, habit persistence in consumption, monopolistically competitive domestic sector and world price-taker export sector, capacity-adjusted production, as well as functioning banking sector. Fiscal and monetary policies were formulated following predetermined rules. Each equation is obtained from optimization decision in the sectors as well as specifications of shocks. The model was parametized by calibration, based on careful selection of stylized facts, input-output table, and various econometric models employed at the Bank. The shocks that perturb the economy in this model include 1) Productivity shock; 2) Price shock; 3) Exchange rate shock; and 4) Monetary policy shock.

Apart from Tanboon (2008) at the BOT, there are a few related research studies which also adopt the New Keynesian DSGE framework for Thailand. Aiyar and Tchakarov (2008) and Amornvivat et al. (2009) Bayesian estimate semi-structural NK models, along the same line with Pongsaparn (2008). Again, since these models are not derived from optimization problems, the deep parameters are not defined and estimated.

More relevant to our study are the works by Chuantantikamon (2008) as well as Alp and Elekdag (2012). Chuantantikamon (2008) performs Bayesian estimation of an open-economy DSGE model with sticky prices and habit formation in consumption for Thailand. He shows that by including the consumption friction, its impulse responses track a hump shape consistent with VAR empirical suggestion. His estimate of nominal rigidity also suggests that the reoptimizing interval of domestic price contract is around 3 quarters. Meanwhile, Alp and Elekdag (2012) estimate an elaborate open-economy NK-DSGE model, focusing on the counterfactual experiments when three powerful shocks hit the Thai economy, namely the 2008 Global Financial Crisis, as well as the Japan Earthquake and Thai Flood in 2011. However, neither of these studies provides a thorough investigation of the empirical importance of the friction inclusions as well as an assessment of DSGE forecast performance by comparing it with BVAR models, both of which will be carried out in our subsequent sections.

3. Bayesian Estimation

The general choice for working with DSGE models is between calibration and estimation. Calibration relies solely on inference from external sources to assign values for each parameter. This includes micro-level relationships found in existing studies, and stylized facts. Estimations, on the other hand, make use of the observable data and model to determine the parameter values, varying from Generalized Method of Moments (GMM) estimation, full-information likelihood function estimation, and Bayesian estimation (An and Schorfheide, 2007). The Bayesian estimation, in particular, combines the data with assumptions on prior distributions to determine the posterior distributions for parameter.

3.1 Advantages of Bayesian Estimation

Bayesian estimation has gained popularity among DSGE researchers because of a number of considerations. Estimating DSGE models using Bayesian approach, according to Canova (2007), can lessen the usual concerns of DSGE models, particularly the misspecifications from the imposition of strong restrictions as well as the possibility of singular covariance matrix. This hinges on that the derivation of the posterior distributions in Bayesian estimation is independent of whether the models correctly replicate the data generating process or not.

According to An and Schorfheide (2007), although misspecification can post an issue for any estimation method, the estimation of DSGE models is particularly more susceptible due to their strong restrictions. However, Bayesian methods of weighing likelihood function with prior density prevent posterior density to peak in unlikely ranges. This weighing process benefits the numerical maximization and the Markov-chain Monte-Carlo (MCMC) methods thanks to the curvature the priors add on to the posterior density function. Additionally, by choosing to equate the number of shocks and the number of observable variables to be included in the model, the possibility of misspecification and singularity of covariance matrix can be preempted.

Moreover, the Bayesian estimation also facilitates the comparison between different DSGE models. According to Canova (2007), in addition to the informal comparison between the models' impulse response functions, researchers can also judge the models based on the fitness to data. The posterior odds ratio shows the forecasting performance of different model specifications, and thus this method can be used to identify the best model as implied by the Bayes factor. The following subsection explores on the Bayesian rule more deeply.

3.2 Bayesian Methods

According to An and Schorfheide (2007), Bayesian estimation of DSGE models is a mixture of maximum likelihood method and calibration. DSGE estimation by means of likelihood function alone is possible but may lead to locating improbable values for parameters. To prevent this, Bayesian estimation introduces the calibration component by attaching "priors" as weights to the likelihood function. The priors act as the guiding initial guesses around which the algorithms perform sampling processes with an aim to trace the posterior distributions.

The main ideas behind the Bayesian methods are as follows. According to Griffoli (2013), Bayesian estimation brings together data and priors, which represent our initial beliefs about parameters' distributions. The density of data is denoted by $p(\Psi_T|\theta_{\mathcal{M}},\mathcal{M})$, equivalent to the likelihood function $\mathcal{L}(\theta_{\mathcal{M}}|\Psi_T,\mathcal{M})$. On the other hand, the priors enter as the probability density functions for the parameter vector $\theta_{\mathcal{M}}$ conditional on the model, denoted as $p(\theta_{\mathcal{M}}|\mathcal{M})$. The posterior density of our interest is described by $p(\theta_{\mathcal{M}}|\ \Psi_T,\mathcal{M})$. By using the Bayes theorem, the posterior density can be expressed as a product of prior density and likelihood function, scaled by the marginal density function, defined as $p(\Psi_T |\, \mathcal{M}) = \int_{\theta_{\mathcal{M}}} p(\theta_{\mathcal{M}}; \Psi_T |\, \mathcal{M})\, d\theta_{\mathcal{M}} = \int_{\theta_{\mathcal{M}}} p(\Psi_T | \theta_{\mathcal{M}}, \mathcal{M}) * p(\theta_{\mathcal{M}} | \mathcal{M})\, d\theta_{\mathcal{M}}$.

$$p(\theta_{\mathcal{M}} |\, \Psi_T, \mathcal{M}) = \frac{p(\Psi_T | \theta_{\mathcal{M}}, \mathcal{M}) * p(\theta_{\mathcal{M}} | \mathcal{M})}{p(\Psi_T |\, \mathcal{M})}$$

$$= \frac{\mathcal{L}(\theta_{\mathcal{M}} | \Psi_T, \mathcal{M}) * p(\theta_{\mathcal{M}} | \mathcal{M})}{\int_{\theta_{\mathcal{M}}} p(\Psi_T | \theta_{\mathcal{M}}, \mathcal{M}) * p(\theta_{\mathcal{M}} | \mathcal{M})\, d\theta_{\mathcal{M}}}$$

The numerator on RHS is called posterior kernel, i.e. $\kappa(\theta_{\mathcal{M}} |\, \Psi_T, \mathcal{M}) \equiv p(\Psi_T | \theta_{\mathcal{M}}, \mathcal{M}) * p(\theta_{\mathcal{M}} | \mathcal{M})$, which is directly proportional to the posterior density $p(\theta_{\mathcal{M}} |\, \Psi_T, \mathcal{M})$ of our interest.

Based on the above foundation, when the model and data on observable variables are given, the Kalman filter, or other particle filters for nonlinear models, can be used to calculate the likelihood function. The posterior kernel is then a product of the likelihood function and the priors. By the Metropolis-Hastings methods, the parameter values are drawn and the accepted values are then used to plot a histogram of the posterior distribution.

The following section describes algorithms for Bayesian estimation of posterior distributions, which are based from Canova (2007) and the DYNARE documentation by Griffoli (2013).

<u>Bayesian Estimation Algorithm</u>

B1) Rewrite the DSGE model in state-space representation

B2) Specify the prior distributions $p(\theta_{\mathcal{M}} | \mathcal{M})$

B3) Calculate the (log) likelihood function $\ln \mathcal{L}(\theta_{\mathcal{M}} | \Psi_T, \mathcal{M})$ using Kalman filter recursion

- Calculate log posterior kernel from the likelihood function and prior distribution $\ln \kappa(\theta_{\mathcal{M}} | \Psi_T, \mathcal{M}) = \ln \mathcal{L}(\theta_{\mathcal{M}} | \Psi_T, \mathcal{M}) + \ln p(\theta_{\mathcal{M}} | \mathcal{M})$

B4) Maximize the log posterior kernel with respect to the parameter vector $\theta_{\mathcal{M}}$ to find the mode of posterior distribution

B5) Estimate the posterior distribution $p(\theta_{\mathcal{M}} | \Psi_T, \mathcal{M})$ by means of **Metropolis-Hastings methods**

<u>Metropolis-Hastings Algorithm</u>

MH1) Pick a starting value, θ^0, usually the posterior mode from B4)

MH2) Draw a new candidate value, θ^*, from a jumping distribution, a Gaussian distribution with a mean equal to the previous value

- $\mathrm{J}(\theta^* | \theta^{t-1}) = \aleph(\theta^{t-1}, c\Sigma_m)$

MH3) Compare the candidate to the previous value in evaluating the posterior kernel κ

- Acceptance ratio r $= \frac{p(\theta^* | \Psi_T)}{p(\theta^{t-1} | \Psi_T)} = \frac{\kappa(\theta^* | \Psi_T)}{\kappa(\theta^{t-1} | \Psi_T)}$ where κ is the product of likelihood density and prior

MH4) Based on the acceptance ratio,

- If r ≥ 1, i.e. $p(\theta^* | \Psi_T) \geq p(\theta^{t-1} | \Psi_T)$, accept the candidate: $\theta^t = \theta^*$ and update the mean of the jumping distribution in MH2
- Otherwise, accept the candidate ($\theta^t = \theta^*$) with probability (r); reject the candidate and use the previous value: $\theta^t = \theta^{t-1}$ with the probability (1- r)

MH5) Repeat MH2-MH4 for sufficient number of rounds to construct a histogram of accepted candidates which represents the posterior distribution of interest

4. Model Specification and Data

This section describes a NK-DSGE model with monopolistic competition and monetary authority, following mainly the version explained in Ireland (2004) and Dave and Dejong (2011), as well as exploring the data used for our estimation with Bayesian methods. In essence, the model economy consists of 4 sectors, namely, households, intermediate producer firms, final producer firms, and a central bank. Households own the intermediate goods-producing firms receiving net profit from their operation and at the same time earn labor income by supplying working hours. The intermediate goods enter a monopolistically competitive market, whereas, the finished goods operate in a perfect competition setting. The market power of the intermediate goods producers allows for price setting behavior and the ensuing resistance to adjust freely. Central bank infuses the economy with money and conducts a rule-based monetary policy. Against these 4 sectors, there are 4 driving forces in our model, namely preference, technology, cost-push, and monetary policy shocks.

4.1 Households

The model economy is populated by households with the same utility function, choosing the use of their resource (labor hours, h_t), the consumption (C_t), and the real money holdings ($\frac{M_t}{P_t}$). Analytically, this aggregate resource allocation problem can be solved at a representative household level, where each household maximizes expected discounted utility. The following functional form defines the utility function:

$$E_t \sum_{t=0}^{\infty} \beta^t [a_t \ \ln(C_t) \ + \ \ln\left(\frac{M_t}{P_t}\right) \ - \ \left(\frac{1}{\eta}\right) h_t^{\eta} \ ]$$

The household utility is additive-separable, increasing in consumption of final goods and real money balance, while decreasing in working hours, all time-discounted by the factor $\beta_t \in (0,1)$. The parameter a_t represents the exogenous preference shock to the demand for consumption.

The representative agent is, at the same time, facing with a budget constraint, where labor income is generated from supplying labor services to intermediate producer firms for the hourly wage W_t. For each period, the household also collect additional incomes from transfer (T_t) and dividend (D_t), distributed by the central bank and the ownership of the goods producing sector. The income, after consuming C_t units of final goods at the price $P_t$in the current period, adds to the household's wealth in the forms of cash and r_t-interest bearing bond holdings (M_t and B_t respectively), carried over to the next period. Therefore, the budget constraint takes the form:

$$W_t h_t + T_t \ + D_t - \left(\frac{B_t}{r_t} - B_{t-1}\right) - (M_t - \ M_{t-1}) = P_t C_t$$

Formulated this problem into unconstrained dynamic maximization, the Lagrangean equation gives out the following first ordered conditions (F.O.C.) according to labor hours, real bond, and real money balances, respectively:

$$\frac{\partial \mathcal{L}}{\partial h_t}: \qquad h_t^{\eta-1} = \frac{a_t}{C_t}\left(\frac{W_t}{P_t}\right) \tag{1}$$

$$\frac{\partial \mathcal{L}}{\partial \frac{B_t}{P_t}}: \qquad \frac{a_t}{C_t}\left(\frac{1}{r_t}\right) = \beta\, E_t\left[\frac{a_{t+1}}{C_{t+1}}\left(\frac{P_t}{P_{t+1}}\right)\right] \tag{2}$$

$$\frac{\partial \mathcal{L}}{\partial \frac{M_t}{P_t}}: \; \frac{a_t}{C_t} = \left(\frac{M_t}{P_t}\right)^{-1} + \beta\, E_t\left[\frac{a_{t+1}}{C_{t+1}}\left(\frac{P_t}{P_{t+1}}\right)\right] \tag{3}$$

4.2 Final Producing Firm

A representative final producer firm acquires an intermediate good (Y_{it}), $i \in (0,1)$ at the price P_{it} as an input to assemble for finished goods (Y_t) which, in turn, can be sold at the market price P_t. Its objective profit function and the production constraint appears as

$$\Pi^F = P_t Y_t - \int_0^1 P_{it} Y_{it}\; di$$

$$Y_t = \left[\int_0^1 Y_{it}^{\left(\frac{\theta_t - 1}{\theta_t}\right)}\; di\right]^{\left(\frac{\theta_t}{\theta_t - 1}\right)}$$

The maximization problem gives out the first-ordered condition for the demand for intertermediate goods Y_{it}. Because the production relies on a constant-return-to-scale technology described above and the condition that market for finished goods is perfectly competitive, the profit will eventually be driven down to zero. Given the zero profit, the price index P_t can be expressed as a function of intermediate goods prices P_{it}. This allow us to write

$$Y_{it} = Y_t\left(\frac{P_{it}}{P_t}\right)^{-\theta_t} \tag{4}$$

$$P_t = \left[\int_0^1 P_{it}^{\;1-\theta_t}\; di\right]^{\left(\frac{1}{1-\theta_t}\right)} \tag{5}$$

From (4), we can identify the degree of price responsiveness of the intermediate goods demand by the parameter θ_t.

4.3 Intermediate Producing Firms

At another end, a continuum of intermediate producer firms supply goods (Y_{it}) to the final producers. The intermediate goods are not perfectly substitutable, thus the firms retaining monopolistic market power. To run the production, a representative intermediate producer firms hire labor services from households to manufacture output (Y_{it}) with the current level of technology Z_t. The intermediate production function is expressed in

$$Y_{it} = Z_t h_{it}$$

Meanwhile, the demand for the intermediate goods is symmetric to the final producer solution, which is given, again, by equation (4):

$$Y_{it} = Y_t \left(\frac{P_{it}}{P_t}\right)^{-\theta_t}$$

Since the representative intermediate firm is owned by households and its market value dependent on the real dividend $\frac{D_{it}}{P_t}$, the firm maximizes the objective function:

$$\Pi^I = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{a_t}{C_t}\right) \left(\frac{D_{it}}{P_t}\right)$$

where $\beta^t \left(\frac{a_t}{C_t}\right)$ indicates the marginal utility from real dividend to the representative household at time t. As a result of sticky prices, the real dividend is not equal to the real profit as there exists non-zero cost of price adjustment that enters this profit maximization problem. The real dividend is written as

$$\frac{D_{it}}{P_t} = \frac{P_{it}Y_{it} - W_t h_{it}}{P_t} - \frac{\phi}{2}\left[\frac{P_{it}}{\bar{\pi}P_{it-1}} - 1\right]^2 Y_t \tag{6}$$

The second term on the RHS of (6) shows the cost of changing prices as a function of real output and the intermediate price, controlled by the parameter ϕ and the steady-state inflation $\bar{\pi}$.

Combining these constraints, we maximize the objective function with respect to P_{it} to arrive at the following first-ordered condition:

$$(\theta_t - 1)\left(\frac{P_{it}}{P_t}\right)^{-\theta_t}\left(\frac{Y_{it}}{P_t}\right) = (\theta_t)\left(\frac{P_{it}}{P_t}\right)^{-\theta_t - 1}\left(\frac{Y_{it}}{P_t}\right)\left(\frac{W_t}{Z_t}\right)\left(\frac{1}{P_t}\right) - \phi\left[\frac{P_{it}}{\bar{\pi}P_{it-1}} - 1\right]^2 \frac{Y_t}{\bar{\pi}P_{it-1}}$$

$$- \beta\phi E_t\left(\frac{a_{t+1}}{a_t}\right)\left(\frac{C_t}{C_{t+1}}\right)\left(\frac{P_{it}}{\bar{\pi}P_{it-1}} - 1\right)\frac{Y_{t+1}P_{it-1}}{\bar{\pi}P_{it}^2} \tag{7}$$

If the intermediate firms face zero cost of price adjustment, the second and third terms of (7) are eliminated such that we can rewrite the first ordered condition that describes the intermediate goods pricing as

$$P_{it} = \left(\frac{\theta_t}{\theta_t - 1}\right)\left(\frac{W_t}{Z_t}\right).$$

4.4 Central Bank

A rule-based monetary policy characterizes the central bank behavior. In principle, the interest rate response is governed by a set of variables, including the output gap and the inflation differential from the target set by the central bank (defined as the steady-state inflation or the long-run average).

To obtain the measure of output gap, we begin by defining it as the differential between actual and potential outputs. To calculate the potential output or the output at full capacity of this economy, we solve the social planner problem for an efficient allocation of resources in the model. The social planner maximizes the households' utility function of the form:

$$E \sum_{t=0}^{\infty} \beta^t \left[a_t \ \ln(Y_t^*) \ - \left(\frac{1}{\eta}\right) \left(\int_0^1 h_{it} \, di\right)^{\eta} \right]$$

Note that, in this idealized world, the real money balance does not enter the utility function and there is no rigidity in price adjustment ($\phi = 0$). This means the only constraint for the problem is the final production function: $Y_t^* = Z_t \left[\int_0^1 h_{it}^{\left(\frac{\theta_t - 1}{\theta_t}\right)} \, di \right]^{\left(\frac{\theta_t}{\theta_t - 1}\right)}$.

Solving this problem, we have the potential output as $Y_t^* = Z_t \, a_t^{\frac{1}{\eta}}$, and the output gap can be calculated as:

$$x_t = \frac{Y_t}{Y_t^*} = \frac{Y_t}{Z_t \, a_t^{\frac{1}{\eta}}} . \tag{8}$$

Having all the necessary ingredients, we express the monetary policy rule as the nominal interest rate response to its own lag, the inflation, economic growth, and output gaps, respectively. Equation (9) shows this in terms of log-deviation from steady state. The serial correlation is introduced for the sake of replicating the central bank's attempt in smoothing the interest rate movement (Clarida, Gali, & Gertler, 2000). The parameters ρ_r , ρ_π, ρ_g, ρ_x measure the elasticities of the interest rate responses to these policy targets.

The innovation ε_{rt} shows the serially uncorrelated zero-mean monetary policy shock with the standard deviation σ_r. The monetary policy feedback rule, thus, takes the form

$$\hat{r}_t = \rho_r \hat{r}_{t-1} + \rho_\pi \hat{\pi}_t + \rho_g \hat{g}_t + \rho_x \hat{x}_t + \varepsilon_{rt} \tag{9}$$

4.5 Innovations

The driving forces in this model economy, to summarize, arise from 4 sources. These include the monetary policy shock ε_{rt}, the preference shock ε_{at}, the cost-push shock $\varepsilon_{\theta t}$, and the technology shock ε_{zt}. All shocks are stochastic, following the Independently and Identically Distributed Normal distribution with zero mean and its own variance σ_j^2. The autoregressive processes of preference and cost-push shocks feature the $|\rho_a|$ and $|\rho_\theta| < 1$. The technology shock, on the other hand, has a unit root, obeying a random walk process with a drift $\ln(\bar{Z})$. This necessitates the normalization procedure described in more detail in the following subsection.

$$\varepsilon_{rt}, \varepsilon_{at}, \varepsilon_{\theta t}, \varepsilon_{zt} \sim IIDN(0, \sigma_j^2); \quad j = r, a, \theta, z$$

$$\ln(a_t) = \rho_a \ln(a_{t-1}) + \varepsilon_{at} \tag{10}$$

$$\ln(\theta_t) = (1 - \rho_\theta) \ln(\bar{\theta}) + \rho_\theta \ln(\theta_{t-1}) + \varepsilon_{\theta t} \tag{11}$$

$$\ln(Z_t) = \ln(\bar{Z}) + \ln(Z_{t-1}) + \varepsilon_{zt} \tag{12}$$

4.6 Linearized Model

The next step to linearize the model for estimation requires us to define a symmetric equilibrium, where all intermediate goods are identical such that all individual decision is the same as aggregate one.

$$Y_{it} = Y_t\,; \quad P_{it} = P_t\,; \quad D_{it} = D_t\,; \quad h_{it} = h_t.$$

Together with two additional market clearing conditions, namely $M_t = M_{t-1} + T_t$ and $B_t = B_{t-1} = 0$, we can then rewrite the household budget constraint, Euler equation, and the intermediate firms' FOC as

$$Y_t = C_t + \frac{\phi}{2}\left[\frac{\pi_t}{\bar{\pi}} - 1\right]^2 Y_t \tag{13}$$

$$\frac{a_t}{C_t}\left(\frac{1}{r_t}\right) = \beta E\left[\frac{a_{t+1}}{C_{t+1}}\left(\frac{1}{\pi_{t+1}}\right)\right] \tag{14}$$

$$\begin{aligned}(\theta_t - 1) = (\theta_t)\left(\frac{C_t}{a_t}\right)\left(\frac{Y_t}{Z_t}\right)^{\eta-1}\left(\frac{1}{Z_t}\right) - \phi\left[\frac{\pi_t}{\bar{\pi}} - 1\right]^2 \frac{\pi_t}{\bar{\pi}} \\ - \beta\phi E_t\left(\frac{a_{t+1}}{a_t}\right)\left(\frac{C_t}{C_{t+1}}\right)\left(\frac{\pi_{t+1}}{\bar{\pi}} - 1\right)\left(\frac{\pi_{t+1}}{\bar{\pi}}\right)\frac{Y_{t+1}}{Y_t}\end{aligned} \tag{15}$$

In order to arrive at the final specification, the following steps are in order. First, remove non-stationary component in the model. Because of the unit root in technology shock (ε_{zt}), we detrend the variables associated with Z_t, denoted by variables with lower case. Note that the rate of output growth $g_t = \frac{Y_t}{Y_{t-1}}$ is also I(0) by definition. Therefore, all following variables are stationary.

$$y_t = \frac{Y_t}{Z_t}; \quad c_t = \frac{C_t}{Z_t}; \quad z_t = \frac{Z_t}{Z_{t-1}}\;;\; x_t = \frac{Y_t}{Z_t\, a_t^{\frac{1}{\eta}}} = \frac{y_t}{a_t^{\frac{1}{\eta}}}$$

Second, log-linearize the models around steady state values. The steady state values are denoted by variable with upper bar. In steady state, output, consumption, inflation rate, interest rate, and output gap are all growing at a constant rate. That is, $y_t = \bar{y}$; $c_t = \bar{c}$; $\pi_t = \bar{\pi}$; $r_t = \bar{r}$; $x_t = \bar{x}$; $g_t = \bar{g}$. Define the log deviation from steady state value of a variable x as $\hat{x}_t = ln(x_t) - \ln(\bar{x}) = ln\left(\frac{x_t}{\bar{x}}\right)$ (Cochrane, 2001), we then can write the model of 8 linearized equations as follows:

$$\hat{x}_t = E_t(\hat{x}_{t+1}) - \left(\hat{r}_t - E_t(\hat{\pi}_{t+1})\right) + (1-\omega)(1-\rho_a)\hat{a}_t \quad (16)$$

$$\hat{\pi}_t = \beta E_t(\hat{\pi}_{t+1}) + \psi \hat{o}_t - \hat{e}_t \quad (17)$$

$$\hat{x}_t = \hat{y}_t - \omega \hat{a}_t \quad (18)$$

$$\hat{g}_t = \hat{y}_t - \hat{y}_{t-1} + \hat{z}_t \quad (19)$$

$$\hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_{at} \quad (20)$$

$$\hat{e}_t = \rho_e \hat{e}_{t-1} + \varepsilon_{et} \quad (21)$$

$$\hat{z}_t = \varepsilon_{zt} \quad (22)$$

$$\hat{r}_t = \rho_r \hat{r}_{t-1} + \rho_\pi \hat{\pi}_t + \rho_g \hat{g}_t + \rho_x \hat{x}_t + \varepsilon_{rt} \quad (24)$$

In the IS curve with expectation (16), the parameter ω stands to replace $\frac{1}{\eta}$, while in the New Keynesian Phillip curve (17) the parameter $\psi = \frac{\eta(\theta-1)}{\phi}$. The cost-push shock in the intermediate firm's FOC is now $\hat{e}_t = \frac{\hat{\theta}_t}{\phi}$. Equations (16)-(24) form our *Baseline model*.

The two equations of IS curve (16) and New Keynesian Phillip curve (17) are both forward-looking and this could post a problem empirically. The macroeconomic data time series are generally characterized as dependent on its own lags, featuring high autocorrelation. By not explicitly modeled the lags of output gap and inflation, when carrying out the estimation, we may face the risk of overestimating certain shocks. Therefore, we modify the *Baseline model* by adding lagged dependent variables ($\hat{x}_{t-1}$ and $\hat{\pi}_{t-1}$) to the RHS of equations (16) and (17), as proposed by Ireland (2004), in the following fashion:

$$\hat{x}_t = \alpha_x \hat{x}_{t-1} + (1-\alpha_x) E_t(\hat{x}_{t+1}) - \left(\hat{r}_t - E_t(\hat{\pi}_{t+1})\right) + (1-\omega)(1-\rho_a)\hat{a}_t \quad (25)$$

$$\hat{\pi}_t = \beta\{\alpha_\pi \hat{\pi}_{t-1} + (1-\alpha_\pi) E_t(\hat{\pi}_{t+1})\} + \psi \hat{x}_t - \hat{e}_t \quad (26)$$

Where the two additional parameter α_x and α_π govern the degree of the backward-looking components. We aim to test the importance of both parameters with the data, and show the role the backward-looking behavior plays in the economy and in the overall performance of the model. Thus, our *Modified model* consists of equations (18)-(26).

Note that with this modification of the theoretical model we do not change its long-run (steady state) path, i.e. the steady states of the Baseline and Modified model remain the same. For the IS, the theoretical equation (16) indicates that the current output gap, with other variables constant, relies only on the long-run process of forward-looking output gap ($\hat{x}_{t+1}$). The modification in equation (25) only implies that the current output gap adjusts to the AR(1) process of the weighted average between the past and forward-looking output gaps, which would converge to only the forward-looking output gap ($\hat{x}_{t+1}$) with the expectation that $\alpha_x = 0$.

4.7 Data

Considering the 5 key variables in the model ($\hat{r}_t, \hat{\pi}_t, \hat{g}_t, \hat{y}_t, \hat{x}_t$), only the first three are observable; namely the short-run nominal interest rate ($\hat{r}_t$), the inflation rate ($\hat{\pi}_t$), and the output growth rate ($\hat{g}_t$). Output and output gap are not directly calculated in the concern over the detrending factor Z_t. All the shocks ($\hat{a}_t$, $\hat{e}_t, \hat{z}_t, \varepsilon_{rt}$) in the model are also assumed to be exogenous and unobservable.

All data series for Thailand used in the estimation are in logarithmic transformation, from 1994Q1 to 2013Q4, for the total of 80 observations. The interest rate r_t is the quarterly average of interbank overnight lending rates, as published by the Bank of Thailand. Inflation rate π_t is calculated from the first difference of GDP deflator, and the output growth rate g_t the first difference of real per capita GDP. Both of which are seasonally adjusted, published quarterly by the National Economic and Social Development Board of Thailand (NESDB). The steady state values around which we calculate the log deviation terms come from the long run average values over the sample period.

5. Results and Interpretations

This section presents the results and interpretations of the Bayesian estimation of our NK-DSGE *Baseline* and *Modified models*, using Thailand quarterly data as described above. In subsection 5.1, the posterior estimates of the deep parameters inform us about some characteristics of the Thai economy and the conduct of monetary policy. Then we turn to examine the dynamic impacts of the four shocks through the use of impulse response functions and the variance decompositions in subsection 5.2 and 5.3, respectively.

5.1 Priors and Posterior Estimates

The prior distributions as well as the posterior estimation results of the deep parameters and the four exogenous shocks are reported in Table 3-1.

Table 3-1 Posterior Estimates of Baseline and Modified Models

Parameters		**Priors**			**Posterior Mean**	
		Dist.	**Mean**	**Stdev**	***Baseline***	***Modified***
Lagged x in IS	α_x	beta	0.50	0.10	-	0.5436
Lagged π in PC	α_π	beta	0.50	0.10	-	0.4507
Discount factor	β	beta	0.99	0.01	0.9848	0.9889
Labor supply elasticity	ω	beta	0.33	0.10	0.0081	0.0085
Output gap in PC	ψ	gamma	0.25	0.05	0.3495	0.3243
Persistence: Preference	ρ_a	beta	0.50	0.20	0.8948	0.8738
: Cost-push	ρ_e	beta	0.50	0.20	0.6505	0.4587
Taylor: Output gap	ρ_x	beta	0.50	0.10	0.5390	0.6945
: Output growth	ρ_g	beta	0.50	0.10	0.4789	0.6539
: Inflation	ρ_π	gamma	1.50	0.25	2.7916	3.3689
Stdev of shocks						
Preference	$\sigma_{\varepsilon_{at}}$	invg	0.10	2.00	2.4929	2.0631
Cost-push	$\sigma_{\varepsilon_{et}}$	invg	0.10	2.00	0.0179	0.0180
Technology	$\sigma_{\varepsilon_{zt}}$	invg	0.10	2.00	0.0306	0.0285
Monetary Policy	$\sigma_{\varepsilon_{rt}}$	invg	0.10	2.00	0.2271	0.2251
Log Marginal Likelihood					**187.85**	**211.33**

<u>Priors</u>

In both the *Baseline* and *Modified models*, the values for prior means and their distributions are based on existing studies for Thailand and other countries, as well as author's calculation. The discount rate (β) and the omega ($\omega = \frac{1}{\eta}$) are referred to earlier works by Tanboon (2008) at the Bank of Thailand. The discount rate of 0.99 also corresponds to the annualized rate of interest in Thailand of approximately 4 percent, our steady state value, while the omega is set to match with the wage elasticity of labor supply of 0.33, as calibrated by Tanboon (2008). Meanwhile, the parameter psi (ψ), which stands for the degree to which inflation responds to the change in output gap in equation (17) and (26), is set to follow a gamma distribution with mean 0.25 and standard deviation of 0.05, following Pongsaparn (2008).

Interest rate rule indicates that central bank puts higher weight on inflation consideration ($\rho_\pi = 1.5$), compared with those for output growth and output gap, consistent with the current monetary policy regime of inflation targeting in Thailand. We then follow Smets and Wouters (2007) who used a harmonized set of stochastic processes: the four shocks are described by an inverse-gamma distribution of the same mean and degree of freedom. Also following Smets and Wouters (2007), the AR(1) processes for technology and cost-push persistence follow a beta distribution with a mean of 0.5.

In the *Modified model*, the backward-looking components of the IS relation (25) and Phillips Curve (26), α_x and α_π, are assumed to have a loose beta distribution with a mean of 0.5. In the test of their importance, we avoid making too restrictive judgment, allowing the data to be indicative.

Posteriors

In order to compare the two models, the last row of Table 3-1 reports the marginal likelihood, which measures the model fit in terms of out-of-sample forecast performance. The higher value of the marginal likelihood, the better the model in predicting the data. The marginal likelihood can be used as a basis for comparison across different model specifications as outlined in Smets and Wouters (2007).

Based on the marginal likelihood, it is evident that the *Modified* outperforms the *Baseline* model. The marginal likelihood of the *Modified* model improves from the *Baseline* model by 24. This points out that the lagged of output gap and inflation added in equations (25) and (26) enhance the model's explanatory power. Therefore, we will mainly pay attention to the *Modified model* in the following analysis.

From the posterior estimates on the *Modified model* column of Table 3-1, we extract the following four interesting aspects about Thai economy and monetary policy.

First, for the Phillips curve, the backward-looking behavior is significant but moderate. The degree of inflation inertia as implied by the additional parameter α_π is shown to be moderate (0.45), slightly larger than the evidence found in Pongsaparn (2008) for the Thai economy (0.25). The movement in current inflation depends on both the past and forward-looking inflations, implying a relatively flexible adjustment of prices in response to the output gap. With the posterior estimate of 0.32, the parameter ψ also indicates the moderate cost of nominal price adjustment, the sacrifice of output when inflation changes.

Secondly, in the IS relation, with the constant real interest rate and preference shock, the current output gap responds almost equally to the fluctuations in past and forward-looking output gaps, with α_x=0.54. This is in line with international evidence that the coefficient of the lagged output gap would assume a range between 0.5-0.9 (Berg et al., 2006). Past output gap plays a crucial role in influencing current behavior of the households. This serves as an indicator that the economy may face additional frictions that are not explicitly modeled such as habit persistence in consumption (Ireland, 2004). Also, the very small omega (ω) suggests that the preference shock will have a large influence on the output gap, thanks to the coefficient (1-ω). This will become apparent in the impulse response analysis.

Thirdly, the posterior estimates of the parameters in the interest rate rule confirm our hypothesis regarding inflation targeting. Given the model and the data, the inflation consideration is estimated to retain a notable weight in the monetary policy decision (ρ_π=3.37). Nevertheless, central bank's responses to both output growth and output gap are also important. It is evident that the monetary policy also takes output growth into consideration even though it is not in the official target.

Lastly, preference shock is highly persistent and has the largest standard deviation, indicating its potentially significant role in explaining the model's dynamic. Given the model specification, the preference and cost-push shocks are described as AR(1) processes.

The parameter ρ_a indicates the persistence of preference shock, and the posterior estimate gives out a large value of 0.87. These results are comparable with those reported in Ireland (2004) for the US, at the value of 0.95. The large estimates of ρ_a indicate that when the economy faces with preference shocks, the impacts would be resonated in the economy long after the shock ended.

The standard deviations of each shock are also reported in the lower panel of Table 3-1. In particular, we see that the preference shock (ε_{at}) is not only long-lived, but also has the largest variance. The second source of contributor for movements in data come from short-term interest rate shock, while both cost-push shock ($\varepsilon_{\theta t}$) and technology shock (ε_{zt}) have limited influence on the model's dynamics. In the next subsection, we investigate the effect of each shock in greater detail.

5.2 Impulse Response Functions

To examine the bearings of the four shocks on the Thai economy, we look at the impulse response functions as shown in the following figures. The impulse response functions summarize the dynamic impacts of a shock on the endogenous variables of interest over time. The black line shows the mean impulse response, while the gray area shows the confidence band of 90 percent.

A positive preference shock is assumed to have an expansionary impact on the economy, given that households derive greater utility out of each unit of consumption. But note that the preference shock has a very large variation, and accordingly its impact on the economy is expected to be also considerable. As shown in Figure 3-1, one standard deviation increase in preference shock (σ_{at}) gives rise to 7 basis points increase in output growth (Note: 100 basis points equals 1 percentage point). Output gap also increase, by 7 basis points, pushing inflationary pressure that results in an increase of 3 basis points in inflation.

Figure 3-1 Impulse Response Functions to Preference Shock

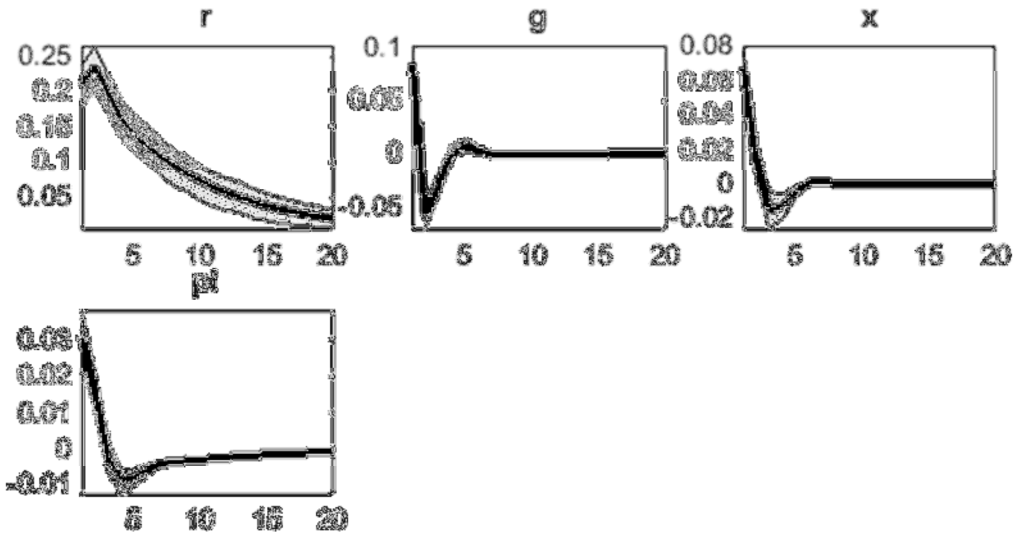
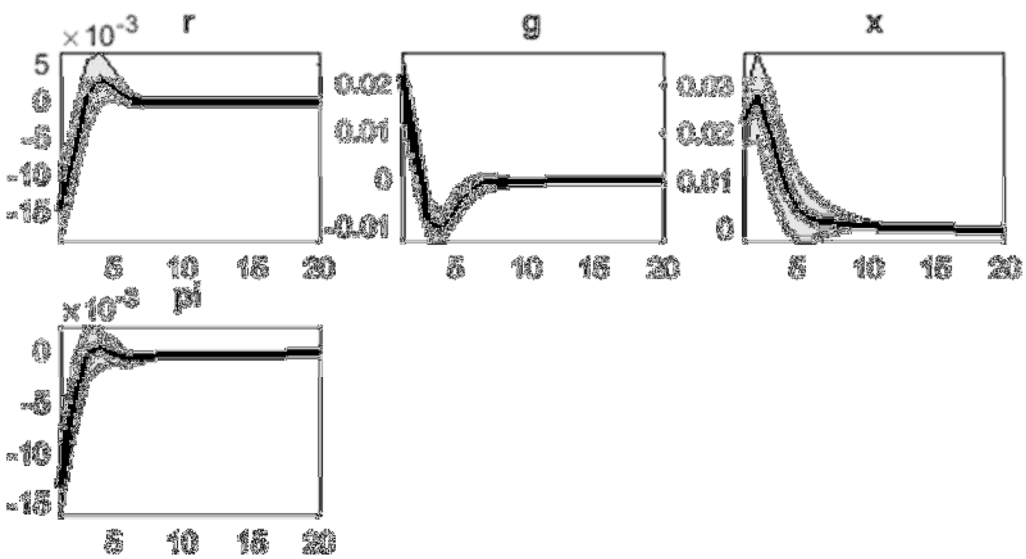


Figure 3-2 Impulse Response Functions to Cost-push Shock



Meanwhile, positive cost-push shock translates into larger markup for the firms, driving up their demands for inputs as well as production. In Figure 3-2, one-standard-deviation cost-push shock translates into output growth acceleration and at the same time inflation deceleration. The lower inflationary pressure requires lower interest rate in the monetary policy rule. By the response function, the short term interest rate declines by 1.5 basis point after the cost-push shock. Since, the efficient level of output does not respond to cost-push shock, the increase in output (positive output growth) also raises the output gap by 2.5 basis points.

The technology shock affects the level of potential output as well as the output growth. One standard deviation increase in technology shock directly leads to an increase in output growth of 2 basis points, as seen in Figure 3-3. However, because of a stronger impact of technology improvement on the level of potential output, the output gap declines slightly by 0.5 basis points. With smaller output gap, the inflation decreases by a negligible 0.3 basis points. Note that the standard error of technology shock is very small, implying its limited impacts on key indicators.

As shown in the Figure 3-4, the monetary policy is shown to have an impact on both output growth and output gap. One standard deviation increase in short-term interest rate lowers the output growth by 6 basis points. After the interest rate increase, a slightly larger impact is felt in the output gap, which declines by 6 basis points. With the falls in output gap and output growth, inflationary pressure is also lower. Thus, it is observed that the interest rate increase drives down the inflation by 3 basis points. The effect of higher interest rate on inflation fades off by the fifth quarter where it returns to steady state (zero deviation from steady state).

Figure 3-3 Impulse Response Functions to Technology Shock

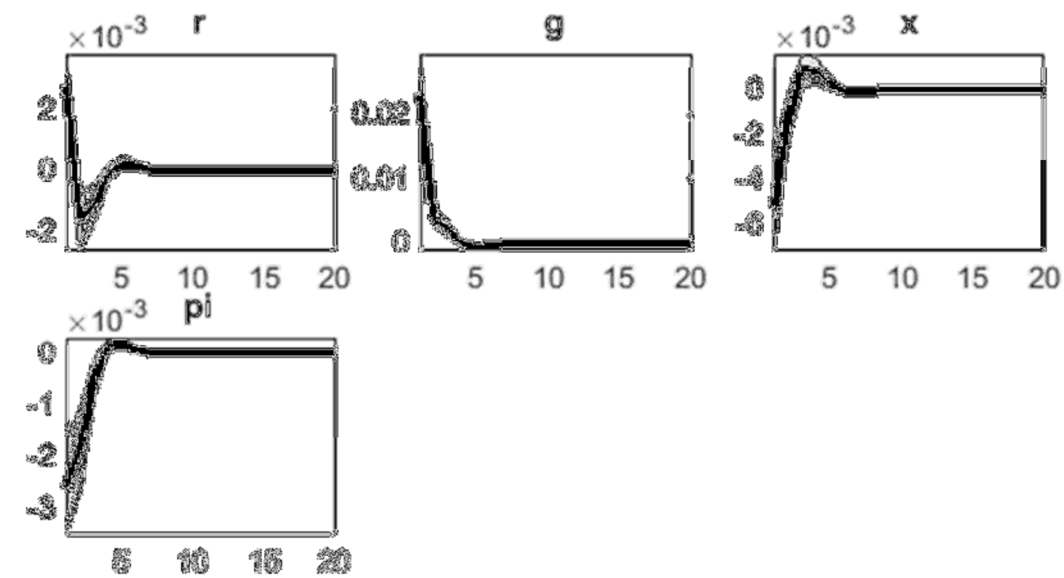
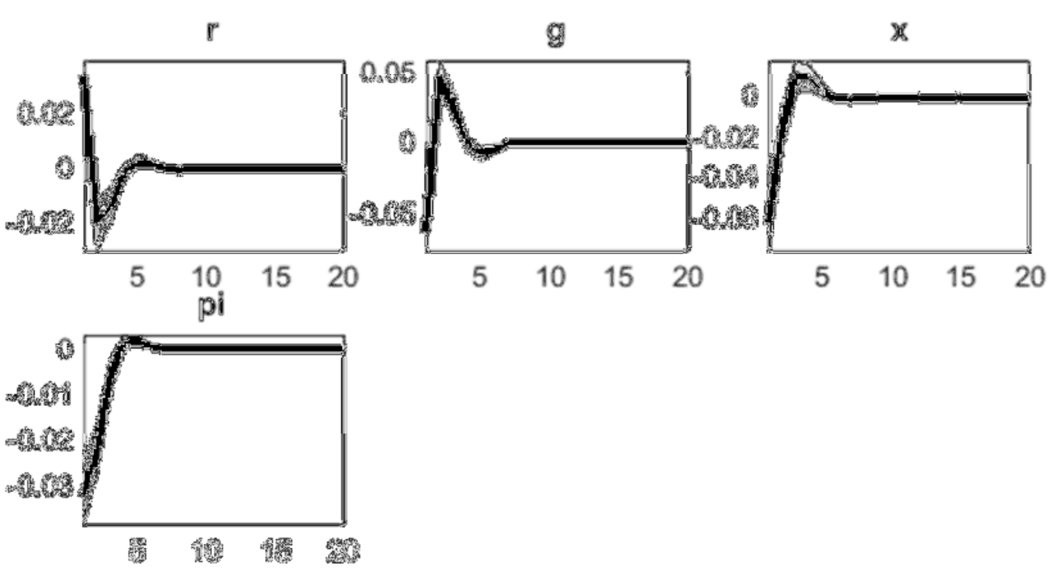


Figure 3-4 Impulse Response Functions to Interest Rate Shock



Looking across all four shocks, the Bayesian impulse response functions allow us to have a clearer and more meaningful picture of the four shocks in our model economy. All response functions return to steady state within the span of 10 quarters. Meanwhile, it is notable that the preference and interest rate shocks have relatively larger impacts on all key macroeconomic indicators of interest (output growth, output gap, and inflation), compared with those of cost-push and technology shocks.

5.3 Forecast Error Variance Decompositions

In order to further examine the effects of the four exogenous shocks, Table 3-2 shows the forecast error variance decompositions of the three observable variables at different forecast horizons: the first quarter up to the infinite horizon as implied by the 100th quarter.

A quick glance over the three panels (a), (b), and (c) of Table 3-2 allows us to reconfirm the findings from the impulse response function analysis that the preference shock is the most influential driver of fluctuations in all three variables. In panel (a) for the output growth, over the long-run, the preference shock explains as large as 60 percent of output growth variance and 50 percent of inflation variance. The preference shock is mostly the sole driver of the fluctuations in short-term interest rate, a finding consistent with Ireland (2004) for the US.

Monetary policy shock, on the other hand, is also important in contributing to the variances of the key variables in the model. The interest rate shock is attributable for about 30 percent of the variance in the output growth and 40 percent in the inflation fluctuations. Nevertheless, in general, both cost-push and technology shocks have minor impacts on the three observables, except at the short-run horizon, where the cost-push shock explains about 10 percent of the inflation variance.

Table 3-2 Forecast Error Variance Decompositions

(a) Output Growth

Shocks	Q1	Q4	Q8	Q12	Q100
Preference	63.43	62.58	62.39	62.39	62.39
Cost-push	4.63	4.30	4.50	4.51	4.51
Technology	4.52	2.95	2.93	2.93	2.93
Monetary Policy	27.42	30.17	30.18	30.18	30.17

(b) Inflation

Shocks	Q1	Q4	Q8	Q12	Q100
Preference	48.59	47.63	49.78	50.28	50.56
Cost-push	9.99	8.26	7.94	7.87	7.82
Technology	0.34	0.36	0.34	0.34	0.34
Monetary Policy	41.08	43.75	41.94	41.51	41.28

(c) Interest rate

Shocks	Q1	Q4	Q8	Q12	Q100
Preference	97.21	98.93	99.20	99.27	99.30
Cost-push	0.54	0.19	0.15	0.13	0.13
Technology	0.02	0.01	0.01	0.00	0.00
Monetary Policy	2.23	0.87	0.65	0.59	0.57

5.4. Comparison of Forecast Performance

Thanks to our methodology, the Bayesian estimation, we calculate the (log) marginal likelihood, which measures the out-of-sample forecasting power of the model given the data. We the n perform a comparison of the forecast performance based on this measure between the estimated Modified model and the statistical BVAR models of up to 8 lags, using the same data set, with the results reported in Table 3-3.

The BVAR with 3 lags beats all other specifications. Relative to our Modified model, the BVAR of all lags also show a superior forecasting performance. Given the well-known powerful performance of BVAR and the restricted structure of the DSGE model, this is not unexpected. Nevertheless, it provides the motivation for our future work to deal with a DSGE specification that is rich enough to better describe and capture the data dynamics.

Table 3-3 Forecast Performance Comparison

	Log Marginal Likelihood
DSGE(Modified)	211.33
BVAR(1)	330.39
BVAR(2)	356.09
BVAR(3)	356.36
BVAR(4)	355.48
BVAR(5)	356.00
BVAR(6)	352.64
BVAR(7)	350.30
BVAR(8)	345.77

6. Conclusions

In this study, we estimate a small NK-DSGE model for Thailand using the Bayesian method. Compared with the RBC family, the NK-DSGE models attempt to mirror the real world imperfections as well as the persistent behavior of macroeconomic data by incorporating additional frictions. Our parsimonious model follows Ireland (2004) in which the only rigidity in the economy is in the forms of the monopolistic competitive price setting behaviors. And by incorporating the central bank adopting interest rate rule, this NK-DSGE model is capable of eliciting insights regarding monetary policy impacts in Thailand.

To evaluate the model, the Bayesian approach makes use not only the data, but also the priors, the initial guesses of the structural parameters. The distributions of priors in our model are based on existing studies, both from Thailand and international points of view. The specification of prior distributions provides the weights for the parameters' likelihood functions, facilitating the numerical maximization. The Metropolis-Hastings algorithm then explores the parameter's subspace with the jumping distribution and acceptance ratio before drawing the respective histogram that represents the posterior distribution of that parameter. In short, the Bayesian estimation combines the maximum likelihood method with calibration, helping us to overcome the limitations of both approaches.

Our posterior estimation results as well as the dynamic analysis provide four important insights about the Thai economy and its monetary policy.

Firstly the lagged output gap and inflation are both significant in the *Modified model*. This implies that there is a role for the backward-looking behaviors to play in the determination of IS and Phillips curves. Households' and firms' decision making processes are not relying solely on the expectation of future output gaps and inflations, but also their respective lags. The comparison between Baseline and Modified models based on marginal likelihood also lend greater support for the inclusion of lags. It is thus noteworthy that for future research we might want to explicitly model a greater set of frictions into the model, such as habit formation and investment adjustment cost.

Secondly, the significant but moderate inflation inertia (α_π) as well as cost of adjusting inflation (ψ) in the Phillips curve imply that the monetary policy has relative flexibility in responding to inflation and output gap. According to Berg et al. (2006), in an opposite case where inflation is highly unresponsive, i.e. highly dependent on its own lags, monetary policy needs to move well in advance and by a large magnitude to ensure the timely impacts on current inflation. Meanwhile, a substantial cost in adjusting inflation to the change in output gap would dictate a difficult tradeoff for a stabilizing policy.

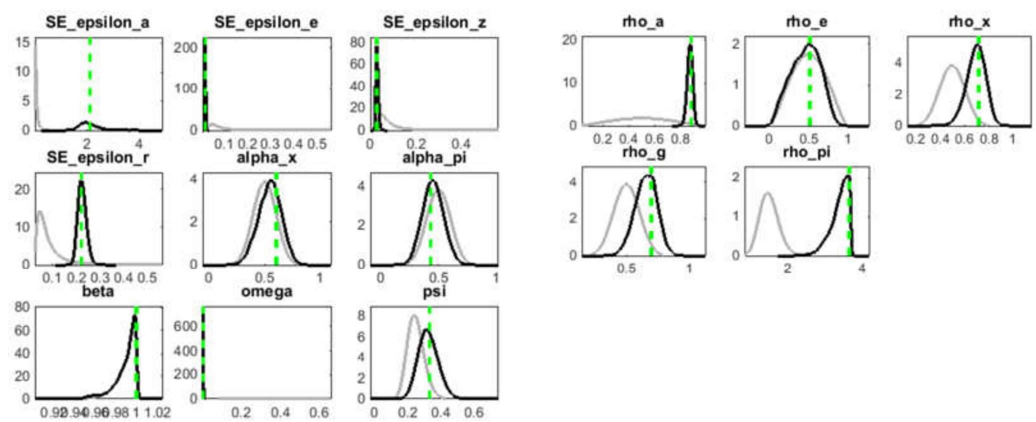
Thirdly, the posterior estimates of the weights in the interest rate rule reconfirm our belief regarding Thailand's monetary policy regime. The BOT has implemented inflation-targeting framework since 2000, setting its priority in maintaining the economy stability through low and stable inflation. And the regime's objective is reflected in the data as well as our posterior estimation, with interest rate rule putting notably larger weight for inflation gap. Nonetheless, it is worth noting that monetary policy also takes into account the considerations over output gap and growth in its decisions.

Lastly, looking across all four shocks featuring in our model, we can observe that preference shock makes up the largest contribution to economic fluctuations in the data. However, the monetary policy shock by means of short-term interest rate is also instrumental in influencing other key components of the economy. Through the impulse response functions of the interest rate shock, we observe the transmission of higher interest rate to a decline in output gap and the resulting fall in inflation, while the variance decomposition also displays the strong influence of the interest rate shock on both real and nominal variables, compared with the technology and cost-push shocks.

It is worth noting that the estimated results and their policy implications mentioned in this chapter should be taken with care, in conjunction with the concern that the sample period (1994-2013) covers the important structural change. Particularly, the effects of the 1997 Financial Crisis were transformative and drastic on the Thai economy and the conduct of monetary policy. For interested readers, the results and analyses in the next chapter are not subject to the same caution.

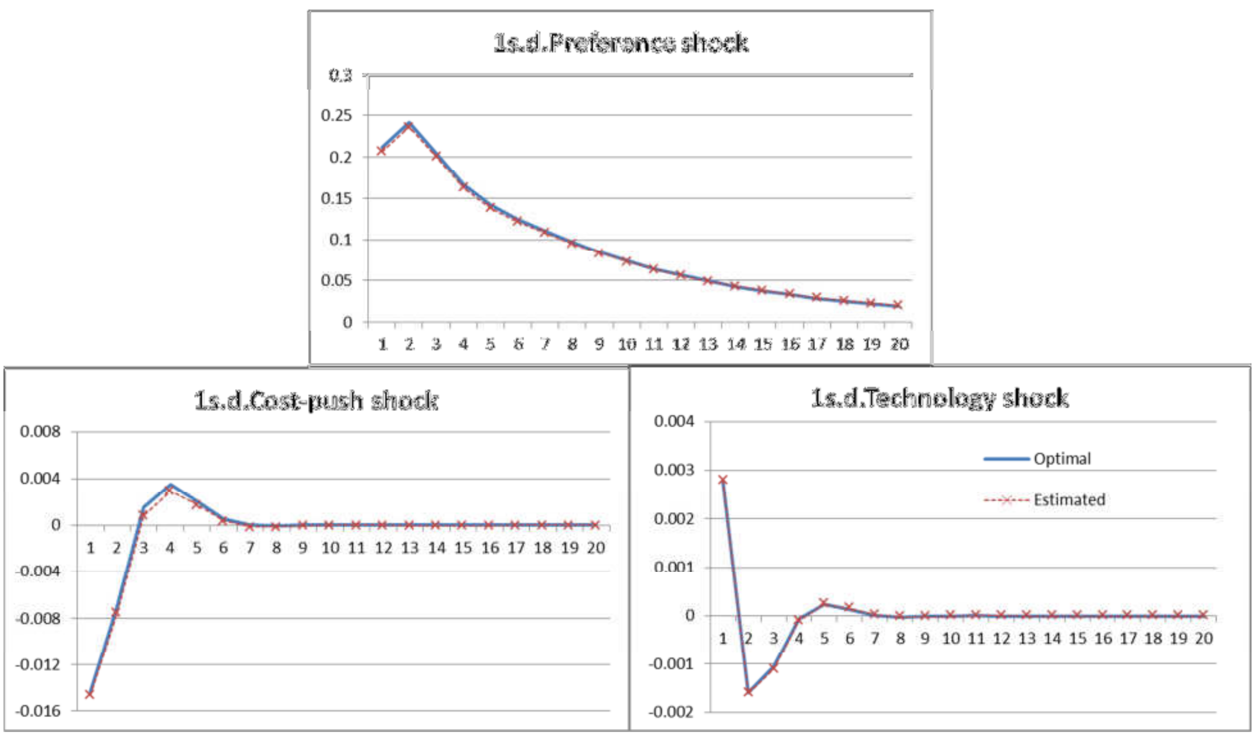
Appendix 3-1 Priors VS Posterior Distributions

The following chart displays the comparison between the prior (gray line) and the posterior distributions (black line) with the indication of the posterior mode (dotted vertical line). The comparison between the priors and posteriors can inform us about the importance of the information content contained in the data. A shift away from the prior and a narrower standard deviation indicates that the data adds important information into the estimation of the posteriors. Notice that all of our parameters are specified, without the bi- and multi-modals.



Appendix 3-2 Optimal Monetary Policy

This following charts provide a comparison of monetary policy responses to shocks based on the estimated (Modified) model and the ones implied by the optimal policy, shown below in the dashed and solid line, respectively. The optimal monetary policy is derived from solving the social planner's optimization problem (Adjemian et al., 2007; Adolfson et al., 2008; Nakornthab, 2009; Griffoli et al., 2013), by assuming that the central bank minimizes a quadratic loss function of two arguments: inflation and output gap. The following figures show the short-term interest rate responses to preference, cost-push, and technology shocks.



CHAPTER 4

NOMINAL AND REAL FRICTIONS IN THAI MONETARY DSGE MODEL: A BAYESIAN ESTIMATION

1. Introduction

This chapter studies the impacts of Thailand's monetary policy in a medium-sized DSGE model. In order to account for the non-neutral effects of monetary policy on key variables, some modifications of the classical assumptions must be made. Following Smets and Wouters (2007), we adopt the Bayesian approach to estimate a monetary DSGE model featuring price and wage stickiness, as well as frictions in real variables.

In contrast to RBC family, the New-Keynesian models address key behavioral and institutional rigidities observed in the actual functioning of the economy and incorporate them into the DSGE framework. These 'monetary' DSGE models are fit to analyze the impacts of monetary policy on real variables. We adopt this as the goal for this study, and our results confirm the effects of monetary policy shocks on not only output, but also consumption, investment, and hours worked.

The rationale for adding the rigidities into the DSGE model is not by haphazard choice. Rather, it builds upon the foundation provided by microeconomic studies of the observed market practices and imperfections. For instances, fixed-duration price and wage contracts prevent some economic agents to respond to contemporaneous markup shocks; private consumption decisions may depend on its own lags when households try to smooth their consumption across periods, i.e. maintaining their habit of consumption. Embracing these rigidities into the model improve its fit to aggregate data and also provide us with deeper insights regarding the behavior of economic agents.

The Bayesian approach used in the evaluation of our DSGE model has many advantages. To arrive at the posterior distributions of the parameters, Bayesian estimation combines the data with the researcher's initial beliefs regarding the parameters by means of priors. Also, as part of the posterior estimation, the calculation of the marginal likelihood provides a measure of model fit which can then be used as a basis for model comparison. Based on this methodology, this study provides an investigation of how each friction impact the model's overall performance in order to reveal its empirical importance. Additionally, our contribution also lies in the model fit assessment of the estimated NK-DSGE for Thailand, by comparing its forecasting power with that of the BVAR of different lags using the same data set.

The rest of the paper is organized as follows. Section 2 and 3 review the justification and evidences in the literature for the addition of the rigidities and frictions into DSGE framework, while the entire setup of the model is described in Section 4. More details of the Bayesian estimation methodology as well as data description can be found in

Section 5. Then, Section 6 looks into the estimation results, impulse response functions, and interpretations, before offering sensitivity analysis and forecast performance test. Section 7 summarizes major conclusions.

2. Nominal Rigidities

This section explores the key characteristics of the NK-DSGE models that separate it from the RBC literature. In particular, the imperfections in the economy create frictions that delay the process and timing the model responds to shocks, when compared with the economy characterized by full flexibility. In this section, we explore the case where both prices and wages are prevented to change in despite the alteration of price-setting conditions. A constraint in the forms of contracts fixes prices and wages for a period of time. The rationale to model these rigidities is to mimick the behavior of the real world's aggregate prices and wages, which the microeconomic studies reveal to be adjusted rather infrequently or at a long interval. Below, we take turn to look at these nominal rigidities in more details. Subsection 2.1 discusses international evidences of price/wage stickiness, and Subsection 2.2 reviews the evidence from Thailand.

2.1 Evidences of Nominal Rigidities

Nominal rigidities refer to the delayed responses to shocks featured in the prices of goods and factors of production. Taylor (1999) points out that the nominal rigidities are important for the monetary policy analysis research, where the delays in price and/or wage responses allow money to have pulpable real impacts on the economy. In this subsection, we look into the evidence of how sticky prices and wages are.

Why we need to model price stickiness? Is there a so-called stickiness in the price setting process? Taylor (1999) offers extensive summary of microeconomic studies with evidences on staggered pricing. As cited in Taylor (1999), Blinder (1994) uses survey data and finds that the mode frequency of price changes is *annually*, with around 90 percent of the surveyed firms leaving their prices unchanged for more than one year; Buckle and Carlson (1995) study the small businesses in the US and finds that it takes around 8 months for them to change their prices; in the UK, Domberger and Fiebig (1993) also finds the evidence of price staggering in the skewed distributions of price changes across 80 industry groups.

More recently, Klenow and Malin (2010) provide stylized facts of the pricing behavior based on international microeconomic evidence, including the prices in consumer and producer price index (CPI and PPI) baskets, barcode data from retailers, as well as the surveys conducted on sellers a.k.a. price setters. The conclusions of the study stress the important observations of how prices staying at the same levels for a lengthy period. There are four points worth to recapitulate here: 1) prices are not changed continuously, i.e. a diverge from full flexibility assumption, with price changes averaging around once or twice a year for U.S. and Euro areas; 2) when ignored the temporary price changes (in sales or discounts), the reference prices are even stickier; 3) price changes are larger than the inflation that triggered the changes; 4) changes in prices and wages exhibit synchronization. Particular attention should be paid to the frequency of the price changes, and it is reported in the study that between 1988-2005 the mean price changes occur at the frequency of 26.1% in the US monthly CPI basket, and much lower in the Euro area, at 15.1%. The frequency of price changes is larger for the emerging market countries, like Brazil, Mexico, and Chile, where growth and inflation drive the economy faster.

How about the rigidities in wage setting process? Are they as prevalent as the price stickiness? The rationale for rigidities in wages is also well founded. Below, we examine both general observations and conclusions of international studies on wage stickiness.

Taylor (1999) points out that there is little synchronization in wage setting behaviors across firms, drawing conclusions from an array of empirical studies. The inflexibility of wage is due to the nature of the employment contract that is usually fixed for an extended period of time. Based on unionized sector data, almost all employment contracts are for one year or longer. For the U.S. economy, within a given quarter, the ratio of workers with their wages adjusted in the contract is only 15 percent, and for a given year, the ratio is 40 percent, and heterogeneity is observed across industries (Taylor (1983) as cited in Taylor (1999)). Furthermore, average duration that wages remain at the same level is reported to be about 7 quarters (Cecchetti (1984) as cited in Taylor (1999)). Inflation is also an important consideration, with the frequency of wage changes positively relating to the rate of inflation (Card and Hyslop (1997) as cited in Taylor (1999)).

More recently, Barattieri et al. (2010) studies micro panel data (Survey of Income and Program Participation (SIPP) by the Bureau of Labor Statistics) between the period 1996-2000 for the wage stickiness. The authors treat the measurement errors and find that wages are sticky with the probability of wage change at 18 percent or 5.6 quarters for the hourly workers, and even lower frequency for the salaried workers. Little heterogeneity is, however, observed across the nine industries in the study, while there is also little seasonality in the wage readjustment timing, with the frequency of wage change almost constant throughout the year.

2.2 Nominal Rigidities in Thailand

Turning to the evidence for Thailand, Chantanahom et al. (2004) study the pricing behavior and inflation process based on Thai sectoral price data (CPI and PPI baskets) between 1995 and 2004. The analysis of CPI basket shows that after the financial crisis in 1997, the prices in Thailand's CPI baskets changed less frequently compared to the pre-crisis era. In particular, over 45 percent of CPI basket changed their respective prices every 9-12 months or longer. This implies that their prices change only once a year or at even lower frequency, providing a substantial support for persistence in prices.

Not only the prices are slowly adjusted, but there are other mechanisms that fuel the price stickiness in Thailand. The authors (Chantanahom et al., 2004) provide two key considerations. First, the government price ceiling policy can induce slow price movement. Around 30 percent of CPI basket items are administered[3] by the Ministry of Commerce,

[3] According to the Thailand's Department of Internal Trade (DIT) (http://www.dit.go.th/Price_20_170/2558/205_March.pdf), as of March 2015, there are 205 items of goods and services in the administered list, ranging from food and beverages, daily necessities, electrical appliances, transports and fuels, to raw materials and construction goods. These are categorized into three main groups: 1) Sensitive list (20 products) which is monitored daily; 2) Priority Watch List (6 products) which is monitored twice per week; and 3) Watch List (179 products) which is monitored every two weeks. According to Buddhari and Chensavasdijai (2003), the state administration of these prices includes monitoring, control (price ceilings), and intervention. This is to ensure that prices are reasonable and for some products it is required that the price adjustment must be planned and reported to the Ministry in advance.

meaning that they are not allowed to increase their prices beyond the set ceilings. Their prices are shown to change less frequently than the non-administered group, 4.38 as opposed to 7.22 times per year. Second, inflation targeting framework can also be another enhancing mechanism that fosters price stickiness. By anchoring inflation expectation, the monetary policy regime with strong emphasis on keeping inflation low and stable at a targeted level can induce slower price adjustment behavior. When facing shocks, economic agents believing that the central bank would take an action to curb excessive inflation would therefore restrain from resetting their prices as much as otherwise.

Chantanahom et al. (2004) also look into the price adjustments in the PPI basket and point out that when compared with the CPI, the PPI basket exhibits even greater stickiness with over 55 percent change prices every 9 months or longer (in the post-crisis period). In sum, evidences from both consumer and producer goods reconfirm our assumption of price stickiness in Thailand.

To conclude, this section discussed the evidences for the two sources of nominal frictions, namely the price and wage stickiness. As the literature emphasizes, the inclusion of nominal rigidities is the key contribution of NK literature, allowing monetary policy to wield significant influence on the real variables. Because prices and wages are not fully flexible, their responses to shocks are not as instantly as in the RBC literature. This becomes the key characteristic of New Keynesian DSGE models, where after the shock hits the economy, gradual adjustments of price/wage translate into the delayed responses of output and inflation, the outcomes more in line with the observation of the macroeconomic aggregate data.

3. Real Frictions

Apart from nominal frictions introduced above, the model proposed by Smets and Wouters (2007) also features other forms of inertia, arising directly in the aggregate real variables. This section focuses our attention on the two major components: the habit persistence and investment adjustment cost. Both kinds of inertia are supported by microeconomic theories as well as empirical evidences, while, from the practitioners' perspective, the incorporation of these inertia also helps enhance the model's performance. The following two subsections deal with habit formation in consumption and non-zero adjustment cost in investment, respectively. The last subsection 3.3 presents some evidence of the aggregate inertia in Thailand.

3.1 Habit Persistence

Habit persistence was mentioned as far back as Brown (1952). In his paper, Brown studies consumption behavior with respect to its own lag, using Canadian data. In his words, "the habit persistence effect is produced by the highest previous level of real consumption experienced." Brown tests for the significance of consumption habit effect in a linear consumer demand function and finds that the current consumption is best explained by income levels as well as lagged consumption.

How habit persistence explicitly enters into the consumer utility function for monetary policy analysis is explained by Fuhrer (2000). Fuhrer defines the habit persistence as current consumption (C_t) relative to its own past value, implying the consumer's need to maintain level of consumption in reference to his past routine. The utility function U_t is written as

$$U_t = \frac{1}{1-\sigma}\left(\frac{C_t}{{Z_t}^{\gamma}}\right)^{1-\sigma} \quad ; \; Z_t = \rho Z_{t-1} + (1-\rho)C_{t-1}$$

where Z_t expresses the reference level which depends on lagged consumption C_{t-1} as well as the lag of the reference level itself. Two parameters are of particular importance: γ shows the degree of habit persistence effect on utility and ρ implies the persistence of the reference level (i.e. longer lags of past consumption).

According to Fuhrer (2000), this habit effect gives rise to 'excess smoothness' observed in private consumption expenditure. With habit formation in utility function, Fuhrer argues that a structural model can replicate output (spendings) and inflation responses to monetary policy shocks that are consistent with the impulse response functions given by the less restricted models like VAR. By capturing the persistence in consumption, a major component of expenditure, the total spending exhibits a hump-shaped response to monetary policy shocks. Consequently, this delayed response of spending further prolongs the inflation response, in line with the evidence observed in aggregate data.

3.2 Investment Adjustment Cost

Gould (1968) discussed the role of investment adjustment cost in the firm's problem. The author proposes the adjustment cost (S) as a function of gross investment with the following properties: $S(I) > 0$, $S'(I) > 0$, $S(0) = 0$, and $S''(I) > 0$, which imply that the adjustment cost is an increasing convex function. From the firm's perspective, this adjustment cost enters directly into the firm's profit maximization as an additional cost along with those from labour and capital services. In Gould's words, "[T]*he actual investment path is in itself a decision which will affect profits and therefore should be either in the criterion function or recognized as a constraint on the maximization of this function*."

More recently, the adjustment cost is introduced into DSGE framework. In Christiano et al. (2005) the investment adjustment cost function is inserted into the law of motion for capital, yielding

$$K_{t+1} = (1-\delta)K_t + F(I_t, I_{t-1})$$

where the capital next period (K_{t+1}) depends on the capital stock currently available adjusted by the depreciation at the rate of δ. There is also the investment technology function (F), in which the current investment is translated into the next period physical capital as follows.

$$F(I_t, I_{t-1}) = [1 - S\left(\frac{I_t}{I_{t-1}}\right)]I_t \quad \text{where } S(1) = \ S'(1) = 0, \text{ and } \ S''(I) > 0.$$

The adjustment cost function of this form punishes any large shift of investment in comparison to the earlier level.

According to Christiano et al. (2011), the reason for including the investment adjustment cost is also empirical. The authors argue that with the adjustment cost, the DSGE model can replicate impulse response function of investment to monetary policy shocks, comparable to that given by VAR. Without the adjustment cost, the model runs the risk of portraying a "counterfactual" too large investment expansion after a rise in interest rate. The adjustment cost function above that takes penalty when I_t increases too quickly from I_{t-1} can help prevent this. With the adjustment cost, the model can produce a reasonable reaction in investment, with the peak effect lags several quarters after the initial monetary policy shock.

3.3 Persistence in Thailand's Aggregate Data

Tanboon (2008) develops a medium-sized DSGE for Thailand with a particular focus on identifying the impacts of monetary policy and the different channels of transmission mechanism. Using calibration based on previous microeconomic studies, international studies, and his own regression works, Tanboon evaluates the small-open-economy model equipped with not only nominal rigidities but also aggregate persistence as well as trade and viable banking sectors. With respect to our discussion on the role of aggregate inertia, Tanboon (2008) provides stylized facts about the Thai economy's business cycle as well as the persistence of the macroeconomic data. It is found that for Thailand case, the persistence, as depicted by the autocorrelation coefficient, of key macro variables are substantial. Output, consumption, as well as investment are found to be dependent on their lags in the range between 0.6 and 0.7. The author argues that this becomes the basis for the inclusion of real rigidities, namely habit formation in consumption and investment adjustment cost, in his model. This provides the supporting evidence and encouragement for the inclusion of both inertia in our model.

In sum, this section reviews the inertia inside aggregate real variables, namely consumption and investment. The inertia mechanisms take current consumption and investment referencing to the levels in the preceding period. This persistence in real variables plays a complementary but vital role (see Chistiano et al. (2005) for detail) to the nominal rigidities discussed in the previous section. Together, the foundation laid in section 2 and 3 provide a stepping stone for the description of our model based on Smets and Wouters (2007).

4. Model Specification

The model used in this study is based closely on the medium-sized New Keynesian DSGE model outlined by Smets and Wouters (2007) and Smets and Wouters (2006). With two factors of production, the economy features four interlinked sectors, including households, goods producing sector, labour union sector, and the government. Nominal and real frictions are incorporated into the economy, arising from price and wage stickiness; price and wage indexations to past inflation; fixed cost in terms of output; the habit persistence in consumption; adjustment cost in investment and capital utilization rate. There are in total seven exogenous processes facing the economy. Details of the model are further delineated by sector below, and the last subsection presents the log-linearized system.

4.1 The 4 Sectors

4.1.1 Households

The economy is populated by indefinite number of identical households with an expected non-separable utility function of the form:

$$E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma_c}(C_t - hC_{t-1})^{1-\sigma_c}\right] \left[exp\left(\frac{\sigma_c - 1}{1+\sigma_L} L_t{}^{1+\sigma_L}\right)\right].$$

The household derives utility from current consumption (C_t) relative to its own lag and from supplying labour hours (L_t) to employment in production process, all discounted by the discount factor β. The parameter h expresses the degree of habit persistence in consumption, in which the household, according to the habit already formed, derives utility from current consumption referencing on the level consumed last period. That is, only the current consumption which is greater than a certain proportion of last period consumption would make the household better off.

The household maximizes its utility with respect to the following three constraints:

$$C_t + I_t \leq \frac{W_t L_t}{P_t} + \frac{Div_t}{P_t} + \frac{R_t^k K_t^S}{P_t} - a(Z_t)K_{t-1} + \left(\frac{B_{t-1}}{P_t} - \frac{B_t}{P_t R_t \varepsilon_t^b}\right) + T_t$$

$$K_t = (1-\delta)K_{t-1} + \varepsilon_t^i \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t$$

$$K_t^S = Z_t K_{t-1}$$

Firstly, the budget constraint describes that the real expenditures (Consumption C_t and Investment I_t) are limited by the household's real incomes. Nominal items can be deflated into real terms, using the price level P_t. Nominal incomes are generated from labour work at the wage rate W_t, dividend income Div_t paid by the labour union, rental income of capital ($R_t^k K_t^S$) net of real adjustment cost function $a(Z_t)K_{t-1}$, and the net revenue from bond B_{t-1}. The real transfer or tax by the government is captured by T_t.

Secondly, the law of motion for capital suggests that the current level of capital K_t depends on the capital from last period net of depreciation at the rate δ, plus the new investment I_t. The function $S(\cdot)$ of the current level of investment relative to the level last period determines the investment adjustment cost. ε_t^b and ε_t^i are the stochastic shocks on bond premium and investment price. Both follow AR(1) process such that $\ln(\varepsilon_t^b) = \rho_b \ln(\varepsilon_{t-1}^b) + b_t$ and $\ln(\varepsilon_t^i) = \rho_i \ln(\varepsilon_{t-1}^i) + i_t$ where $b_t \sim N(0, \sigma_b)$ and $i_t \sim N(0, \sigma_i)$, respectively.

Thirdly, the last constraint facing the households shows that the current level of capital supplied to the production sector (K_t^S) is determined by the capital installed last period adjusted with the utilization rate Z_t.

Combining the constraints with the objective function using Lagrange multipliers, we can derive the following first-ordered conditions:

$$\frac{\partial \mathcal{L}}{\partial C_t}: \ \Lambda_t = \left[\exp\left(\frac{\sigma_c - 1}{1+\sigma_L}\right) {L_t}^{1+\sigma_L}\right] [C_t - hC_{t-1}]^{-\sigma_c}$$

$$\frac{\partial \mathcal{L}}{\partial L_t}: \ \Lambda_t \left(\frac{W_t}{P_t}\right) = (\sigma_c - 1){L_t}^{\sigma_L} \left[\exp\left(\frac{\sigma_c - 1}{1+\sigma_L}\right) {L_t}^{1+\sigma_L}\right] [C_t - hC_{t-1}]^{1-\sigma_c}$$

$$\frac{\partial \mathcal{L}}{\partial B_t}: \ \Lambda_t = \beta \varepsilon_t^b R_t \left[\frac{\Lambda_{t+1}}{\pi_{t+1}}\right]$$

$$\frac{\partial \mathcal{L}}{\partial I_t}: \ \Lambda_t = \Lambda_t \, \varepsilon_t^i \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\left(\frac{I_t}{I_{t-1}}\right)\right] + \beta[\Lambda_{t+1} \, \varepsilon_{t+1}^i \, S'\left(\frac{I_t}{I_{t-1}}\right)^2]$$

$$\frac{\partial \mathcal{L}}{\partial K_t}: \ \Lambda_t^K = \beta E_t \left[\Lambda_{t+1} \left(\frac{R_{t+1}^k Z_{t+1}}{P_{t+1}} - a(Z_{t+1})\right)\right] + \Lambda_{t+1}^K (1-\delta)$$

$$\frac{\partial \mathcal{L}}{\partial Z_t}: \ a'(Z_t) = \frac{R_t^k}{P_t}$$

The value of the capital stock can be denoted by the Tobin's $Q_t = \frac{\Lambda_t^K}{\Lambda_t}$, the relative shadow prices of capital to consumption goods.

4.1.2 Goods Producing Sector

Households obtain consumption goods from the production sector, which contains two different stages. Intermediate producers compile labour and capital under the current level of technology to manufacture their products. The intermediate goods, characterized by imperfect substitutability, allow intermediate producers to set prices and extract non-zero profit. On the contrary, final producers operate in a perfectly competitive market selling homogenous final goods to the households, making no profit in return. Price stickiness arises in the intermediate production stage, where only a proportion of intermediate producers can change their prices in a given period.

Final Producers/Retailers

The final production, or Retailing, requires no labour service nor capital inputs to assemble and deliver the final goods (Y_t) at the price (P_t) to the households. The final goods are aggregated as in Kimball (1995) from all available intermediate goods $Y_t(i)$ purchased at the price $P_t(i)$. Thus, the final good producers face the profit maximization of the form:

$$Max_{Y_t,Y_t(i)}\,\Pi^F = P_tY_t - \int_0^1 P_t(i)Y_t(i)\,di$$

$$Subject\ to\ \int_0^1 G(\frac{Y_t(i)}{Y_t};\varepsilon_t^p)di = 1$$

All intermediate goods $Y_t(i)$ are indexed by i on the continuum between 0 and 1, and the aggregator function G is strictly increasing concave. According to Kimball (1995), the final goods production function can be said to exhibit constant returns to scale, which characterizes the perfectly competitive market. Meanwhile, the exogenous process ε_t^p represents the shocks to the elasticity of demand for input (intermediate goods), and thus the markup (of the intermediate producers); where $\ln(\varepsilon_t^p) = \rho_b \ln(\varepsilon_{t-1}^p) + MA_p \mathrm{p}_{t-1} + \mathrm{p}_t$; $\mathrm{p}_t \sim N(0, \sigma_p)$. Solving the F.O.C., we can write

$$Y_t(i) = Y_t G'^{-1}\left[\frac{P_t(i)}{P_t}\int_0^1 G'\left(\frac{Y_t(i)}{Y_t}; \varepsilon_t^p\right) * \left(\frac{Y_t(i)}{Y_t}\right) di\right]$$

Intermediate Producers

Unlike the final goods case, the market for intermediate goods is characterized by imperfection. In particular, the increasing returns to scale of the production technology and non-homogenous nature of the intermediate goods gives rise to the monopolistic competitive environment, which in turn brings about the price stickiness in our model economy.

As for inputs, the intermediate producers hire the labour service $L_t(i)$ and capital K_t^s at their market prices to manufacture intermediate goods, which in turn can be sold to the final goods producers. Consequently, the intermediate goods producing firms face the cost minimization of the form:

$$Min_{L_t(i), K_t^s(i)} W_t L_t(i) + R_t^k K_t^s$$

$$\text{Subject to } Y_t(i) = \varepsilon_t^a \, [K_t^s(i)]^{\alpha} \, [\gamma^{\,t} L_t(i)]^{1-\alpha} - \gamma^{\,t}\Phi$$

The production function of the intermediate producers uses labour-augmenting technology with the trend growth rate of the economy denoted by $\gamma^{\,t}$, and the fixed cost (in terms of real output) is represented by Φ. Total factor productivity (TFP), implied by ε_t^a , follows the autoregressive form $\ln(\varepsilon_t^a) = \rho_a \ln(\varepsilon_{t-1}^a) + a_t$ where $a_t \sim N(0, \sigma_a)$. Setting Lagrangean function, with the multiplier Θ_t, the F.O.C. of this minimization problem are

$$\frac{\partial \mathcal{L}}{\partial L_t(i)} : \; W_t = \Theta_t \,(1-\alpha)\, \varepsilon_t^a \gamma^{\,(1-\alpha)t} \left[\frac{K_t^s(i)}{L_t(i)}\right]^{\alpha}$$

$$\frac{\partial \mathcal{L}}{\partial K_t^s} : \; R_t^k = \Theta_t \,(\alpha) \varepsilon_t^a \gamma^{\,(1-\alpha)t} \left[\frac{L_t(i)}{K_t^s(i)}\right]^{1-\alpha}$$

Combining the two, we can derive that $\frac{W_t}{R_t^k} = \frac{1-\alpha}{\alpha}\left(\frac{K_t^s(i)}{L_t(i)}\right) = \frac{1-\alpha}{\alpha}\left(\frac{K_t^s}{L_t}\right)$. This indicates that in the equilibrium where the capital-labour ratio is the same for all firms, the relative prices of labour and capital inputs is proportional to the capital-labour ratio.

The intermediate producers then maximize their profit based on the fact that they can reset their prices; however, only a fraction of all intermediate producers can perform this reoptimization in any given period. The problem can be restated as

$$Max_{\tilde{P}_t(i)} \, \Pi_t^{IP} = E_t \sum_{s=0}^{\infty} \xi_p \, \beta \left[\frac{\Xi_{t+s} P_t}{\Xi_t P_{t+s}}\right] \left(\widetilde{P}_{t+s}(i)\left(\prod_{q=1}^{\infty} \pi_{t+q-1}^{\iota p} \overline{\pi}^{1-\iota p}\right) - MC_{t+s}\right) Y_{t+s}(i)$$

$$subject\ to\ \; Y_{t+s}(i) = Y_{t+s}\, G'^{-1}\left(\frac{P_t(i) X_{t,s}}{P_{t+s}} \tau_{t+s}\right)$$

Where the firm faces the Calvo probability of $1 - \xi_p$ to reoptimize the price. $\widetilde{\mathrm{P}}_{t+s}$ is the new reoptimized price, $\pi_t = \frac{P_t}{P_{t-1}}$ is the inflation at time t and $\overline{\pi}$ is the steady state inflation, MC_{t+s} is the marginal cost and equivalent to the multiplier Θ_t above, $\beta\left[\frac{\Xi_{t+s}\mathrm{P}_t}{\Xi_t P_{t+s}}\right]$ is the discount factor for the intermediate producers, $\tau_t = \int_0^1 G'\left(\frac{Y_t(i)}{Y_t}; \varepsilon_t^p\right) * (\frac{Y_t(i)}{Y_t})di$, and $\mathrm{X}_{t,s} = \begin{Bmatrix} 1 & ;\ for\ s = 0 \\ \prod_{q=1}^{\infty} \pi_{t+q-1}^{\iota p} \overline{\pi}^{1-\iota p} & ;\ for\ s = 1,2,3, \dots, \infty \end{Bmatrix}$ where the parameter ιp governs the degree of indexation to past inflation.

Solving this maximization problem, we can write aggregate price index as

$$P_t = \left(1 - \xi_p\right) P_t(i) G'^{-1}\left[\frac{P_t(i)\tau_t}{P_t}\right] + \ \xi_p \pi_{t-1}^{\iota p} \overline{\pi}^{1-\iota p}\ P_{t-1} G'^{-1}[\frac{\pi_{t-1}^{\iota p}\overline{\pi}^{1-\iota p} P_{t-1}\tau_t}{P_t}]$$

4.1.3 Labour Unions

In order to mimick the stickiness in wage, households do not supply labour service directly to the production sector. Symmetric to the staggered pricing in the goods producing sector introduced above, the wage setting contains friction that arises from two stages in delivering labour service to actual employment: (intermediate) monopolistic labour unions and final labour packers.

Households supply homogenous labour service to intermediate labour unions which bundle them by means of Kimball (1995) aggregator to create differentiated labour services $L_t(i)$, which in turn are sold to the labour packers before the final homogenous labour service L_t is employed by the intermediate producing firms. Intermediate labour unions operate in a monopolistic competitive market and due to their market power are able to set the wage rate with mark-ups. The non-zero profits of the labour unions are then transmitted to the households' budget constraint in the form of dividends Div_t.

Labour Packers

On one hand, labour packers operate in a perfectly competitive market, supplying the labour service (L_t) to the production sector at the wage rate (W_t). Labour packers, thus, maximize the profit function of the form:

$$Max_{L_t, L_t(i)}\, \Pi_t^{LP} = W_t L_t - \int_0^1 W_t(i) L_t(i)\, di$$

$$Subject\ to \int_0^1 H(\frac{L_t(i)}{L_t}; \varepsilon_t^w) di = 1$$

We can derive F.O.C.: $L_t(i) = L_t H'^{-1}\left[\frac{W_t(i)}{W_t}\int_0^1 H'\left(\frac{L_t(i)}{L_t}\right)\left(\frac{L_t(i)}{L_t}\right) di\right]$.

Intermediate Labour Unions

On the other hand, intermediate labour unions pool labour hours from households to create imperfectly substitutable labour service ($L_t(i)$), allowing themselves market power to set wage rate ($W_t(i)$) from the labour packers.

In order to replicate the stickiness in wages, not all labour unions reoptimize the wage rates in a given period. This Calvo approach to wage setting creates a delay in wage responses. In particular, the parameter ξ_w indicates the degree of wage stickiness, such that when $\xi_w = 1$ the wage is permanently fixed, and when $\xi_w = 0$ the wage is fully flexible. Labour unions face the following maximization problem:

$$Max_{\widetilde{W}_t(i)}\ \Pi_t^{LU} = E_t\ \sum_{s=0}^{\infty} \xi_w^s\, \beta \left[\frac{\Lambda_{t+s} \mathrm{P}_t}{\Lambda_t P_{t+s}}\right] \left(\widetilde{\mathrm{W}}_t(i)\left(\prod_{q=1}^{\infty} \gamma \pi_{t\mp q-1}^{\iota w} \overline{\pi}^{1-\iota w}\right) - \mathrm{W}_{t+s}^{H}\right) \mathrm{L}_{t+s}(i)$$

$$Subject\ to \quad \mathrm{L}_{t+s}(i) = \mathrm{L}_{t+s}\, H'^{-1}\left(\frac{\mathrm{W}_{t+s}(i)\mathrm{X}_{t,s}}{\mathrm{W}_{t+s}} \tau_{t+s}\right)$$

$$\mathrm{X}_{t,s} = \begin{Bmatrix} 1 & ;\ for\ s = 0 \\ \prod_{q=1}^{\infty} \pi_{t+q-1}^{\iota w} \overline{\pi}^{1-\iota w} & ;\ for\ s = 1,2,3, \dots, \infty \end{Bmatrix}$$

$$\tau_t = \int_0^1 H'\left(\frac{L_t(i)}{L_t}\right) * \left(\frac{L_t(i)}{L_t}\right) di$$

The term $\beta \left[\frac{\Lambda_{t+s} \mathrm{P}_t}{\Lambda_t P_{t+s}}\right]$ represents the intertemporal discount factor facing the labour unions, while $\mathrm{W}_{t+s}(i)$ shows the wage rate set by the unions and W_{t+s}^{H} the wage paid to households. Regarding the two constraints, only a proportion of labour unions are able to reoptimize the wage rate at $\widetilde{\mathrm{W}}_t(i)$ to maximize the markup, while the rest of the unions take the same wage rate that grows along with the economy and a combination of indexation with past and steady state inflations ($\pi_{t\mp q-1}$and $\overline{\pi}$), as governed by the parameter ιw.

Solving the F.O.C., we can write the aggregate wage index as

$$W_t = (1 - \xi_w)\widetilde{W}_t(i) H'^{-1}\left[\frac{\widetilde{W}_t(i)\tau_t}{W_t}\right] + \ (\xi_w)\gamma \pi_{t-1}^{\iota w} \overline{\pi}^{1-\iota w}\, W_{t-1} H'^{-1}\left[\frac{\gamma \pi_{t-1}^{\iota w} \overline{\pi}^{1-\iota w} W_{t-1}\tau_t}{W_t}\right]$$

4.1.4 Government

In this model economy, the government delivers the amount of public goods/expenditure (G_t) equal to the tax revenues (T_t) and the net bond borrowings from the households. In other words, the government faces a budget constraint of the form:

$$P_t G_t \ = \ T_t + \left(\frac{B_t}{R_t} - B_{t-1}\right).$$

The public goods relative to the steady state output path is defined by $\varepsilon_t^g \ = \ G_t/\gamma^t Y_t$, and it follows the process: $ln\left(\varepsilon_t^g\right) = \rho_g ln\left(\varepsilon_{t-1}^g\right) + \rho_{ga}\ (a_t) + \ g_t$ where $g_t \sim N\left(0, \sigma_g\right)$

At the same time, the government, via central bank, conducts monetary policy by setting the short-term interest rate according to a variant of feedback rule proposed by Taylor (1993). In particular, the central bank determines the appropriate level of short-term interest rate on consideration of the gaps in inflation rate, output level, and output growth from their respective targets, indicated by the upper-barred variables (steady state values). The parameter ρ indicates the degree of interest rate smoothing, where the current interest rate moves gradually from its own historic value. The output gap is determined by the deviation of current output (Y_t) from the potential output (Y_t^p), identified as the level of output when the economy faces fully flexible price and wage.

$$\frac{R_t}{\bar{R}} = \ (\frac{R_{t-1}}{\bar{R}})^{\rho} \left[\left(\frac{\pi_t}{\bar{\pi}}\right)^{r\pi} \left(\frac{Y_t}{Y_t^p}\right)^{ry}\right]^{1-\rho} [\left(\frac{Y_t}{Y_t^p}\right) / \left(\frac{Y_{t-1}}{Y_{t-1}^p}\right)]^{rdy}\ \varepsilon_t^r$$

Where ε_t^r represents the monetary policy shock that follows the AR(1) process:

$$\ln(\varepsilon_t^r) = \rho_r \ln(\varepsilon_{t-1}^r) + \mathrm{rr}_t \ \text{ where } \mathrm{rr}_t \sim N(0, \sigma_r)$$

Resource Constraint

By combining the households and government budget constraints, we can derive the economy-wide resource constraint of the form:

$$Y_t = C_t + I_t + G_t + a(Z_t)\bar{K}_{t-1}.$$

The total output equals the summation of consumption, investment, and public goods, plus the capital stock carried over from last period (adjusted with capacity utilization rate Z_t).

4.2 Exogenous Processes

As in Smets and Wouters (2007), this model economy features seven exogenous processes in the four sectors described above. They can be summarized again as follows:

Sector	Shocks	Process
Households	Intertemporal Preference (Financial Risk Premium)	$\ln(\varepsilon_t^b) = \rho_b \ln(\varepsilon_{t-1}^b) + b_t$ where $b_t \sim N(0, \sigma_b)$
	Investment Technology	$\ln(\varepsilon_t^i) = \rho_i \ln(\varepsilon_{t-1}^i) + i_t$ where $i_t \sim N(0, \sigma_i)$
Firms	TFP	$\ln(\varepsilon_t^a) = \rho_a \ln(\varepsilon_{t-1}^a) + a_t$ where $a_t \sim N(0, \sigma_a)$
	Price Markup	$\ln(\varepsilon_t^p) = \rho_b \ln(\varepsilon_{t-1}^p) + MA_p p_{t-1} + p_t$ where $p_t \sim N(0, \sigma_p)$
Labour	Wage Markup	$\ln(\varepsilon_t^w) = \rho_w \ln(\varepsilon_{t-1}^w) + MA_w w_{t-1} + w_t$ where $w_t \sim N(0, \sigma_w)$
Government	Exogenous Spending	$\ln(\varepsilon_t^g) = \rho_g \ln(\varepsilon_{t-1}^g) + \rho_{ga}(a_t) + g_t$ where $g_t \sim N(0, \sigma_g)$
	Monetary Policy	$\ln(\varepsilon_t^r) = \rho_r \ln(\varepsilon_{t-1}^r) + rr_t$ where $rr_t \sim N(0, \sigma_r)$

4.3 Log-Linearized Model

The log-linearized version of the above economy is described by 14 equations. Note that the tilde lower case is the variables detrended by the growth rate (γ^t), while the lowercase variables are expressed in terms of log-deviation from its steady state value (denoted by the upper-barred uppercase). For instance, the consumption $c_t = \ln(\widetilde{c_t} - \bar{C})$, where $\widetilde{c_t} = \frac{C_t}{\gamma^t}$. More detail of log-linearization of these equations can be found in the Model Appendix of Smets and Wouters (2006).

Equation	Specification
Aggregate Resource	$\boldsymbol{y_t = c_y c_t + i_y i_t + z_y z_t + \varepsilon_t^g}$ $1 = c_y + i_y + g_y$; $i_y = (\gamma - 1 + \delta)k_y$; $z_y = \bar{R}_t k_y$
Consumption Euler	$\boldsymbol{c_t = c_1 c_{t-1} + (1 - c_1)E_t(c_{t+1}) + c_2\big(l_t - E_t(l_{t+1})\big)}$ $\boldsymbol{-c_3(r_t - E_t(\pi_{t+1}) + \varepsilon_t^b)}$ $c_1 = (h/\gamma)/(1 + h/\gamma)$; $c_2 = (\sigma_c - 1)(\bar{W}\bar{L}/\bar{C})/\sigma_c(1 + h/\gamma)$ $c_3 = (1 - h/\gamma)/(1 + h/\gamma)\,\sigma_c$
Investment Euler	$\boldsymbol{i_t = i_1 i_{t-1} + (1 - i_1)E_t(i_{t+1}) + i_2 q_t + \varepsilon_t^i}$ $i_1 = 1/(1 + \beta\gamma^{1-\sigma_c})$ $i_2 = 1/(1 + \beta\gamma^{1-\sigma_c})\gamma^2\varphi$
Value of capital	$\boldsymbol{q_t = q_1 E_t(q_{t+1}) + (1 - q_1)E_t\big(r_{t+1}^k\big) - (r_t - \pi_{t-1} + \varepsilon_t^b)}$ $q_1 = (\beta\gamma^{-\sigma_c})(1 - \delta) = (1 - \delta)/(\bar{R}_t + (1 - \delta))$
Production Function	$\boldsymbol{y_t = \phi(\alpha k_t^s + (1 - \alpha)l_t + \varepsilon_t^a)}$
Capital Installation	$\boldsymbol{k_t^s = k_{t-1} + z_t}$
Capital Utilization rate	$\boldsymbol{z_t = z_1 r_t^k}$ where $z_1 = \frac{1-\psi}{\psi}$
Capital Accumulation	$\boldsymbol{k_t = k_1 k_{t-1} + (1 - k_1)i_t + k_2 \varepsilon_t^i}$ $k_1 = \dfrac{1-\delta}{\gamma}$; $k_2 = (1 - \dfrac{1-\delta}{\gamma})(1 + \beta\gamma^{1-\sigma_c})(\gamma^2\varphi)$

NK-Phillips Curve	$\boldsymbol{\pi_t = \pi_1\pi_{t-1} + \pi_2 E_t(\pi_{t+1}) - \pi_3\mu_t^p + \varepsilon_t^p}$ $\pi_1 = \iota_p/(1+\beta\gamma^{1-\sigma_c}\iota_p)\ ;\ \pi_2 = \beta\gamma^{1-\sigma_c}/(1+\beta\gamma^{1-\sigma_c}\iota_p)$ $\pi_3 = \left(\frac{1}{1+\iota_p\beta\gamma^{1-\sigma_c}}\right)\left(\frac{(1-\beta\gamma^{1-\sigma_c}\xi_p)(1-\xi_p)}{\xi_p\left((\phi_p-1)\varepsilon_t^p+1\right)}\right)$
Rent	$\boldsymbol{r_t^k = -(k_t - l_t) + w_t}$
Price Markup	$\boldsymbol{\mu_t^p = \alpha(k_t^s - l_t) - w_t + \varepsilon_t^a}$
Wage Markup	$\boldsymbol{\mu_t^w = w_t - \left(\sigma_L l_t + \frac{c_t - hc_{t-1}}{1-h}\right)}$
Real Wage	$\boldsymbol{w_t = w_1 w_{t-1} + (1-w_1)\left(E_t(w_{t+1}) + E_t(\pi_{t+1})\right) - w_2\pi_t + w_3\pi_{t-1} - w_4\mu_t^w + \varepsilon_t^w}$ $w_1 = 1/(1+\beta\gamma^{1-\sigma_c})\ ;\ w_2 = (1+\beta\gamma^{1-\sigma_c})/(1+\beta\gamma^{1-\sigma_c})\iota_w$ $w_3 = \iota_w/(1+\beta\gamma^{1-\sigma_c})\ ;\ w_4 = \left(\frac{1}{1+\beta\gamma^{1-\sigma_c}}\right)\left(\frac{(1-\beta\gamma^{1-\sigma_c}\xi_w)(1-\xi_w)}{\xi_w\left((\phi_w-1)\varepsilon_t^w+1\right)}\right)$
Monetary Policy	$\boldsymbol{r_t = \rho r_{t-1} + (1-\rho)\{r_\pi\pi_t + r_y(y_t - y_t^p)\} + r_{dy}\{(y_t - y_t^p) - (y_{t-1} - y_{t-1}^p)\} + \varepsilon_t^r}$

5. Methodology and Data Description

This section reviews the evaluation methods used in our study and provides the detail regarding the data. Following Smets and Wouters (2007), we adopt the Bayesian approach to estimate the structural parameters as well as the seven shocks of interest. Bayesian estimation allows us to specify the prior distributions of the parameters in addition to the likelihood function of the data. The first part of this section provides a brief introduction of the Bayesian estimation, including the Bayes' Theorem and the roles of priors. Then the second part discusses our sample of Thailand data focusing on choices, sources, and transformations.

Bayesian Estimation

The parametization in this study is based on Bayesian estimation. According to Dave and DeJong (2011), Bayesian methods provide a direct link between structural models and the use of external information, namely the priors. Bayesian methods allow us to write conditional probability with respect to the parameters based on a combination of the observed data, the model specification, and the prior distribution. The choice of priors hinges on the judgment of researchers, and therefore unlike the maximum likelihood method, the posterior distribution in Bayesian estimation does not rely solely on the information contained in the data, but also the specification of priors.

The foundation of this methodology is the Bayes' Theorem, which states that the conditional probability of A given B is

$$p(A|\, B) = \frac{p(B|A) * p(A)}{p(B)}.$$

Given this premise, according to Griffoli (2013), when we consider our framework, the posterior density function, $p(\theta_{\mathcal{M}}|\, \Psi_T, \mathcal{M})$ on the left hand side below, can be expressed as a conditional probability density of the parameter vector $\theta_{\mathcal{M}}$ given the data Ψ_T and the model $\mathcal{M}$. On the right hand side, the numerator is called posterior kernel, equal to the data density $p(\Psi_T|\theta_{\mathcal{M}}, \mathcal{M})$ multiplied by the prior $p(\theta_{\mathcal{M}}|\mathcal{M})$.

$$p(\theta_{\mathcal{M}} |\ \Psi_T, \mathcal{M}) = \frac{p(\Psi_T | \theta_{\mathcal{M}}, \mathcal{M}) * p(\theta_{\mathcal{M}} | \mathcal{M})}{p(\Psi_T |\ \mathcal{M})}$$

The denominator $p(\Psi_T |\ \mathcal{M})$ is the marginal density function, or marginal likelihood, which can be equivalently written as $\int_{\theta_{\mathcal{M}}} p(\Psi_T | \theta_{\mathcal{M}}, \mathcal{M}) * p(\theta_{\mathcal{M}} | \mathcal{M})\, d\theta_{\mathcal{M}}$. Because the denominator does not depend on $\theta_{\mathcal{M}}$, the posterior density is proportional to the posterior kernel.

Thus, the kernel is a key criterion. From the above equation, the posterior kernel can be found by combining the data density with the prior. Often, the data density $p(\Psi_T | \theta_{\mathcal{M}}, \mathcal{M})$ is calculated using the Kalman filter. With the help of Metropolis-Hastings sampling method, a candidate parameter value is drawn, and based on a specific rule the candidate parameter value is kept or discarded. The parameter values that are kept can be used to plot a histogram that approximately represents the posterior distribution of that parameter. For more detailed explanation of the algorithms for Bayesian estimation, refer to Section 3.2 of the Chapter 3 as well as Canova (2007), Griffoli (2013), and Smets and Wouters (2007).

Data Description

This subsection explains the data sources and transformations. There are seven observable time series entering into our model. These include, namely, the per-capita real output, consumption, and investment, along with inflation, interest rate, working hours, and real hourly wage. Since our data is limited by the publication of GDP and its components, we use quarterly frequency, and the sample covers between 2001Q2 and 2014Q4, for a total of 55 observations. Although the GDP and interest rate series can trace as far back as 1993Q1, the labour data is constrained by short availability from 2001 onwards.

The quarterly GDP and its components (Private Consumption Expenditure (PCE) and private capital formation) along with the number of hours worked per worker[4] are obtained from the National Economic and Social Development Board (NESDB), while the GDP deflator is calculated as the ratio between nominal and real GDP. The per capita amounts are calculated based on the number of persons aged 15 or older in the labour force. The average monthly nominal wage and the interbank overnight lending rate (annual) are acquired from the Bank of Thailand.

Regarding data handling, all series are seasonally adjusted, except the interest rate. All nominal amounts are expressed in real terms by using the GDP deflator. Inflation is the log difference of the GDP deflator. Aside from the interest rate and the log transformation of hours worked, the rest of data are expressed in log first differences. The short-term interest rate per annual is adjusted into quarterly frequency by dividing it by 4. Average hourly wage is calculated by assuming constant monthly working hours (8 hours/day times 22 days per month). Quarterly hours worked are calculated by assuming each quarter comprise 13 working weeks.

Additional to the model specifications outlined in Section 4, there are seven measurement equations, corresponding to the seven endogenous variables, as in Smets and Wouters (2007). These equations provide the links between the observed data and the

[4] The number of hours worked per worker is published from 2001Q1 to 2014Q1 by NESDB. For the data in the last three quarters of 2014, we calculate the estimates from the hours worked for the whole Kingdom of Thailand in the Labour Force Survey published by Thailand's National Statistical Office (NSO).

model variables. In particular, the observed data is decomposed in order to identify the model variable and its steady state. The GDP and its components as well as the real wage, all enter the model as growth rates, which are calculated as the log first differences. They are assumed to have a common steady state growth γ_{ss}, while π_{ss} , l_{ss} , and r_{ss} show the steady state inflation rate, labour hours, and interest rate, respectively. Steady state labour hours is normalized to zero, implying that the variable Hours worked is $ln(Hours) - l_{ss}$. These are summarized in Table 4-1 below.

Table 4-1 Data and Measurement Equations

Variable	**Data**	**Measurement equations**
Output	GDP	$dln(\text{GDP}) = \gamma_{ss} + (\text{y}_t - \text{y}_{t-1})$
Consumption	C	$dln(C) = \gamma_{ss} + (\text{c}_t - \text{c}_{t-1})$
Investment	I	$dln(I) = \gamma_{ss} + (\text{i}_t - \text{i}_{t-1})$
Real Wage	W	$dln(W) = \gamma_{ss} + (\text{w}_t - \text{w}_{t-1})$
Inflation	GDP Deflator	$dln(Deflator) = \pi_{ss} + \pi_t$
Hours Worked	Hours	$ln(Hours) = l_{ss} + l_t$
Interest rate	R	$R = \text{r}_{ss} + \text{r}_t$

6. Estimation, Results and Analysis

This section presents the Bayesian estimation results of the DSGE model described in Section 4. The Bayesian approach requires the specification of prior distributions before deriving the posterior estimation of the deep parameters as well as the seven structural shocks, and this is shown in Subsection 6.1. For further dynamic analysis, subsection 6.2 takes a look at the impulse response functions of the key shocks in the model. Subsection 6.3 offers the forecast error variance decompositions. Lastly, subsection 6.4 compares the forecast performance of our DSGE model with those of Bayesian Vector Autoregressive (BVAR) models, through the measure of marginal likelihood.

6.1 Priors and Posterior Estimates

Prior

In keeping with the Bayesian approach outlined in the previous section, we combine the data and the prior distributions in order to estimate the deep parameters of the DSGE model. The priors are set in a similar manner as in Smets and Wouters (2007). Particularly, the seven shocks in the model are set to have a stochastic component with a standard error following an inverse-gamma distribution with mean 0.1 and 2 degrees of freedom, while the AR(1) and MA(1) components of the shocks are assumed to follow a beta distribution with mean 0.5 and a standard deviation of 0.2. By choosing the same and rather loose priors, we treat all shocks equally and let the informational content in the data decides their importance.

Regarding the frictions, the probabilities in reoptimizing prices and wages are set to follow a beta distribution with mean 0.5 and standard deviation of 0.1. The same prior distributions are assumed for the indexation of prices and wages to lagged inflation. For real frictions, the mean of habit persistence is set at 0.85, referencing to the calibration work by Tanboon (2007). Investment adjustment cost is represented by a normal distribution with mean 4 and standard deviation 1.5, as in Smets and Wouters (2007) and Christaino et al.(2005). The elasticity of capital utilization rate to the change in rental rate of capital follows a beta distribution with mean 0.5 and standard deviation 0.15.

Another set of priors of interest is those in the modified Taylor rule. The short-term interest rate movement is assumed to vary by 1) its own lag and 2) other policy concerns including inflation, output gap, and output growth. The priors for these monetary policy considerations are assumed to all follow normal distributions. For the inflation consideration, the prior is set to be larger than those for the output gap and output growth to reflect the strong emphasis of inflation targeting framework.

As in Smets and Wouters (2007), there are five parameters which are held fixed. These include 1) the quarterly depreciation rate at 0.0105; 2) the labour market markup at 1.05; 3) the exogenous spending ratio at 0.25; 4) and 5) the curvature parameters of Kimball aggregator in both the goods and labour markets at 10. We based the first two values on the calibration work for Thailand by Tanboon (2008), while the third value comes from the share of total output deducted private consumption and investment over the period 1996-2014. The last two are borrowed from Smets and Wouters (2007) to represent the price and wage setting behaviors.

Posteriors

Turning to the posterior estimates, Table 4-2 reports the prior and posterior distributions of all parameters, with a 90% confidence interval. Several of the parameters have posterior estimates close to their prior means, indicating the consistency between the initial guess (priors) and the informational content contained in the data. In contrast, the posterior estimates which move far from their priors manifest the additional gain of employing the data in our Bayesian methodology.

All of the stochastic processes have high dependence on its own lag, as indicated by the persistence parameters (ρ), except the disturbances in investment technology, monetary policy, and price markup. Out of the seven structural shocks, the shocks in TFP, exogenous spending, and investment technology are of particular significance. Although the monetary policy shock is the smallest among the seven, it does not directly translate that it has no impacts on the economy as further analysis will show below.

Looking at the real frictions, the habit persistence parameter shows the posterior mean of 0.55, smaller than the large prior obtained from the earlier calibration study (Tanboon, 2008) as well as the earlier estimation findings for Thai and Malaysian economies (Alp & Elekdag, 2012; Alp, Elekdag, & Lall, 2012). Despite the difference, our estimate still indicates a significant degree of habit formation in Thai consumption data and the important role of the reference level in households' utility function. In comparison, for the US economy, Smets and Wouters (2007) and Christiano et al (2005) found the habit formation parameter to be in the range of 0.6-0.7, and for the Euro area, Smets and Wouters (2003) reported the parameter to be 0.59.

The elasticity of adjustment cost in capital utilization (ψ) is estimated to be close to the prior value, reflecting the relative flexibility in changing capital utilitization rate in response to the changes in rental rate of capital. The investment adjustment cost (φ) is estimated to be important but slightly lower than the prior, implying significant responsiveness of the investment to the real value of capital (q_t).

The (inverse) elasticity of labour supply (σ_L) is also well approximated by our initial guess, and also in close vicinity with the earlier estimation work by Chunatantikamon (2008) of 1.63. Our estimate implies an inelastic response of labour hours to changes in real wage, consistent with microeconomic view of the individual labour supply decision (Christiano et al., 2011; Chetty et al., 2011). Nevertheless, in relative terms, the degree of inelasticity is less than the one reported in Chapter 3, likely because of the presence of labour unions and the wage markup.

The characteristics of the price- and wage-setting behaviors in Thailand are also revealed. The price and wage stickiness parameters ($\xi_p$and ξ_w) are estimated to be 0.82 and 0.66, respectively. The average duration of the contract is given by $(1-\ \xi)^{-1}$, according to Eichenbaum and Fisher (2007).This implies that the price and wage contracts are reoptimized on average at the interval of approximately 5 and 3 quarters, respectively. For price stickiness in particular, this appears longer than the earlier estimation works for Thailand by Chuantantikamon (2008) and Alp and Elekdag (2008), which indicate that the price reoptimizing interval is around 3 and 1.63 quarters, respectively. However, the micro study mentioned earlier appears to suggest that a majority of Thai prices stay fixed for 9-12 months or longer (Chantanahom et al., 2004). Our Calvo parameter for prices is also in line with 0.859 estimated for the Malaysian economy by Alp, Elekdag, and Lall (2012).

For the indexation to past inflation rate, the estimates show that it is more important in wage-setting decision than in price-setting environment. Also worth pointing out is that the extent of price indexation to past inflation rate (ι_p =0.39) turns out to be in line with the degree of inflation inertia (α_π =0.45) we found in the previous chapter. Despite the differences in samples between the two chapters, the estimates still pick up a significant but moderate dependence of current inflation to its own lag.

Regarding the monetary policy, the short-term interest rate is estimated to be heavily dependent on its own lag, with the posterior mean as high as 0.95. This points out the notable degree of interest rate smoothing in the policy framework. On the other hand, output growth is shown to have negligible regards in interest rate consideration. The dynamics of monetary policy is mainly driven by the output gap (0.15) and inflation (1.35) concerns, emphasizing the stabilization objective of the inflation-targeting framework adopted in Thailand since 2000. This is notably in contrast with the finding of Smets and Wouters (2007) for the US, where inflation and output growth represent the main targets of the Federal Reserves, consistent with its dual mandates of price stability and employment.

Table 4-2 Prior Distributions and Posterior Estimates

Parameters		Prior Distribution (Mean, Stdv)	Post. Mean	90% Interval	
Persistence in TFP shock	ρ_a	Beta (0.500, 0.200)	0.8927	0.8266	0.962
...in Risk Premium	ρ_b	Beta (0.500, 0.200)	0.7969	0.5562	0.9826
...in Exo. Spending	ρ_g	Beta (0.500, 0.200)	0.7652	0.6375	0.8958
...in Invest. Tech	ρ_q	Beta (0.500, 0.200)	0.2839	0.0754	0.4736
...in Monetary Policy	ρ_m	Beta (0.500, 0.200)	0.3886	0.2094	0.5617
...in Price Markup	ρ_π	Beta (0.500, 0.200)	0.4312	0.0985	0.7683
...in Wage Markup	ρ_w	Beta (0.500, 0.200)	0.7657	0.6198	0.9148
MA in P Markup shock	θ_p	Beta (0.500, 0.200)	0.7405	0.4469	0.9402
...in W Markup shock	θ_w	Beta (0.500, 0.200)	0.4910	0.2583	0.7348
Habit Persistence	h	Beta(0.850,0.100)	0.5550	0.3979	0.7218
Elast. Consumption	σ_c	Norm(1.500, 0.375)	0.8765	0.6398	1.1095
Elast. for Labour supply	σ_L	Norm(2.000,0.750)	1.7312	0.6095	2.8447
Elast. Inve. Adjust Cost	φ	Norm(4.000, 1.500)	3.1747	1.5121	4.8574
Elast. Capital Utilization	ψ	Beta(0.500, 0.150)	0.5702	0.3516	0.7842
Fixed Cost	Φ	Norm(1.250,0.125)	1.6897	1.5283	1.8606
Calvo Prob. Wage	ξ_w	Beta(0.500,0.100)	0.6628	0.5541	0.7748
Calvo Prob. Price	ξ_p	Beta(0.500,0.100)	0.8289	0.7535	0.906
Indexation Wage	ι_w	Beta(0.500,0.150)	0.6040	0.3853	0.824
Indexation Price	ι_p	Beta(0.500,0.150)	0.3889	0.1415	0.6295
Exogenous Spending	ρ_{ga}	Norm(0.500,0.250)	0.7873	0.5622	0.9943
Share of Capital	α	Norm(0.370,0.500)	0.3314	0.2543	0.4079
Taylor rule R smoothing	ρ	Beta(0.750,0.100)	0.9487	0.9297	0.9673
…Inflation	r_π	Norm(1.500,0.250)	1.3519	0.9857	1.6963
…Output gap	r_y	Norm(0.125,0.050)	0.1515	0.0822	0.2191
…Output growth	r_{dy}	Norm(0.125,0.050)	0.0455	0.0213	0.0682
SS Inflation	π_{ss}	Gam(0.650,0.100)	0.6805	0.5247	0.8347
SS Discount factor	β_{ss}	Gam(0.250,0.100)	0.2565	0.0856	0.4112
SS Hours worked	l_{ss}	Norm(0.000,2.000)	1.0607	-1.0872	3.1944
SS Growth	γ_{ss}	Norm(0.680,0.100)	0.5109	0.3870	0.6381
Standard Deviation of Shocks					
TFP	σ_a	InvG(0.100,2.000)	1.5854	1.3182	1.8626
Risk Premium	σ_b	InvG(0.100,2.000)	0.2910	0.0862	0.5189
Exogenous Spending	σ_g	InvG(0.100,2.000)	1.5455	1.2938	1.7904
Invest. Technology	σ_q	InvG(0.100,2.000)	1.5673	1.1962	1.9594
Monetary Policy	σ_m	InvG(0.100,2.000)	0.0967	0.0771	0.1159
Price Markup	σ_π	InvG(0.100,2.000)	1.0594	0.8547	1.2675
Wage Markup	σ_w	InvG(0.100,2.000)	1.1480	0.8494	1.4395

6.2 Dynamic Analysis

Impulse Response Functions

In order to learn more about the dynamics of our DSGE model, we look at the impulse response functions of the seven exogenous shocks. As we have seen from the posterior estimates, there are four key shocks which drive the fluctuations in our model economy. We examine their impulse response functions of the following variables: *y, c, inve, w* represent the output, consumption, investment, and hourly wage, respectively, while *labobs* stands for labour hours, *pinfobs* for inflation, and *robs* for short-term interest rate. (Appendix 4-2 shows the impulse responses of all *observed* variables)

Productivity shock is expected to have a positive impact on the real variables, particularly the output. When a TFP shock hits the economy, total production of goods surges for the same units of inputs. The effects of TFP shock are shown in Figure 4-1. The improved technology allows for larger production as well as an increase in both household consumption and investment, a permanent rise up until the 20^{th} quarter. On the flip side, given the improvement in productivity, the same level of output can be enjoyed with an increase in leisure hours, translating into a reduction in hours worked. Higher productivity and larger supply of output in general also result in lower inflationary pressure as evident in the decline in inflation rate of about 0.03 percent.

A shock to exogenous spending directly affects the total output, leading to a strong upward increase in output as shown in Figure 4-2. Other things being equal, the upsurge in output requires an increase in employment, inducing labour to work longer hours. The sharp increase in exogenous spending implies that the government may need to tax more or issue more bonds for financing, and this results in a negative response in both consumption and investment in our model. Overall, inflationary pressure remains low despite the sharp increase in output, as reflecting in the trivial ascent in price levels.

Figure 4-1 Impulse Response Functions to TFP Shock

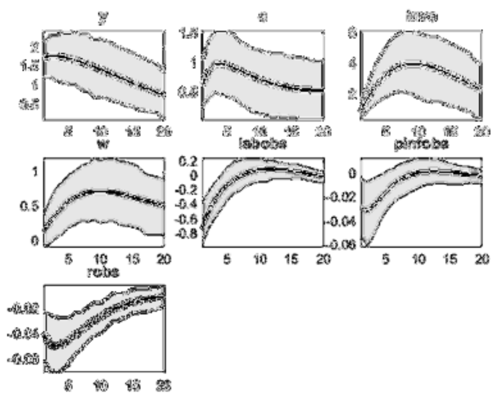
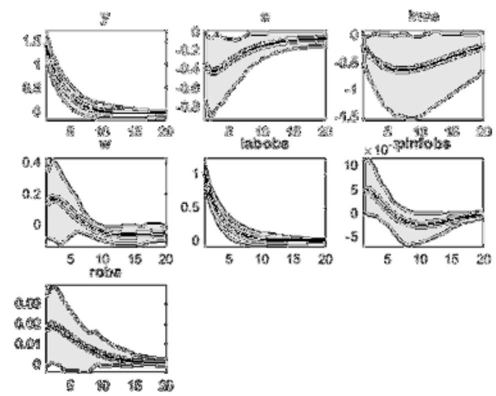


Figure 4-2 Impulse Response Functions to Exogenous Spending Shock



A positive shock to investment-specific technology shock produces a notable and permanent increase in investment, almost reaching percent growth rate, in Figure 4-3. The strong rise in investment pushes an increase in total output as well. Since the shock is specific to investment and other things being constant, consumption responds passively by registering a negative growth.

The impulse response functions for the risk premium shock are shown in Figure 4-4. An increase in risk premium affects both consumption and investment Euler equations, causing an upsurge in both variables. Larger discount factor implies less utility from future consumption and stimulate current consumption. The same goes for investment decision. Therefore, total output rises, driving an increase in inflationary pressure on both prices and wages.

Figure 4-3 Impulse Response Functions to Investment-Specific Technology Shock

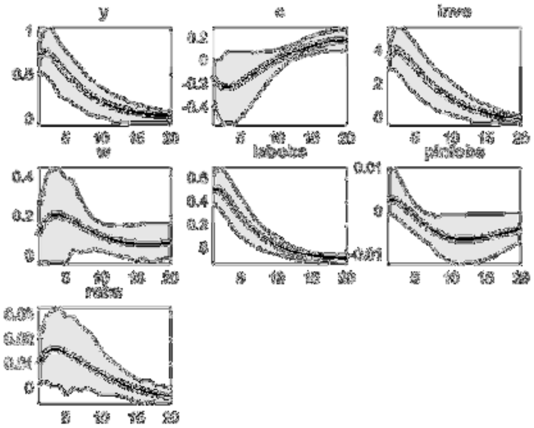
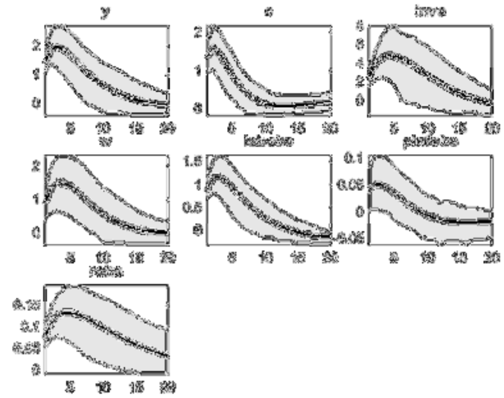


Figure 4-4 Impulse Response Functions to Risk Premium Shock



Price markup shock produces impulse response functions shown in Figure 4-5. An increase in inflation about 0.5 percent results in a decline of about 0.5 percent in total output and consumption. This implies a strong deteriorating impact of a sharp rise in price on the entire economy. The lower production also induces lower employment in the short run. Given the heavy fall in both demand and production, the feedback rule requires a lower interest rate.

Figure 4-6 displays the effects of an increase in wage markup shock. As evident from the graph, the rise of 2 percent in wage rate pushes the inflation to increase by 0.1 percent two quarters afterward. The positive impact of a positive wage shock induces households to consume and invest more. On the flip side, other things constant, the rise in wage allows households to work less, reflecting in the decline in hours worked. With the rise in inflationary pressure, interest rate is expected to increase, reaching the peak at around the 5th quarter after the initial shock.

Figure 4-5 Impulse Response Functions to Price Markup Shock

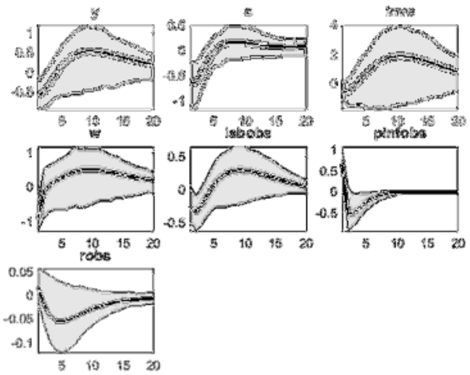


Figure 4-6 Impulse Response Functions to Wage Markup Shock

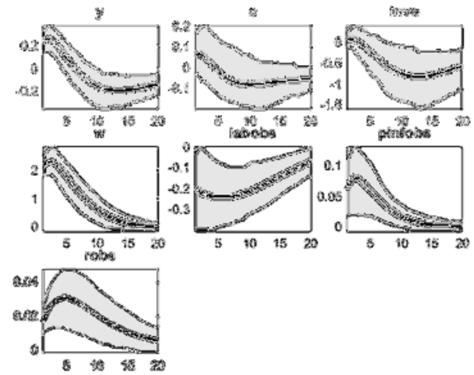
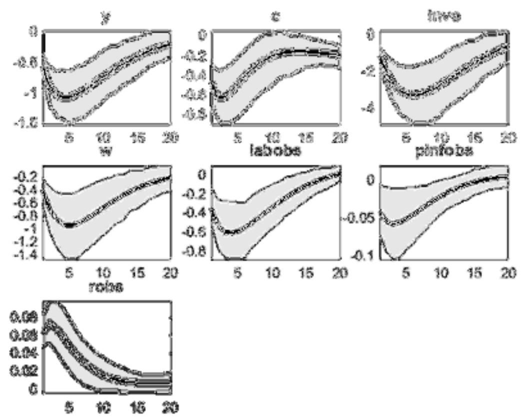


Figure 4-7 Impulse Response Functions to Monetary Policy Shock



Given the posterior estimates of important frictions, both real and nominal, in the model, we expect that the monetary policy would have non-neutral impacts on the economy, especially the real variables. From Figure 4-7, when a positive monetary policy shock hit the economy, translating into a higher short-term interest rate of about 0.06 percent, the other key variables, both nominal and real, registered a decline. Both output and private consumption decline immediately by approximately 0.5 percent but reach the troughs at the 4th and 3rd quarter, respectively. The impact on investment is larger, an immediate decrease of 1 percent and the trough of 3 percent in the 6th quarter after the shock. Inflation shows a relatively smaller response to the monetary policy shock, compared to the real variables, with the largest decline of 0.06 percent in the 3rd quarter after the shock. Wages also fall in the face of higher interest rate, and this causes the labour hours to sink to the trough of 0.6 percent at the 5th quarter after the shock.

Forecast Error Variance Decompositions

To further assess the dynamic impacts of the seven structural shocks, another tool we adopt is the forecast error variance decomposition[5], which allows us to see the underlying drivers of the key variables' dynamics. We focus our analysis on the four real variables, namely the output, consumption, investment, and hours worked.

Figure 4-8 shows the variance decompositions at seven different horizons, from the first quarter to the infinite horizon implied at the 100th quarter. From the top left panel, the main drivers of the variations in output are from both supply and demand sides: the technology shock which affects production function as well as the exogenous spending and risk premium shocks which influence the aggregate demand. Together, the three shocks explain more than 80 percent of the output fluctuation in the short run. Notice that the strong effect of exogenous spending is rather short-lived, reducing more than half during the first year, while the impact of monetary policy on the output variance comes with a lag, only noticeable at the end of 4th quarter onwards.

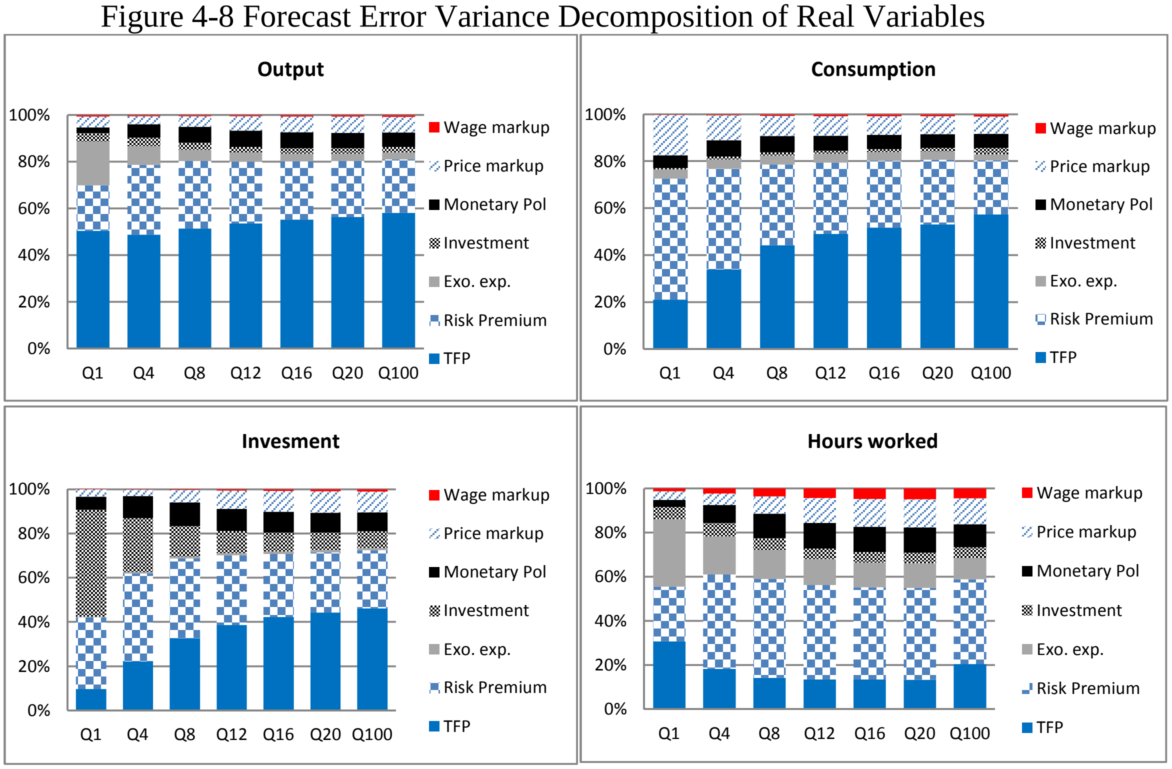
For consumption, the key drivers of its short-run fluctuations are the risk premium and price markup shocks, both of which affect the intertemporal choice and consumption

[5] Appendix 4-3 shows the complete tables of Forecast Error Variance Decompositions

decision. As expected, the investment technology shock leads the contribution on the in private investment, particularly in the short run, with the effect of TFP picks up all through the infinite horizon. Meanwhile, over the long run, aside for a larger influence of the risk premium, the variation in labour hours is driven almost equally by the other six shocks.

Looking across the four real variables, we can observe the relative impacts of the monetary policy shock displayed by the black shaded bars. Although not the largest shock affecting these real variables, the monetary policy accounts for approximately 7 percent fluctuations in both output and consumption, and about 10 percent in investment and hours worked, over the medium term. This again portrays the significant but moderate role of monetary policy in explaining the real variables.

Figure 4-8 Forecast Error Variance Decomposition of Real Variables



6.3 Sensitivity Analysis

In this exercise, we aim to show the effects of each friction on the model's overall performance as indicated by the (log) marginal likelihood measure. This helps point out which friction is important in the model, which one is not, and to what extent.

The experiment performs Bayesian estimation of the baseline model using the same data set, but with the modification of the prior distribution of the friction of interest. Particularly, following Smets and Wouters (2007), the prior mean as well as the variance of the friction are lowered by a substantial amount to emulate the impact of shutting down that friction channel. This process is carried out for each individual source of friction, and the resulting changes in the log marginal likelihood as well as posterior estimates of behavioral parameters are reported in Table 4-3.

The baseline estimation is shown in the (1) column, with the log marginal likelihood of -716.7. Note that the larger the log marginal likelihood can be translated as the better the performance of the model, especially in terms of out-of-sample predictive ability. Therefore, from the table, it is evident that the investment adjustment cost, represented by φ , is the most important friction for this model, given the Thai data. By significantly reducing the prior mean of φ in column (7) to 0.1, the log marginal likelihood faces a sharp fall by 54. With extremely low investment adjustment cost, the estimation picks up a relatively large investment-specific technology shock, reflected in increased standard deviation (σ_q) and persistence (ρ_q).

For the other real frictions, if taking away the fixed cost in production, the model will face a marginal likelihood loss of 18 in logarithm scale. Nonetheless, a big cuts in habit formation parameter and the capital utilization adjustment cost do not produce noticeable effect on the model's performance. In other words, the model is only marginally improved by including these frictions.

Turning to nominal rigidities, the column (2)-(5), the price and wage stickiness parameters (the Calvo probabilities ξ_p and ξ_w) are important to the model as leaving out either of them will result in a lower log marginal likelihood of about 20. Again, pulling away the frictions in prices and wages automatically push up the variances and persistence of their respective shocks. The addition of indexation of wages to the past inflation (ι_w) marginally improves the model's performance, but not the indexation of prices to past inflation (ι_p).

Looking at the posterior estimates of the Taylor rule across the 9 columns, it can be seen that the inflation consideration and the interest rate smoothing component always turn out important, no matter which set of frictions are included in the model. However, the output gap concern is highly sensitive to the exclusion of price and wage stickiness. That means if one believes that the central bank concerns about the output gap stabilization, both price and wage stickiness should be featured in the model economy.

Table 4-3 The Effects of Dropping Frictions on Marginal Likelihood

Model	(1) Baseline	(2) NoPrice $\xi_p = 0.1$	(3) NoWage $\xi_w = 0.1$	(4) NoIndexP $\iota_p = 0.1$	(5) NoIndexW $\iota_w = 0.1$	(6) NoHabit $h = 0.1$	(7) NoInve $\varphi = 0.1$	(8) NoCapU $\psi = 0.99$	(9) NoFixed $\Phi = 1.1$
Log Marginal Likelihood	***-716.7***	***-736.7***	***-733.6***	***-714.3***	***-723.7***	***-718.1***	***-770.8***	***-718.4***	***-735.2***
Parameters					**Posterior Mean**				
ρ_a	0.893	0.979	0.969	0.883	0.905	0.949	0.982	0.921	0.914
ρ_b	0.797	0.904	0.918	0.768	0.851	0.900	0.896	0.874	0.841
ρ_g	0.765	0.772	0.806	0.776	0.774	0.906	0.973	0.749	0.776
ρ_q	0.284	0.392	0.389	0.294	0.283	0.324	0.890	0.262	0.294
ρ_m	0.389	0.278	0.268	0.403	0.375	0.231	0.173	0.386	0.368
ρ_π	0.431	0.960	0.815	0.505	0.421	0.303	0.237	0.465	0.501
ρ_w	0.766	0.938	0.939	0.770	0.760	0.770	0.732	0.741	0.753
θ_p	0.741	0.147	0.439	0.767	0.800	0.768	0.379	0.793	0.826
θ_w	0.491	0.445	0.210	0.487	0.495	0.455	0.494	0.482	0.478
φ	3.175	3.606	5.064	3.335	2.926	3.079	*0.100*	2.761	3.131
h	0.555	0.465	0.390	0.576	0.530	*0.100*	0.184	0.472	0.552
ψ	0.570	0.720	0.648	0.546	0.589	0.688	0.760	*0.990*	0.670
σ_c	0.877	0.876	0.936	0.888	0.843	1.346	1.337	0.841	0.696
σ_L	1.731	1.551	0.726	1.675	1.766	1.205	1.352	1.246	1.984
ξ_w	0.663	0.472	*0.100*	0.651	0.653	0.603	0.669	0.670	0.682
ξ_p	0.829	*0.100*	0.539	0.826	0.832	0.843	0.918	0.838	0.907
ι_w	0.604	0.720	0.531	0.600	*0.100*	0.616	0.618	0.596	0.604
ι_p	0.389	0.692	0.484	*0.010*	0.409	0.357	0.231	0.361	0.365
Φ	1.690	1.807	1.657	1.686	1.588	1.738	1.657	1.657	*1.100*
r_π	1.352	1.494	1.524	1.326	1.317	1.395	1.654	1.380	1.360
ρ	0.949	0.907	0.888	0.948	0.948	0.938	0.927	0.952	0.945
r_y	0.152	-0.058	-0.053	0.148	0.154	0.161	0.093	0.157	0.160
r_{dy}	0.046	0.086	0.098	0.044	0.047	0.062	0.105	0.077	0.062
Stdev. of shocks									
σ_a	1.585	1.480	1.598	1.595	1.667	1.535	1.603	1.562	2.285
σ_b	0.291	0.065	0.056	0.330	0.239	0.175	0.090	0.195	0.249
σ_g	1.546	1.548	1.541	1.562	1.533	1.559	1.574	1.553	1.519
σ_q	1.567	1.595	1.565	1.558	1.571	1.884	9.244	1.623	1.534
σ_m	0.097	0.115	0.121	0.097	0.095	0.100	0.146	0.109	0.102
σ_π	1.059	2.766	0.897	1.204	1.075	1.073	1.035	1.091	1.075
σ_w	1.148	1.529	8.953	1.162	1.248	1.316	1.2357	1.147	1.109

6.4 Forecast Performance

As mentioned in the Section 5 on methodology, the Bayesian approach combines the data density (likelihood function) with the prior distributions, and in the process of obtaining the posterior estimates it also calculates the marginal likelihood. The marginal likelihood (or marginal data density) can be used to measure the model fit and out-of-sample forecast performance, providing researchers with a basis for comparing different model specifications. In this exercise, we carry out an assessment between our DSGE model and Bayesian Vector Autoregressive (BVAR) models of different lags.

The Bayesian VARs are constructed by employing the same data set of seven time series during 2001-2014, as described in Section 5, using the Minnesota priors proposed by Sims (2003), as shown in detail in Villemot (2012). This set of priors consists of “hyperparameters” which control the characteristics and probabilistic distributions of the coefficients such as the tightness (variance) for own and other variables’ lags and the speed of decay of the variance as the number of lags increases, to name a few. The Bayesian approach imposes this set of priors on the unrestricted VARs, and in effect, it ‘shrinks’ the parameters the VARs. For more detail of the BVAR models and its estimation in Dynare, refer to Ciccarelli and Rebucci (2003) and Villemot (2012).

We show the comparison of our DSGE and BVAR models of different lags in Table 4-4, using the marginal likelihood as the measure for out-of-sample forecast performance. By varying the lag length for BVARs, it is evident that BVAR(7) outperforms its own peers and our DSGE model in terms of predictive power. However, it is also noteworthy that our DSGE model, despite its complicate structures and many restrictions, can still compete well with BVARs of the first four lags. This competitive performance of DSGE as opposed to BVARs is consistent with the findings documented in Smets and Wouters (2007) using the US data.

Table 4-4 Comparison of Forecast Performance

	Log Marginal Likelihood
DSGE	-716.6580
BVAR(1)	-721.3807
BVAR(2)	-723.9766
BVAR(3)	-745.0199
BVAR(4)	-743.2735
BVAR(5)	-706.0485
BVAR(6)	-704.5803
BVAR(7)	-688.2697
BVAR(8)	-698.5236

Note: Both DSGE and BAVR(p) are computed based on the same data set (i.e. the seven time series described in Section 5). BVAR(p) uses the Minnesota priors as proposed by Sims (1996) as explained in Villemot (2012).

7. Conclusions

This study seeks to identify and analyze the impacts of monetary policy shock on the Thai economy. In doing so, we adopted the medium-sized New-Keynesian DSGE model as proposed by Smets and Wouters (2007), which features both nominal and real frictions, in addition to a set of seven structural shocks. This setup of the model economy is designed taking into account the observed rigidities in real world such as the less than fully flexible contracts in price- and wage-setting that prevent both to respond to changes in markups, or the habit of consumption. With these frictions, we expect to show non-neutral effects of monetary policy on real variables.

In order to evaluate the DSGE model, we employ Bayesian approach by combining information from both the data and our initial beliefs regarding the model parameters. The posterior results reveal several important points regarding behavioral parameters and the structural shocks. Investment adjustment cost is important while habit persistence in consumption and capital utilization rate adjustment cost are found to be significant but moderate. The habit parameter is smaller in magnitude as opposed to the earlier calibration work by Tanboon (2008) but in close vicinity to the estimations for US and the EU area. Calvo probabilities in price and wage settings suggest that the average duration of price and wage contracts in the economy are about 5 and 3 quarters, respectively. Indexation to past inflation is important for wage but has a comparatively limited role in price setting. We identified that the shocks with the largest variance are TFP, exogenous spending, and investment-specific technology shocks.

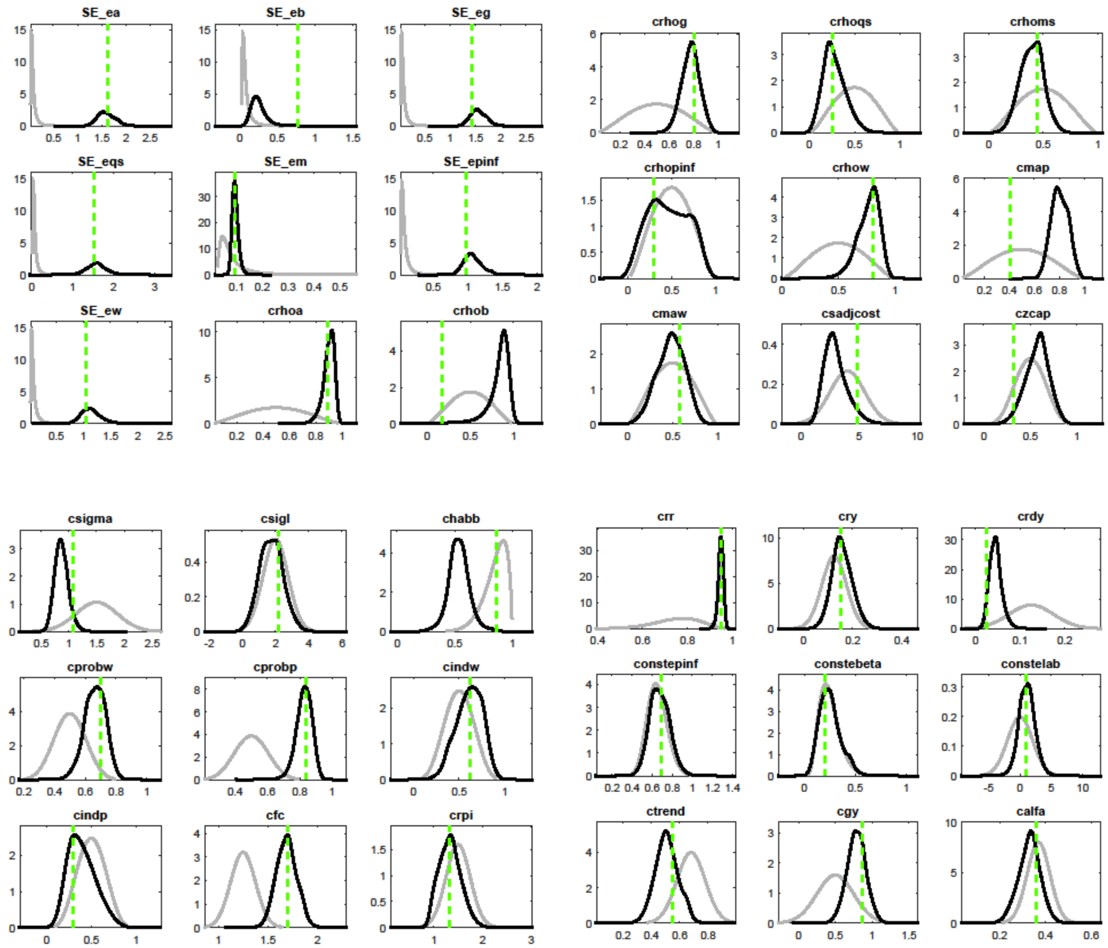
From the parameters in the modified Taylor rule, we show that the monetary policy in Thailand places a strong emphasis on inflation, a finding consistent with the implementation of inflation targeting framework since 2000. In maintaining the economy's stability, output gap is also another important consideration of interest rate consideration, which is reassured by the posterior estimate. Output growth has a limited role in monetary policy decision as implied by the framework as well as by our model. A notable degree of interest rate smoothing is also observed.

Furthermore, monetary policy has a moderate but significant impact on the economy. From the impulse response functions, we have shown how the dynamics of the monetary policy shock unfold in the economy. Consistent with our expectation, an increase in short-term interest rate produces an immediate decline not only in the inflation but also in all real variables: output, consumption, investment, and hours worked. The peak effect of the higher interest rate is felt in output at the 4th quarter, consumption and inflation at the 3rd quarter, while the lags are relatively longer for investment and labour hours at 6th and 5th quarter, respectively.

The non-neutrality of monetary policy is further reconfirmed by the forecast error variance decompositions of the four real variables, which suggests that over the medium terms the monetary policy shock accounts for the 7 percent fluctuations in output and consumption, and as large as 10 percent in investment and labour hours.

Using marginal likelihood as an indicator of model fit in terms of forecast performance, we experiment with dropping each friction in the model and identify that investment adjustment cost significantly contribute to the model's overall performance, while the price and wage stickiness are more important than the indexation of prices to past inflation rate. The comparison of forecast performance also points out that our DSGE model, despite the strong restrictions, can compete well with the purely empirical BVAR models up to the first four lags. This allows us to conclude that the medium-sized NK-DSGE can describe the Thai data as good as BVARs and that the sound theoretical restrictions do not require compromising on model fit.

Appendix 4-1 Prior vs Posterior Distributions

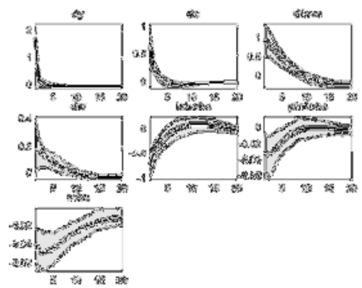


Notation of the parameters

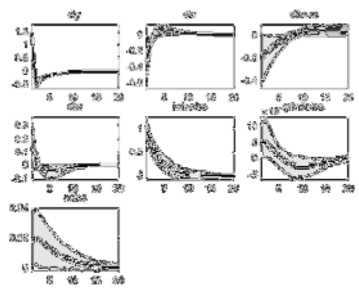
SE_ea	σ_a	crhoa	ρ_a	cmap	θ_p	cprobw	ξ_w	cry	r_y
SE_eb	σ_b	crhob	ρ_b	cmaw	θ_w	cprobp	ξ_p	crdy	r_{dy}
SE_eg	σ_g	crhog	ρ_g	csadjcost	φ	cindw	ι_w	constepinf	π_{ss}
SE_eqs	σ_q	crhoqs	ρ_q	czcap	ψ	cindp	ι_p	constebeta	β_{ss}
SE_em	σ_m	crhoms	ρ_m	csigma	σ_c	cfc	Φ	constelab	l_{ss}
SE_epinf	σ_π	crhopinf	ρ_π	csigl	σ_L	crpi	r_π	ctrend	γ_{ss}
SE_ew	σ_w	crhow	ρ_w	chabb	h	crr	ρ	cgy	ρ_{ga}
								calfa	α

Appendix 4-2 Impulse Response Functions of Observables

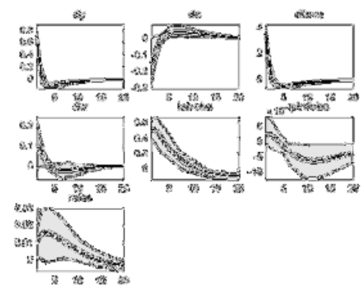
TFP Shock



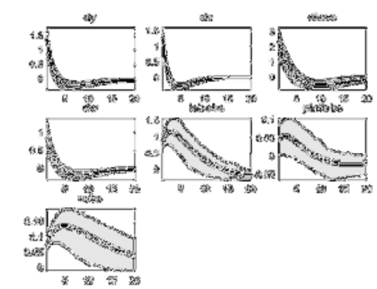
Exogenous Spending Shock



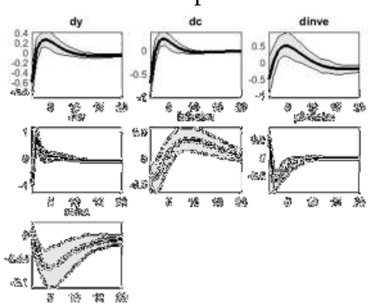
Investment-Specific Shock



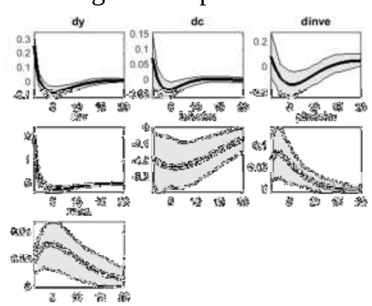
Risk Premium Shock



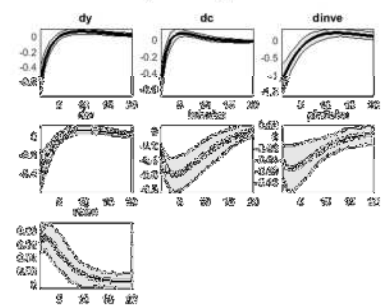
Price Markup Shock



Wage Markup Shock



Monetary Policy Shock



Appendix 4-3 Forecast Error Variance Decompositions

Output	Q1	Q4	Q8	Q12	Q16	Q20	Q100
TFP	50.52	48.86	51.54	53.75	55.35	56.40	58.24
Risk Premium	19.47	29.93	28.93	26.45	24.87	24.03	22.89
Exogenous Spending	18.75	8.04	4.77	3.75	3.36	3.19	2.99
Investment Tech.	3.54	3.64	2.95	2.54	2.34	2.26	2.26
Monetary Policy	2.49	5.63	6.93	6.96	6.75	6.57	6.21
Price Markup	4.70	3.43	4.55	6.16	6.83	6.99	6.78
Wage Markup	0.54	0.46	0.34	0.40	0.49	0.56	0.62

Consumption	Q1	Q4	Q8	Q12	Q16	Q20	Q100
TFP	21.17	34.00	44.35	49.16	51.78	53.25	57.48
Risk Premium	51.57	42.88	34.33	30.41	28.52	27.51	23.03
Exogenous Spending	3.83	4.02	3.88	3.76	3.66	3.54	2.55
Investment Tech.	0.61	1.19	1.32	1.26	1.32	1.50	2.72
Monetary Policy	5.48	7.00	6.93	6.41	6.04	5.86	6.06
Price Markup	17.10	10.51	8.59	8.32	7.95	7.60	7.24
Wage Markup	0.24	0.39	0.58	0.69	0.73	0.73	0.92

Investment	Q1	Q4	Q8	Q12	Q16	Q20	Q100
TFP	9.65	22.11	32.67	38.68	42.25	44.25	46.18
Risk Premium	32.44	39.79	36.01	31.40	28.54	27.14	26.27
Exogenous Spending	0.33	0.72	0.95	1.02	1.05	1.05	1.06
Investment Tech.	48.26	24.37	13.75	10.02	8.54	7.93	7.55
Monetary Policy	5.98	9.86	10.63	10.04	9.40	8.97	8.40
Price Markup	3.22	3.01	5.67	8.22	9.36	9.65	9.42
Wage Markup	0.12	0.14	0.32	0.61	0.85	1.00	1.12

Hours worked	Q1	Q4	Q8	Q12	Q16	Q20	Q100
TFP	30.69	18.19	14.27	13.49	13.41	13.39	20.45
Risk Premium	24.80	42.87	44.68	42.68	41.73	41.60	38.45
Exogenous Spending	30.62	17.18	13.14	11.75	11.28	11.10	9.47
Investment Tech.	5.52	6.10	5.33	4.84	4.72	4.77	4.90
Monetary Policy	3.08	8.10	11.13	11.63	11.52	11.39	10.45
Price Markup	3.92	5.20	7.86	11.26	12.58	12.83	11.85
Wage Markup	1.36	2.36	3.58	4.35	4.76	4.93	4.44

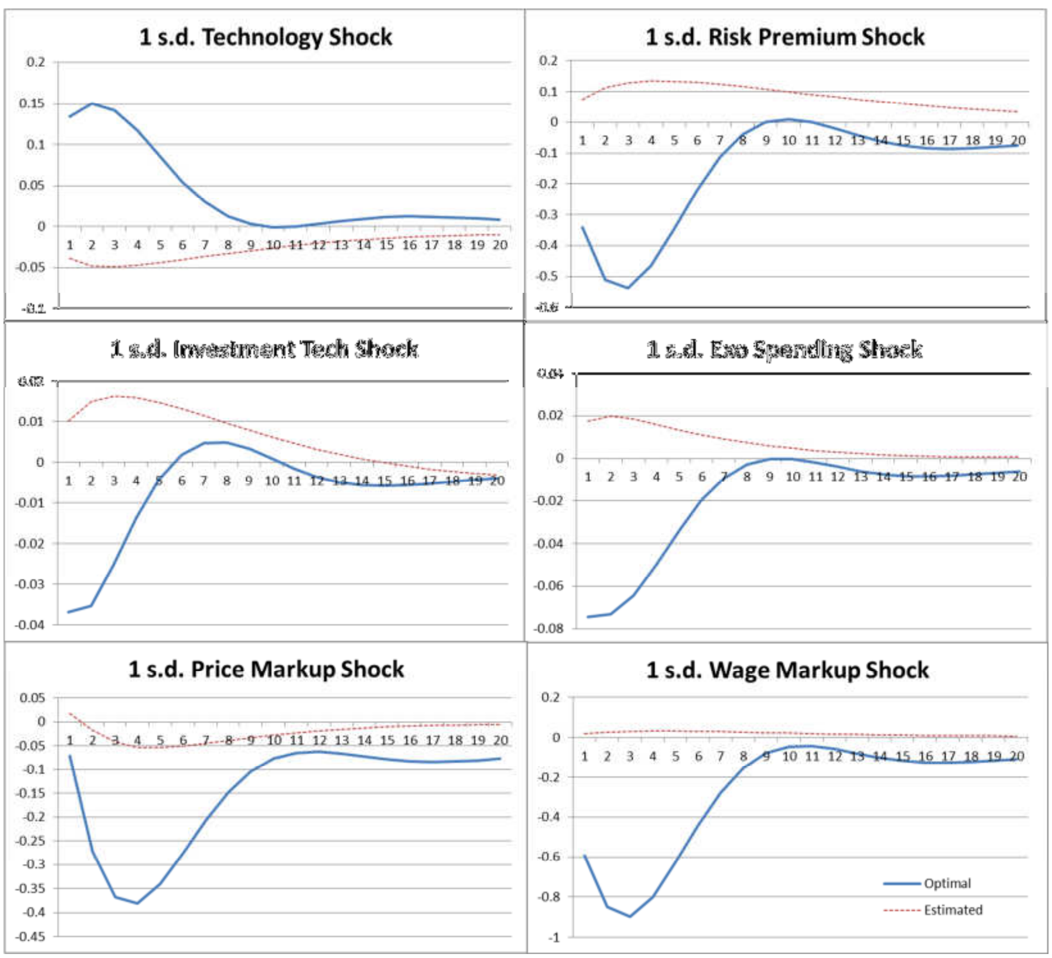
Real Wage	Q1	Q4	Q8	Q12	Q16	Q20	Q100
TFP	1.35	4.67	9.85	14.53	17.94	20.21	26.40
Risk Premium	13.61	25.68	27.42	26.10	24.98	24.32	22.84
Exogenous Spending	0.61	0.73	0.51	0.42	0.41	0.41	0.44
Investment Tech.	0.25	0.58	0.60	0.54	0.52	0.53	0.81
Monetary Policy	2.24	6.09	8.31	8.69	8.55	8.37	7.89
Price Markup	20.92	8.54	9.64	11.75	12.56	12.67	11.87
Wage Markup	61.02	53.71	43.68	37.96	35.04	33.49	29.75

Inflation	Q1	Q4	Q8	Q12	Q16	Q20	Q100
TFP	0.38	0.37	0.39	0.41	0.42	0.42	0.51
Risk Premium	1.03	1.81	2.42	2.62	2.78	2.92	3.25
Exogenous Spending	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Investment Tech.	0.00	0.00	0.00	0.01	0.02	0.02	0.03
Monetary Policy	0.33	0.53	0.78	0.84	0.86	0.87	0.97
Price Markup	97.33	96.07	94.87	94.51	94.31	94.15	93.62
Wage Markup	0.91	1.21	1.53	1.59	1.60	1.61	1.62

Interest rate	Q1	Q4	Q8	Q12	Q16	Q20	Q100
TFP	20.05	15.20	13.93	13.81	13.87	13.97	15.78
Risk Premium	42.34	49.37	52.69	54.55	55.29	55.47	53.64
Exogenous Spending	2.51	1.54	1.22	1.13	1.10	1.09	1.00
Investment Tech.	0.59	0.76	0.81	0.81	0.80	0.80	0.89
Monetary Policy	24.74	15.02	10.41	9.04	8.61	8.49	8.79
Price Markup	7.70	15.53	17.93	17.41	17.01	16.82	16.59
Wage Markup	2.08	2.58	3.01	3.24	3.34	3.37	3.31

Appendix 4-4 Optimal Monetary Policy Responses

The following charts provide the comparison of the interest rate responses to shocks as implied by the estimated model (Baseline) and the optimal policy, shown in the dashed and solid lines, respectively. We solve for the optimal monetary policy responses based on the social planner's problem that aims to minimize the intertemporal loss function. The loss function has a quadratic form and consists of two inputs, the deviations from targets of output gap and inflation. ((Adjemian et al., 2007; Adolfson et al., 2008; Nakornthab, 2009)



CHAPTER 5
CONCLUSIONS

This dissertation focuses on identifying and analyzing the dynamic impacts of the monetary policy in Thailand, based on the estimated New-Keynesian DSGE models. The first DSGE model in Chapter 3 of our analysis features a parsimonious specification with sticky price from the monopolistic competition structure as the only rigidity in the economy, while the second model in Chapter 4 takes on an extensive set of frictions that includes not only price and wage stickiness, but also real frictions in consumption and investment. We perform Bayesian estimation of both models to gain insights about the deep parameters governing behaviors of economic agents as well as showing the dynamic impacts of structural shocks. We also identify which friction is model-improving and which one is not, as well as compare the forecast performance of the estimated DSGE with BVAR models.

The first model with price stickiness in **Chapter 3** shows that the short-term interest rate shock induces non-neutral real responses. In particular, the output measures and inflation decline after a positive interest rate shock. Based on the variance decomposition, we conclude that although smaller than the preference shock, the interest rate shock is of significant influence in explaining the output growth variation.

The lagged output gap and inflation added to the *Baseline model* are estimated to be significant and shown to improve the forecast performance of the *Modified model,* implying the empirically important role of the backward-looking behaviors in households' and firms' decisions. This becomes the basis for our second model which explicitly incorporates more frictions into the structure, and hence allowing for more roles of the lagged nominal and real variables in the economy such as habit formation and investment adjustment cost.

We also discover the significant but moderate degree of inflation inertia (α_{π}) in the Phillips curve, implying that inflation is relatively responsive to other shocks. If the inflation is highly inertial, it would take more actions of the central bank and well in advance in order to accumulate and move the current inflation. Nevertheless, this small NK-DSGE model is outperformed by the BVARs in explaining the Thai data, motivating us to work with a richer model in Chapter 4.

In **Chapter 4** based on the model of Smets and Wouters (2007), the posterior estimates of the behavioral parameters help enhance our understanding of the economy, particularly on the nominal and real frictions. Wage and price stickiness parameters, the Calvo probability in resetting wage and price contracts, stand at about 0.7 and 0.8, implying the average contract duration of around 3 and 5 quarters respectively. Interestingly, the degree of price indexation to past inflation also implies a moderate degree of inflation inertia (π_1), consistent with the finding in Chapter 3.

The habit formation in consumption is estimated to be moderate and slightly smaller than the range of findings in the US and the Euro area. Note also that this habit parameter reflects the consistency with the parameter for the lagged output gap in the IS equation of Chapter 3. The important investment adjustment cost indicates the significant responsiveness of the investment to the real value of capital.

In the Chapter 4, with the interactions of a larger set of frictions and structural shocks, the monetary policy shock plays a smaller role compared to the previous chapter. The three largest shocks in the second model include TFP, exogenous spending, and investment-specific technology shocks, while monetary policy shock has the smallest dispersion. Nonetheless, the variance decomposition analyses reveals that the interest rate shock accounts for 7 percent fluctuation in output and consumption, and as large as 10 percent in investment and hours worked.

From impulse response functions, the magnitude and timing of responses to monetary policy are revealed: one standard deviation increase in interest rate brings a decline in the output as well as consumption and investment, at 1 percent (Q4), 0.6 percent (Q2), and 3 percent (Q6), respectively. Clearly, investment is the most responsive among the GDP components, consistent with the VAR findings for Thailand as well as Japan and the Euro area (Dacharux (2012), Disyatat and Vongsinsirikul (2003), Fujiwara (2003), and Peersman and Smets (2001)).

Focusing on the feedback rule, consistently across both Chapter 3 and Chapter 4, it is evident that monetary policy in Thailand is strongly motivated by inflation and output gap stabilization objectives in line with the Inflation Targeting regime, and their instrument, the short-term interest rate, has the power to induce non-trivial impacts on the key macroeconomic variables as discussed above. For Chapter 4, interest rate smoothing is also identified as a significant component of monetary policy decision, implying the central bank's desire/practice to avoid large and fast movements in the short-term interest rate, also consistent with the findings for the conduct of monetary policy in Malaysia and Korea (Alp, Elekdag, & Lall, 2012; Alp, Elekdag, & Lall, 2011).

The long lags of monetary policy impacts (2-3 quarters for consumption and inflation, one year for output, and 6 quarters for investment) coupled with its gradual approach in adjusting interest rate indicates that the central bank needs to act well in advance in order to achieve the desired outcome on the key variables of interest. In this junction, it also puts a strong emphasis for the central bank to continually and closely monitor the economic outlooks in order to formulate the appropriate strategy.

Compared to the monetary policy, the exogenous spending, i.e. the public expenditure, has a more profound and immediate, but rather short-lived impacts on the economy. One-time one standard deviation increase in public expenditure, as our second model implies, drives up output (1.5 percent) and employment (1 percent) immediately, while the inflationary pressure remains mostly in check. However, given the rational expectation on the part of households, the government stimulus of such form is shown to impose a crowding out effect on both consumption and investment, and thus should be employed with cautions. Besides, as the variance decompositions uncover, the effects of the exogenous expenditure shock fade off rather quickly, reducing more than half at the end of the first year.

Given the Bayesian approach we adopt in estimating the NK-DSGE models, the sensitivity analysis allows us to make empirical conclusions regarding the nominal and real frictions in the NK-DSGE models for Thailand. We identify that the inclusion of investment adjustment cost and fixed cost, as well as price and wage stickiness notably improve the model's overall performance, while the inclusion of the price indexation to past inflation has a reverse effect. This provides a reconfirmation for most of the frictions included in the model and at the same time inform future researchers of the important ingredients of model-building for Thailand.

Last but not least, in the Chapter 4, based on the calculation of marginal likelihood, the comparison of fitness to data shows that the estimated medium-sized DSGE model, despite the strong theoretical restrictions, can compete well with the purely empirical BVAR models up to the first four lags, using the same set of data. Although BVAR of seven lags offers the best fit, its long lags put a greater requirement on the data, which may not be affordable by most emerging economies. On the other hand, by employing the medium-sized NK-DSGE, which takes into account a rich set of real world's rigidities and frictions, we offer coherent explanation of the economy without compromising on its predictive power.

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