Monetary Policy Transmission Mechanism, Financial Frictions in closed and open economy DSGE models

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A thesis submitted for the degree of Doctor of Philosophy (Economics) of the Australian National University

August 2017

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Declaration

This thesis is my own work.

A version of Chapter 2 is published in Journal of Asian Economics:
<URL: https://doi.org/10.1016/j.asieco.2016.10.003.>

A version of Chapter 3 is published in Economic Modelling:
<URL: https://doi.org/10.1016/j.econmod.2017.03.015>

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Sadia Afrin
August 2017
Acknowledgements

My PhD study experience was very exciting and challenging at the same time and I have learnt many new skills while doing experiments with new ideas. I thank Almighty for surrounding me with so many resourceful persons who helped me in different ways and kept me motivated throughout the study period.

At the very first place, I would like to express enormous thanks and gratitude to my supervisor Professor Raghbendra Jha for his excellent guidance in shaping my thesis from the beginning to the end. Professor Jha has shown huge confidence in my research ability that motivated me greatly during the challenging phases of research. I have learnt from his vast knowledge, experiences and insightful comments on my works in countless hours of meetings during the program. In fact, my research work and coursework experience on Macroeconomics during Master’s degree with Professor Jha was one of the inspirations in pursuing a PhD degree in this area of Economics. I am sincerely grateful to him.

I thank Dr. Creina Day, adviser to my panel, for her time in reading my papers and providing valuable comments and suggestions. I also thank Dr. Blane Lewis in my panel for his questions and comments during the seminars. Dr. Lewis was very easy going and encouraging person since I know him in the department.

In addition to my panel, I thank Timothy Kam of Research School of Economics, Professor Prema-chandra Athukorala, Professor Hal Hill, Ross McLeod, Chris Murphy, Anthony Swan, Robert Sparrow and everyone in the Arndt-Corden Department of Economics of Crawford School of Public Policy for their valuable comments and suggestions.

I acknowledge the contributions of the Department of Education of Australian Government for providing me with sufficient funds for my PhD study under Endeavour Postgraduate Research Scholarship. The scholarship allowed me to concentrate in my research work without any concern about funding issues.
I would like to convey special thanks to Professor Johannes Pfeifer of University of Cologne for his patience and hours of time to answer my every questions relating to DSGE model estimations, although he does not know me in person. Without his help, my estimation works could be impossible to finish in time.

I also acknowledge the help and motivations that I have received from my colleagues in Bangladesh Bank, especially Imam Abu Sayeed, Md Waheduzzaman Sarder and Mahboob Elahi Akhter for providing me with data and explanations. I also thank Professor Selwyn Cornish for helping me with Australian data issues and Daniel Rees of Reserve Bank of Australia for a useful discussion on modelling Australian economy. I am grateful to my PhD colleagues and friends in Crawford School: Rajan Panta, Gan-Ochir Doojav, Yashodha Warunie Senadheera, Kai-Yun Tsai, Ariun-Erdene Bayarjargal, Hoai Bao Nguyen, and Deni Friawan to name a few whose questions and suggestions were motivating to me for moving ahead. I also thank anonymous referees of various journals for their comments that helped me to improve my works in Chapters 2-3.

I thank Heeok Kyung and Sandra Zec of Arndt Corden Department of Economics and the CAP IT team for their great jobs to support my PhD research life in this department. I extend my appreciation to the Seminar organizing committee of the department and all participants of my seminars. I am grateful to Dr. Megan Poore of Crawford School of Public Policy for her suggestions on thesis writing. I also thank Anne Patching for her amazing support towards me during my stay in Crawford School from Masters to PhD degrees. From Academic Skills and Learning Centre of ANU, I thank Dr. Jay Woodhams for his suggestions on Chapter 4 and overall thesis structuring.

Finally, I thank my wonderful family – my parents, husband, parents-in-law, my sister Tahmina Tania and brother Tauhid Anwar - who constantly showed their supports and confidence on me. I dedicate this thesis to my parents - Talebur Rahman and Anjuman Ara, and my husband Abu Chaleh for the valuable time they have sacrificed and for seeing me through.

Without all of their support the thesis would never been completed.
Abstract

The broad objective of the thesis is to analyze the monetary policy transmission and relative importance of various shocks in business cycles after considering the financial sector structure for both developing and developed countries in three self-contained chapters (Chapter 2-4). The thesis contributes both theoretically and empirically to the literature relating to monetary policy, financial frictions and competition structure, exchange rate pass through and open economy in general, using Structural Vector Auto-Regression (SVAR) and Dynamic Stochastic General Equilibrium (DSGE) models. Since the global financial crisis, a growing awareness of the roles of financial frictions has led to renewed interests in transmission mechanisms of monetary policy and other shocks. Two different financial frictions are incorporated in the DSGE models of Chapter 3-4 while Chapter 2 does not explicitly model financial friction and uses SVAR model to analyze the research questions.

The effectiveness of monetary policy and its economy wide transmission mechanism are relatively unexplored in Bangladesh where financial sector is still developing. Hence, in Chapter 2, I investigate the effectiveness of monetary policy and its transmission mechanism with special emphasis on the lending channel. A SVAR model for Bangladesh is constructed, taking into account the exchange rate and monetary policy regimes in the identification scheme. The estimated model finds support for empirical regularities and existence of the bank lending channel. However, exchange rate channel appears less effective, reflecting a high degree of market intervention by the Bangladesh Bank.

Frictions complicate the role of the financial sector particularly in the advanced financial markets. Therefore, in Chapter 3, I analyze the transmission mechanism of investment specific technology (IST) shock in presence of frictions between depositors and bankers (a la Gertler and Karadi, 2009) and implications of considering the capital quality and the net worth shocks as financial shocks. I use a DSGE framework in Chapter 3 as it allows to design and experiment shocks and frictions explicitly. The estimated model with a closed economy representation for the US shows that, financial
friction weakens the impacts of IST shocks in business cycles. Also, the financial sector is important not only as amplifier of shocks originating in the real sector, but also as an independent source of shocks affecting the real economy substantially.

Financial sector in many countries are not as competitive as in the US. Therefore, the financial friction discussed in Chapter 3 may not be relevant in those countries. Highly concentrated structure of the financial sector itself creates frictions affecting bank credits in important ways. Thus, in Chapter 4, I construct an open economy DSGE model with an oligopolistically competitive banking sector, considering Australia as an example. Oligopolistic competition is measured through interest markup which depends on the number of competing banks. The number of competitors is determined endogenously. The estimated model for Australia finds a strong stock market effect in presence of oligopolistic banks after a monetary policy shock making the shock less effective and such banks may amplify external shocks. Also, these banks appear to be more resilient to financial shocks indicating healthy bank balance sheet positions.

The big picture projected by the dissertation is, the depth and complexity of the financial sector affect the way intermediaries contribute to cyclical fluctuations when shocks including monetary policy hit the economy. For example, IST shock's impacts on output are weakened by the financial frictions through a bank balance sheet effect when intermediaries are highly competitive. However, under oligopolistic bank competition, the IST shock may not trigger effective enough balance sheet effects due to strategic behavior among the banks, leaving a large role for the shock to play. Policy implications of the thesis along with a discussion on future research directions are summarized in Chapter 5.
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Chapter 1

Introduction

1.1 Context and Aim of the thesis

The financial sector plays a central role in economic activity due to its intensive connection to the agents in modern economies, particularly through credit intermediation activities. Hence, policymakers need to have a clear understanding of the financial sector. Macroeconomic models are effective tools to achieve this understanding. This is demonstrated by literature. These models guide policymakers in decision making by providing inputs in terms of implications of shocks, frictions and predictions of future movements of variables. The choice of macroeconomic model to be used depends on the perception by policymakers about the way the economy works and the level of theoretical and empirical coherences among competing models. In the global perspective, the choice of models also depends on the availability and quality of data. The class of Structural and Bayesian Vector Auto-Regression (VAR) models and the Dynamic Stochastic General Equilibrium (DSGE) models are widely used in empirical and theoretical macroeconomic research to understand the transmission mechanisms and the economy wide effects of monetary policy and other shocks (see Pagan 2003 for a historical overview of macro models). After the global financial crisis, DSGE models have been expanded substantially to incorporate various aspects of the financial sector. Since then academics and policymakers have growing perceptions that having a monetary authority through a monetary policy rule in the model
without an explicit financial sector can make the model grossly incomplete.

This thesis, therefore, constructs appropriate models based on the country characteristics and data availability to analyse the transmission mechanisms of monetary policy and other shocks in the context of one developing and two developed countries. The literature on monetary policy transmission mechanism is vast in the context of high income countries where financial sectors are complex and more market oriented. However, there is a renewed interest on monetary policy literature in these countries due to increased perceptions about financial frictions and importance of these frictions in shock propagations, as highlighted recently by the global financial crisis. Many empirical studies in this line are worth re-investigating in the presence of financial frictions to update the knowledge of business cycles. The complexity in the nature of the financial sector generates various frictions that lead researchers to focus on different aspects of the sector when constructing models; examples include the bank capital dynamics, information asymmetry in lending market or in deposit market. All these approaches highlight that financial sector deserves special attention when assessing the effectiveness of a policy or impacts of various exogenous events on the real sector variables such as output and employment as well as inflation.

In contrast, the monetary policy literature is still limited in the context of emerging developing countries for three main reasons (see Montiel et al. 2010 for review of monetary policy in developing countries). First, there is lack of financial inclusiveness. Real sector transactions are not fully conducted through formal financial sector, hence, large part of economic activities remain unaccounted for. This leaves less room for monetary policy to interact with the real economy. Also general equilibrium models that assume that the formal sector accounts for majority of economic transactions become difficult to fit in. Second, financial variables such as lending rates are often exogenous, rather than market determined which makes monetary policy blunt. However, the gradual reform movements towards the market based policy instruments and exchange rate float, make
monetary policy interesting to investigate, applying popular modelling techniques. Third, there is lack of sufficient and good quality time series data. Thus, monetary policy and external shocks in many developing countries remain unexplored in model based analysis. These facts motivate the thesis to explore the channels of monetary policy in Bangladesh as a representative of monetary aggregates targeting countries with increasing financial inclusion in the first substantial chapter. Subsequently, the thesis focuses on investigations relating to frictions in high income countries where financial markets are advanced and complicated.

Therefore, the main aims of the thesis are, first, to analyse the effectiveness and channels of monetary policy for an emerging small economy; second, to analyse the role of financial sector in presence of frictions in financial and real sectors for advanced financial market economies by adopting models based on country characteristics and data availability.

In view of the first objective, a structural Vector Auto-Regression (SVAR) model is constructed for Bangladesh with small open economy features. For the second objective, Dynamic Stochastic General Equilibrium (DSGE) models are constructed for both closed and open economies set up. Model implications are discussed in terms of dynamics of variables towards steady states after a shock and contribution of each shock to the overall variations of a variable in different time horizons. DSGE models are explicit in incorporating complex relationship among variables as well as uncertainties (exogenous events) and overcome the Lucas critique. These features make DSGE models very useful for policy analysis. Thus, the thesis adopts DSGE framework to specify the relationships between financial and real sector variables explicitly to estimate the importance of financial frictions and shocks. The popular method in the literature to estimate these models are Bayesian estimation. The Bayesian estimation enables the model to overcome mis-specifications problems that are common in macroeconometric models. Therefore, we obtain estimates of parameters with meaningful structural explanations in DSGE models, unlike the estim-
ated parameters of the SVAR models that contain little economic sense.

The DSGE models in the thesis containing different financial frictions are estimated for the US and Australia. First, Chapter 3 contains a closed economy representation of the US economy and considers stickiness in both output price and nominal wage adjustments and costs in adjusting the level of investment, in addition to the financial friction. The closed economy version of the DSGE model is justified in the literature for the US, given the large size of the US economy. The DSGE model in Chapter 4 is built upon the model in Chapter 3 to represent a small open economy characterised by an oligopolistic financial sectors, such as Australia. Hence, the DSGE model is extended with standard trade features with rest of the world economy in Chapter 4. To allow for incomplete exchange rate pass-through, sluggishness in price adjustment is assumed in trade sectors.

However, estimation of the general equilibrium models are highly data demanding that can be an obstacle in achieving reliable estimates of such models for the emerging developing countries where paucity of data is an issue. Also, the relationship between observed variables in DSGE models can often be summarised in terms of SVAR specifications (Catao & Pagan 2010). In addition, unlike the VAR specification, the Structural VAR model can be restricted based on the features of a small open economy. These issues lead me to construct a SVAR model for Bangladesh in Chapter 2 and estimate the model with short run restrictions and block exogeneity restrictions. Therefore, the thesis constructs one SVAR model and two DSGE models and estimates them for Bangladesh, US and Australia respectively with a view to analyse monetary policy and roles of various financial frictions.

1.2 Key research questions and results

The thesis consists of three self-contained chapters and a concluding chapter that discusses policy implications and outlook for future research implied by the three self-
1.2. Key research questions and results

Effective implementation of monetary policy depends on the policymaker’s clear perception of the channels through which policy gets transmitted. These channels remain relatively unexplored in Bangladesh. The monetary policy framework of Bangladesh Bank is monetary aggregates targeting type, using market based tools such as Repo\(^1\) and reverse-Repo since 2002-2003. The exchange rate was officially floated in 2003. However, transmission mechanism of monetary policy was not properly explored for this period in the literature. Hence, Chapter 2 investigates how monetary policy shocks affect the price level and other key macro variables of the country, particularly in the period of market based monetary policy instruments. This question is analysed with especial emphasis on the bank lending channel since Montiel et al. (2010) suggest that bank lending channel of monetary policy transmission is likely to be dominant in transmission mechanism in low income countries. In addition, the chapter investigates how the central bank and the real economy respond to a private credit shock and other external shocks commonly faced by a small open economy? To investigate the research questions, a structural VAR model is constructed based on the economy wide features of Bangladesh which incorporates various domestic and external shocks. The choice of SVAR approach in Chapter 2 is due to its wide applicability in monetary policy research in both developed and developing countries. Another main reason for using SVAR rather than general equilibrium model is the paucity of data for Bangladesh. National income accounts data are mostly available in annual frequency. Since the study period starts from 2003, the limited number of observations of several key variables do not allow us to estimate any big structural model. This fact, in addition to the comparison between DSGE and SVAR models in Section 1.1, suggest that SVAR model is an appropriate choice to analyse monetary policy of Bangladesh with reliable estimates.

\(^1\)Repo is Repurchase agreements. Repo and reverse Repo are ways for short term borrowings-lendings of dealer banks using mainly government securities.
The key results in Chapter 2 are: the current monetary policy framework is able to affect price level significantly and the bank lending channel plays a non-trivial role in policy transmission. A positive credit shock can be inflationary and the monetary authority responds by increasing policy interest rates. In addition, the chapter finds that developments in the rest of the world cause substantial variations in domestic price and other variables. The thesis takes Bangladesh as an example of country groups with monetary aggregates targeting monetary policy frameworks. Hence, the findings and implications are important not just for Bangladesh but for other similar countries as well.

Financial frictions have been known to influence the impacts of economy wide shocks. Hence, in Chapter 3 the role of financial frictions in shock transmission mechanism and implications of financial shock specification have been discussed in an estimated DSGE model. Chapter 3 deals with a bank liability side friction, proposed by Gertler & Karadi (2011) in their calibrated DSGE model. The friction arises due to a moral hazard problem between banks and depositors in a perfectly competitive banking sector. Chapter 3 studies the role of financial sector both as an accelerator of shocks originated in the real economy and as an independent source of shocks that can affect the rest of the economy. The main research questions in this chapter are: what is the transmission mechanism (or role) of investment specific technology shock in presence of bankers-depositors type financial friction and financial shocks when we consider both output and labour price rigidities? Business cycles literature (Justiniano et al. 2010 for example) has emphasised investment specific technology shock as one of the main contributor to output fluctuations and the importance of price and wage rigidities in the process. In addition, this chapter seeks to find the relative importance between capital quality and bank net worth shocks, in terms of their abilities to explain variations in output and interest spread. Capital quality shock is an exogenous variation in the quality of productive capital which is a novel feature in Gertler & Karadi (2011) to capture the housing market collapse in the US in 2007.
The research issues in Chapter 3 are interesting in two important dimensions. The first relates to the treatment of financial shock in the model. Although capital quality shock is perceived as a financial shock, the event originates in the real sector. The shock affects bank balance sheet through changing collateral valuations and it is called financial shock because of the balance sheet identity between bank asset and liability. However, the way this shock is constructed does not distinguish between physical destruction and valuation deterioration of capital. Chapter 3 expands on this issue further by including a purely financial shock such as a bank net worth shock in the model. The second dimension of interest relates to the role of nominal wage rigidities in investment specific technology (IST) shock transmission in presence of financial frictions. The chapter analyses the net effect of two opposing forces on output fluctuations: nominal wage rigidities that amplify the shock impacts, and financial frictions that neutralise the shock impacts through asset price channel.

The calibrated model of Gertler & Karadi (2011) is extended with nominal wage rigidities and time varying stochastic survival probability of banks. The extended DSGE model is estimated with US data and the main findings are: investment specific technology shock is attenuated greatly overtime in presence of a liability side financial friction. So the chapter suggests that investment specific technology shock may not be as important as claimed by the previous business cycles literature, depending on the role of the financial sector and frictions therein. Second, the type of finance shock we consider - asset or liability side - in the model has different quantitative impacts. The estimated model suggests that there are benefits of disentangling capital quality shock and bank net worth shock when we analyse financial shocks within such liability side friction. Capital quality is a shock that originates in the real sector by construction and affects interest spread by deteriorating intermediaries’ asset side of balance sheet through collateral channel. Net worth shock, in contrary, originates within the financial sector which belongs to the liab-
ility side of balance sheet. Benefits of disentangling these two shocks relate to the model’s ability to replicate moments and other business cycles properties. The net worth shock works better to replicate data moments in this study.

The financial sector in Chapter 3 is assumed to be perfectly competitive. However, in many countries the financial sector is dominated by only few banks. The strategic behaviour among few banks possessing large market share can lead them to be characterised as oligopolistic. The thesis moves on to investigate the market competition structure of financial sector and associated impacts on business cycles in Chapter 4. Bank concentration ratio provides important information about the nature of competition structure among banks and a high concentration ratio implies strategic behaviour by the banks. The impacts of such strategic behaviour among banks on business cycles have not been sufficiently studied. Considering the importance of high bank concentration for Australia and similar other countries, Chapter 4 deals with the particular aspect of financial frictions arising from imperfect competition in bank industry. Therefore, the main objective of this chapter is to construct a small open-economy DSGE model with a financial sector incorporating oligopolistic competition among banks; and determine how such imperfect competition affects various shock transmissions and dynamics of macro aggregates of a small open economy. In order to strengthen the analysis further, a benchmark model is constructed where banks are perfectly competitive with no frictions. The issue is analysed further by comparing baseline results with those from the competitive bank sector model.

Chapter 4 extends the DSGE model of Chapter 3 with imports, exports and households savings/borrowings from rest of the world. It considers Australia as an example of country characterised by a highly concentrated banking sector and estimate the model with Australian data over its inflation targeting regime. The imperfect competition in bank industry is measured through mark ups in lending rates. The mark up depends on the elasticity in loan demand as well as the number of competing banks. To endogenize the number of
competing banks, it is assumed that bank entry or exit is subject to an entry cost. Bank entry continues until the value of bank is equal to the cost of entry. The main results from the estimated model is that oligopolistic competition with endogenous bank entry produces a procyclical mass of banks and countercyclical mark ups but the magnitudes are smaller for Australia. For monetary policy shock, counter cyclical interest mark up tends to amplify the shock impacts but a strong stock market effect (Gavin 1989) works in the opposite direction. The net effect of monetary policy on aggregate demand is small. For neutral technology shock, oligopolistic banks amplify the shock effects through the bank entry channel. The bank balance sheet effect of collateral valuation on the real economy is weaker due to strategic behaviour among banks. Thus, investment technology shock is no longer attenuated by such financial sector. Thus, presence of oligopolistic competition suggests a different transmission mechanism that may amplify or neutralise various shocks depending on the type of shocks that hit the economy.

In terms of methodology the thesis makes important contributions. In Chapter 2 the model uses an unified approach to monetary policy literature and Exchange Rate Pass Through (ERPT) literature in identifying the SVAR model. This allows to incorporate the exchange rate policy of Bangladesh which is an heavily managed float in practice. Chapter 3 shows that the type of financial shock included—asset or liability side—has important implications in the estimated model and discusses the identification strategy of the two types of shocks in detail. The methodological contribution in Chapter 4 is that it provides a framework to analyse whether oligopolistic banks act as amplifiers or neutralisers to external shocks that are commonly faced by a small open economy like Australia. Another methodological contribution is, the bank entry condition in Chapter 4 is designed in a way that neutral technology shock affects the entry costs of banks inversely. Since neutral technology shock affects both goods production and banking firms production, it is effectively an economy wide shock. Finally, general equilibrium models
with endogenous firm entry are mostly calibrated. Instead of following this tradition, the model is estimated with Bayesian technique for Australian data to draw inferences.

1.3 Structure of the thesis

The thesis has five chapters in total. Chapters 2-4 contain the core research of the thesis. Chapter 2 builds up SVAR model for a small open economy to analyse the monetary policy transmission mechanism. Chapter 3 discusses the role of financial sector and frictions therein and their impacts on post war US business cycles using an estimated DSGE model. Chapter 4 analyses the role of oligopolistic bank competition in the business cycles using an estimated DSGE model for a small open economy. Finally, Chapter 5 summarises the findings and implications of the thesis and future research avenues based on these chapters.
Chapter 2

Monetary policy transmission in Bangladesh: exploring the lending channel

Abstract

The monetary policy transmission mechanism of Bangladesh, especially the lending and exchange rate channels remain largely unexplored during the period of market based monetary policy instruments and the managed float exchange rate regime. This chapter analyses these transmission channels and finds that the monetary aggregates targeting framework is still effective in influencing price level. Bank lending plays a non-trivial role, while the exchange rate channel is less effective in the transmission process, suggesting a high degree of intervention in the foreign exchange market. External shocks appear important for the macro aggregates and domestic credit boom appear inflationary, in which the central bank plays a stabilizing role.

2.1 Introduction

The crucial role played by credit in economic activity was vividly highlighted during the financial crisis of 2007-2010. In normal times, bank credit availability is endogenous to the monetary policy process (Lown & Morgan 2002) and its connection with the real economy depends on the level of financial penetration of an economy. It is the role of credit extension that makes the banking sector a potential source of financial friction in
Credit is an important macroeconomic variable that boosts real economic activity and it is usually viewed through the lens of the traditional ‘bank lending’ channel. However, the broader ‘credit channel’ reveals that credit itself depends on the level of economic activity. This implies the existence of a large formal sector in the economy that depends on the financial sector for various transactions. That is why in the context of the developed financial markets, so many studies investigating the interrelationship between the bank credit and monetary policy are available.

The monetary transmission literature on advanced financial market economies is vast but the same literature on developing economies is lacking, both quantitatively and qualitatively. The successful implementation of a monetary policy stance depends on the monetary authority’s clear perception about the active monetary transmission channels of the economy. Monetary policy influences the real sector through its effects on the financial sector. Hence the size and development of the financial sector, and how widely it is integrated with the real sector, determine the transmission of a policy stance to the real economy.

In a comprehensive review of the structure of the financial sector and monetary policy of countries with various income groups, Montiel et al. (2010) state that the bank lending channel is likely to be dominant for low income countries. The study investigates their observations, along with other empirical regularities of monetary transmission mechanism, by studying Bangladesh’s monetary policy and credit market as example of an emerging developing countries. Given Bangladesh’s nascent secondary bond market and smaller stock market capacity, non-financial firms usually rely on banks for finances. The growing size of the Bangladesh’s banking sector and the bank competition indices, reported in Section 2.4 indicate that the bank lending channel for Bangladesh is an interesting case to study.

The strength of the credit channel, a debated issue prior to the global credit crisis, has been effectively demonstrated, especially in countries with highly complex financial
systems. However, Bangladesh’s bank credit attracted very few studies to date and none have employed an economy-wide model to investigate the simultaneous relationship between monetary policy, credit and the real economy. Of the studies available, Ahmed & Islam (2006) find weak evidence, and Younus (2004) find no evidence of the bank lending channel in Bangladesh. Although Structural Vector Auto-Regression (SVAR) is one of the most commonly used modeling techniques in quantitative macroeconomics that incorporates theory and country specific features, few empirical studies apply this technique to Bangladesh’s economy. Some examples of the monetary transmission literature on developing countries will be reviewed in next section.

Since a thorough exploration of a distinct bank credit channel in Bangladesh’s economy is yet to be conducted, the main goal of this study is to analyze the impact of credit and monetary policy shocks on both price and the real economy, with particular emphasis on the credit channel. We cannot analyze such shocks using simple VAR methodology as VAR does not allow us to impose structural features of Bangladesh, a small semi open economy, in the model. Therefore, the chapter estimates a Structural VAR (SVAR) model for Bangladesh’s economy to explicitly model and analyze shocks including those emanating from the external sector. The SVAR approach is particularly relevant in monetary policy analysis for countries with shorter time series. In this context, the SVAR methodology has advantages over large structural models such as Dynamic Stochastic General Equilibrium (DSGE) models. For example, Dungey & Pagan (2000a) observe that many DSGE models have a SVAR representation in terms of all the variables but in reality some of these variables are unobserved. Hence, the representation in terms of observed variables is typically a structural vector autoregressive moving average process. Catao & Pagan (2010) observe that some structural features of emerging and developing economies are often ignored in the new Keynesian DSGE models. Also the Bayesian estimation technique, commonly used for DSGE model estimation, uses strong priors about parameters
and hence, empirical investigation through this is less about ‘discovery’ than quantifying the parameters of some prescribed model. So, they state that DSGE models are often best used as a macroeconomic skeleton to allow investigators to organize data, rather than to be imposed upon them.

Against this backdrop, this study contributes to the existing literature by constructing a block recursive SVAR model for Bangladesh’s economy over the period 2003 to 2013 to address two principal research questions. First, how do monetary policy shocks affect aggregate price and other real variables through their impacts on bank credit in Bangladesh’s economy (lending channel)? Second, how do the central bank and the real economy respond to a private credit shock? In addition to finding answers to these questions, this model analyzes the responses of the economy to various external shocks.

This study, thus, contributes to the monetary policy literature on emerging and developing economies in general, by examining the monetary policy transmission mechanism of the small semi-open economy of Bangladesh and in particular it explores the credit channel and the role of credit in the economy. Second, this study adopts a unified approach to the monetary policy literature and the Exchange Rate Pass Through (ERPT) literature while identifying the SVAR model for Bangladesh. This enables to include the exchange rate regime of the economy in the model. Third, the identification adopted in this model within the recursive structure is free of empirical anomalies such as the price puzzle, liquidity puzzle and exchange rate puzzle that some earlier studies encountered while using the recursive SVAR. Finally, the economy-wide SVAR model with country-specific characteristics aims to provide reliable evidence on the existence of a credit channel (in the narrow sense) in Bangladesh that the earlier literature appears to have missed.

The study therefore sheds new light on the monetary transmission channels of Bangladesh. The main results are that: (i) monetary policy affects the domestic price level significantly and the bank credit channel plays a non-trivial role in monetary transmission; (ii) a positive
shock to credit can be inflationary and the central bank plays a stabilizing role by raising its policy rate; and (iii) external shocks are important in the movement of domestic macro aggregates. The findings are important in the context of increased challenges faced by the Bangladesh Bank and the demand for gradual financial openness of the Bangladesh’s economy.

The remainder of this chapter is structured as follows. Section 2.2 contains a review of the existing empirical work. The already documented evidence and the gaps that motivate the current study are presented in this section. The stylized facts of the monetary transmission mechanism observed in advanced financial markets are briefly discussed in Section 2.3. A description of the financial environment of Bangladesh is presented in Section 2.4. It provides information that helps interpret the results in this chapter. The methodology and data issues are discussed in Section 2.5. The estimation results and tests for their robustness are presented in Section 2.6 and Section 2.7 respectively. Finally, the implications drawn from the results are presented in Section 2.8.

2.2 Literature

Some of the earliest works on the effects of monetary policy shocks on the real economy have been conducted by Bernanke & Blinder (1992), Sims (1992) and Christiano et al. (1998) for the US economy. Since then vector auto-regression (VAR) has been introduced as a useful tool to analyse monetary policy effects. One influential study in monetary policy literature is that by Kim & Roubini (2000), for six industrialized countries. Their estimated SVAR model solves empirical anomalies such as the liquidity puzzle, price puzzle, exchange rate puzzle and forward discount bias puzzle, all found in earlier VAR studies. Using VAR as well as structural models, Angeloni et al. (2003) in their comprehensive study on the Euro area, find evidence of broad credit channels for many of the Euro area countries. The
monetary policy model developed by Kim & Roubini (2000) and its subsequent literature allow exchange rates to be contemporaneously affected by all variables in the model. This assumption relates to the floating exchange rate regime of advanced economies.

Dungey & Pagan (2000a, 2009a) developed an eleven-variable model for the Australian economy, with special emphasis on monetary policy impacts using a block recursive SVAR approach. However, they do not include bank credit variables in their models. Berkelmans (2005) examines the endogenous relationship between credit and monetary policy of the Australian economy using an SVAR approach, with similar exchange rate assumptions to those proposed by Kim & Roubini (2000). The findings in Berkelmans (2005) suggest that a positive shock to policy interest rate lowers both inflation and credit, whereas the monetary policy plays a stabilizing role in response to a credit shock. This chapter follows the block recursive approach of Dungey & Pagan (2000a, 2009a); considering the small nature of Bangladesh’s economy.

The monetary transmission literature on developing countries finds mixed evidence for the effectiveness of monetary policy and bank lending in influencing price and the real sector of an economy. Aleem (2010) finds that the banking sector plays a dominant role in transmitting monetary policy to the real sector in India while Disyatat & Vongsinsirikul (2003) find a weak bank lending channel for Thailand, in spite of the banks being prime sources of business finances there. For Brazil and Chile, Catao & Pagan (2010) find that interest rate changes have a swifter effect on output and prices compared to advanced economies, and exchange rate dynamics play an important role in monetary transmission mechanisms. These two countries have floating exchange rates and considerable levels of capital account openness. Hence, the active roles of interest rate and exchange rate in monetary policy transmissions are as expected. Catao & Pagan (2010) also find a typical size of a credit shock to have large effects on output and inflation in both economies, but greater in Chile where bank penetration is higher. Given the current level of bank penetra-
tion in Bangladesh, this chapter also examines the impact of credit shock on Bangladesh’s economy.

However, there are problems in adopting the SVAR structures of the developed and commodity exporting countries mentioned above for the case of Bangladesh. For example, the floating nature of exchange rate regimes in the US and Australia may not always be appropriate for developing countries, such as Bangladesh, where exchange rates are either pegged or follow a managed float. The exchange rate in a developing economy may contemporaneously affects other variables, including monetary policy and real sector variables, but is not itself affected contemporaneously by those variables. In addition to having a monetary policy, the central bank can have separate foreign exchange market intervention policy to stabilize the exchange rates. So, for Bangladesh, we cannot allow exchange rate to be contemporaneously affected by the other variables of the model. Another difficulty is, Australia, Brazil and Chile are all commodity exporters and the US is a large open developed economy while Bangladesh is a small open economy and mainly a commodity importer. So the model variables and the SVAR identification scheme applied for Bangladesh in this study are different from those countries.

Another strand of literature that stands in contrast to that developed by Kim & Roubini (2000) is the Exchange Rate Pass Through (ERPT) literature. The ERPT literature, dominated by McCarthy (1999), follows the recursive SVAR approach with Cholesky orthogonalisation. In a small open economy, optimal monetary policy may be affected by the extent of the exchange rate pass through (Adolfson 2001, Devereux 2001, Smets & Wouters 2002, Monacelli 2005). The order of variables in the original ERPT literature is oil price, output gap, exchange rate, import price inflation, and finally wholesale and consumer price inflation. Here the ordering is such that, the consumer price, instead of the exchange rate, is contemporaneously affected by all foreign and domestic variables. This reflects the managed nature of exchange rate regimes, commonly found in developing
and emerging countries. The work of Ito & Sato (2008) incorporates the monetary policy variable in the ERPT framework in order to analyse the impacts of exchange rate changes on inflation in post-crisis Asian economies.

While focusing on the endogenous relationship between credit and monetary policy variables, the model needs to account for the role of the exchange rate in the system. For Bangladesh, Chowdhury & Siddique (2006) find exchange rate fluctuation has no significant impacts on CPI, while Akhtaruzzaman (2005) finds depreciation plays a significant role in the inflationary process. Thus, the proposed SVAR model for Bangladesh’s economy in this chapter treats the conventional monetary policy and the ERPT literature in a unified manner during identification, similar to the identification scheme of Bhattacharya et al. (2011) for India. Bhattacharya et al. (2011) assume that the exchange rate of a small economy is not allowed to move contemporaneously with other macro variables; rather, price is affected by exchange rate and other variables. The ordering seems more sensible in the context of the heavily intervened foreign exchange markets. However, the structural vector error correction model of Bhattacharya et al. (2011) does not include bank credit.

The early monetary policy literature on Bangladesh such as Chowdhury (1986), Chowdhury et al. (1995) does not include credit variables. The vector auto-regression (VAR) study of Chowdhury et al. (1995) suggests that the inflationary process of Bangladesh cannot be explained exclusively by monetarist and structuralist views. During their study period, Bangladesh had a fixed exchange rate system (Bangladesh Bank adopted the floating regime in 2003) and the recursive VAR methodologies applied to those studies are not sufficient to capture the dynamic interactions between foreign and domestic variables.

Youmns (2004) examines the bank lending channel of Bangladesh over the period 1975 to 2000, using the monetary base as the central bank’s policy variable and concludes that the bank lending channel in Bangladesh is non-existent because of the excess reserve in the banking sector. During this period (1975-2000) the central bank did not use market-based
2.2. Literature

Instruments to conduct monetary policy. In order to facilitate the liquidity management afterward, the Bangladesh Bank introduced market-based instruments (Repurchase agreement (Repo) in 2002) and the auction of short-term government securities. The existence of the bank-lending channel in Bangladesh remains largely unexplored in the changed policy environment.

Ahmed & Islam (2006) include private sector advance to analyse the monetary transmission channels of Bangladesh employing the unrestricted VAR approach for the period 1979 to 2005 and find weak evidence of lending and exchange rate channels. Ahmed & Islam (2006) order the variables as reserve money, total deposits, private sector advance, CPI and real GDP. Reserve money is considered as the monetary policy variable, similar to Younus (2004). There is a separate model for the exchange rate channel, which uses reserve money, CPI, nominal exchange rate, export, import and real GDP; however, it does not capture the interaction between credit and exchange rate. The exchange rate channel of monetary policy should not be operative before 2003. The New Open Economy Macroeconomics (NOEM) literature implies that monetary policy affects the real economy through interest rate and exchange rate channels. If the exchange rate is fixed then there is limited scope for an exchange rate channel to operate. Also the dynamic response of economic variables to a monetary policy shock becomes misleading in the absence of relevant foreign variables in the model.

In a six-variable Near VAR model for Bangladesh, Younus (2009) includes India’s money supply to account for the open economy nature of Bangladesh and finds no significant impact of Indian money supply on domestic CPI. However, innovations to the Indian money supply can explain almost 50 per cent of the forecast error variance in lending rates. Bhuiyan (2012) estimates a nine-variable non-recursive SVAR model, containing separate domestic and foreign blocks to better capture the interaction between variables to monetary policy shocks but not bank credit for Bangladesh, using a Bayesian approach.
Further, the model does not account for important policy changes in the financial sector during the period of analysis (1994-2009).

In sum, the review of literature on Bangladesh shows gaps that the credit channel of monetary transmission policy of Bangladesh during the managed float regime has not been explored thoroughly. Thus, the whole monetary policy transmission mechanism in Bangladesh remains vague to some extent and deserves attention.

2.3 The transmission mechanism

When a central bank intervenes in the short-term Treasury Bills (T-bills) market then short run expected inflation remains unchanged because of the sticky price and rational expectation assumptions. Thus, changes in interest rates in the Treasury bills market actually change the short-term real interest rates, which affect households' intertemporal choice of consumption, hence, the aggregate demand. This effect is part of the broader interest rate channel that depends on the rate of intertemporal substitution of consumption and the prevalence of credit rationing (Montiel et al. 2010).

The bank lending channel, on the other hand, arises due to two facts: one relates to the asset side of the bank balance sheet (the imperfect substitutability between bank lending and bonds) and the other relates to the liability side (difficulty in attracting resources other than deposits). When a central bank buys short-term government securities (commercial banks themselves are often the sellers), this increases the amount of free reserves or deposits in the commercial banks. Theoretically, the increase in deposits increases the supply of loanable funds. The increase in loanable funds along with competition among banks would lower the lending rates. Thus, bank dependent agents enjoy more loan facilities, increase their expenditure and therefore, boost aggregate expenditures. In practice, the lending activities also depend on the overall investment scenario and the health of the banking sector.
Similarly, during periods of tight monetary policy, banks are forced to reduce their loan portfolio due to a decline in total reservable bank deposits. This implies that the effectiveness of the bank lending channel depends on the extent to which an increase in free reserves in commercial banks increases the supply of loans, and how much it reduces the lending rate. The broader credit channel includes the balance sheet effects of the borrowers due to monetary policy shock. Here the financial circumstances of the households and firms affect the demand for credit which further exacerbates the economic situation (see Bernanke & Gertler 1995 for detail).

There are other channels that are activated at this point as a result of the change in policy rate, e.g the exchange rate channel. Under the floating exchange rate and perfect capital mobility, the arbitrage between domestic and foreign interest rates should induce capital flows. Uncovered interest parity (UIP) implies that nominal exchange rates will change to restore the equilibrium. The price stickiness implies that in the short run, exchange rates will change to induce the ‘expenditure switching effect’ between domestic and foreign (imported) goods, which is likely to influence the aggregate price level of the economy.

2.4 The financial environment of Bangladesh

Although the growing trend is to move towards an inflation targeting regime, a considerable number of countries, including Bangladesh, continue to follow the monetary aggregates targeting framework for conducting monetary policy operations, and the stabilized arrangement (or peg) for exchange rates management (International Monetary Fund 2014). As exchange rate is highly interactive with credit and policy rate, the exchange rate channel may be impaired if the exchange rate regime is not fully floating. Saxena (2008) finds that nine out of thirteen Asian and Latin American emerging countries opt for foreign exchange
intervention to complement their monetary policy actions.

In the first stage of the transmission mechanism, the change in the monetary policy rate changes the interbank money market rate. In Fig.2.1, Bangladesh’s 91 day T-bill rate, which is used as a proxy for the monetary policy rate in this study, seasonally adjusted interbank money market rates and commercial bank lending rates are plotted in monthly frequency. The drop in T-bill rates after 2008, and rise after 2009, are shadowed by the interbank money market rate (also known as call money rates). The change in the interbank rate is the first stage of monetary policy transmission, then in the next stage, the interbank money market rate should affect the commercial banks lending rates, and therefore, the equilibrium level of credit is determined. In commercial lending rates, we see a considerable degree of stickiness.

Figure 2.1: Bangladesh’s T-bill rates, interbank money market rates and commercial bank lending rates (Years 2004-2014).

Figure 2.2: Bangladesh’s NEER and CPI, in logarithm and de-trended (Years 2003-2014).

Source: Bangladesh Bank.

The stickiness in the commercial lending rate can arise because of the fact that any increase in lending rates may not necessarily increase banks’ earnings due to information asymmetry (Lowe & Rohling 1992). Further, there may be rigidities among customers,
e.g., borrowers may find it costly to switch to other banks that offer better rates, can also create stickiness in loan rates. These facts restrain banks from changing retail lending rates frequently. Also, because of the usual high noise in the money market and the costs associated with rate changes, banks change retail lending rates only if they believe the money market rate change will be persistent Disyatat & Vongsinsirikul (2003). In Bangladesh, the central bank does not control the commercial banks’ lending rates, except for an indicative rate ceiling for lending in agriculture and SME sectors.

The cyclical pattern of the historical data reveals important background information, and also indicates the relevance of the variables included in the model. Thus, from Fig. 2.2 to Fig. 2.6, I present time plots of select variables to show the essential information in the data used to estimate the model. Fig. 2.2 shows the cyclical movements in Nominal Effective Exchange Rates (NEER) and the CPI, both in logarithm which, however, does not reveal any clear co-movements.

Figure 2.3: Bangladesh Bank’s foreign exchange buy-sale over M2 money (Years 2003-2014).

Figure 2.4: Changes in CPI and nominal exchange rates of Bangladesh (Years 2003-2014).

Source: Bangladesh Bank.

Next, I present the information on exchange market intervention by the central bank
measured in terms of the net buy of foreign exchange over broad money (M2 measure) in Fig. 2.3. Negative values indicate net foreign currency sales to the market. This figure provides evidence that the Bangladesh Bank intervenes in the foreign exchange market quite frequently. This supports the conjecture that although official regime is a managed float, the Bangladesh Bank intervenes the foreign exchange market substantially and frequently that makes the regime close to a pegged system. Fig. 2.4 shows the changes in nominal exchange rates and changes in CPI, indicating that the changes in nominal exchange rate are smoother than those in the CPI. This again supports my earlier conjecture on foreign exchange market intervention by Bangladesh Bank.

Figure 2.5: Bangladesh’s M2 money and private sector credit (de-trended) for Years 2003-2014.

Figure 2.6: CPI of Bangladesh and CPI of import partner countries (de-trended) for Years 2003-2014.

Bangladesh’s broad money (M2 measure) and the level of commercial bank credit are presented in Fig. 2.5, and the import weighted CPI of Bangladesh’s major import partner countries along with own CPI are plotted in Fig. 2.6. From Fig. 2.5 we observe that money and credit follows each other closely. We also observe some cyclical co-movements between the domestic CPI and foreign CPI in Fig. 2.6, hence, trading partners price is an important
foreign variable to be included in the model. Next, I present a comparative scenario of Bangladesh’s financial environment in Table 2.1.

The size of the banking sector is important for the effectiveness of the interest rate and the bank lending channels of monetary policy transmission. Table 2.1 shows a dynamic picture of measures of the financial sector size, the bank concentration ratio, the net interest rate margin and the stock market capitalization as a share of GDP for Bangladesh and three income groups.

<table>
<thead>
<tr>
<th>Year</th>
<th>Country Groups</th>
<th>DMB assets/GDP</th>
<th>Bank concentration</th>
<th>Net interest margin</th>
<th>Stock market capitalization/GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>Advanced</td>
<td>1.24</td>
<td>0.67</td>
<td>0.02</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>Emerging</td>
<td>0.63</td>
<td>0.57</td>
<td>0.05</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>LIC</td>
<td>0.32</td>
<td>0.73</td>
<td>0.06</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Bangladesh</td>
<td>0.49</td>
<td>0.77</td>
<td>0.02</td>
<td>0.046</td>
</tr>
<tr>
<td>2015</td>
<td>Bangladesh</td>
<td>0.59</td>
<td>0.29</td>
<td>0.023</td>
<td>0.15*</td>
</tr>
</tbody>
</table>

Source: The ratios for different income groups are from Montiel et al. (2010) and the ratios for Bangladesh are from the Global Financial Development Database (GFDD 2017). * Latest available is for 2012.

The 2005 statistics for the three income groups are from Montiel et al. (2010), and I extend the table for Bangladesh using data from the Global Financial Development Database (GFDD 2017) to compare the financial environment of Bangladesh and various income group countries. The growing banking sector, measured by the Deposit Money Bank (DMB) assets over GDP, indicates a wider connection between the real and the financial sectors. The bank concentration ratio, based on the three largest commercial banks assets, of Bangladesh has decreased substantially from 2005 to 2015 due to growing number of domestic banks. Observing the stock market capitalization for a country relates to the importance of the asset price channel of monetary policy transmission. In Table 2.1, we see that the size of Bangladesh’s stock market is too small to be important. But the ratio has increased almost three times in 2015 compared to 2005. The interest margin
in Bangladesh’s financial sector has remained almost unchanged, as indicated in the same table. If the number of financial market participants is high, and the capability of extending assets is competitive, then overall competition should be high and the concentration ratio should be low. Similarly, competition among intermediaries should result in a lower interest margin. In case of Bangladesh, we see that although the concentration ratio is decreasing, the interest rate margin increases slightly or remains unchanged.

Next I briefly discuss the monetary policy framework of Bangladesh Bank, which is simple and traditional. In monetary aggregates targeting, a required or safe limit of monetary expansion or broad money growth on the demand side is estimated based on the estimated growth of GDP, CPI and income velocity of money demand. After determining the monetary growth, the Bangladesh Bank clears the money market by changing M2 money \( (M2 = \text{money multiplier} \times \text{reserve money}) \). The relation between M2 and reserve money allows the latter to be used as an operating target (Taslim 2001, Ahmed & Islam 2006). The instruments to maintain the targeted broad money growth are Repo, reverse Repo, and T-bill auctions. Repo and reverse Repo rates are the policy rates that change from time to time. Other less frequently used tools are the Cash Reserve Ratio (CRR) and Statutory Liquidity Ratio (SLR).

A stable money demand function is an important pre-requisite for money targeting monetary policy rule. Also the degree of capital flow restriction is important. A policy paper by the IMF (2014) finds that over the period 1990-2012, countries using money as an intermediate target have limited control of the money supply, and the unstable money demand has potentially altered the co-movements between monetary aggregates and inflation or the real economy. This raises the following question: Is the Bangladesh Bank able to influence domestic price movements through its money targeting monetary policy? Empirical works by Ahmed & Islam (2006) and Narayan et al. (2009) suggest that Bangladesh’s money demand function is stable, in contrast to the IMF’s general findings
2.5 Methodology and data

This section describes the methodology and importance of the model’s variables, identification structure and the data issues. This chapter follows the block recursive SVAR approach of Dungey & Pagan (2000a) and Dungey & Pagan (2009a) to build a SVAR model of Bangladesh’s economy in order to analyze the monetary policy. In the next subsection, I discuss the SVAR methodology briefly and then the relevance of the variables.

2.5.1 The SVAR methodology

The VAR model assumes that Bangladesh’s economy can be represented by the following structural equation:

\[ A(L)Y_t + \alpha(L)X_t = \varepsilon_t, \]  
(2.1)

where, \( Y_t \) is an \( n \times 1 \) vector of endogenous variables and \( X_t \) is a \( k \times 1 \) vector of exogenous foreign variables. \( A(L) \) is an \( (n \times n) \) and \( \alpha(L) \) is a \( (k \times k) \) matrix polynomial lag operator. \( \varepsilon_t \) is an \( (n \times 1) \) vector of structural disturbances with zero mean. It is assumed that shocks are mutually uncorrelated. The reduced form of the structural model in Eq.(2.1) can be written with \( p \) lags as

\[ Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + \cdots + A_p Y_{t-p} + \alpha X_t + \epsilon_t, \]  
(2.2)

where, \( \alpha \) is a \( (n \times k) \) matrix and \( \epsilon_t \) is a \( (n \times 1) \) VAR residuals. In the first stage, the reduced form VAR(\( p \)) in Eq.(2.2) is estimated; next, we estimate the parameters in the structural equation in several ways. The reduced form error and the structural shocks are related by

for countries with similar monetary policy frameworks. Also the country’s capital account is still mostly closed.
\[ e_t = B\varepsilon_t, \quad (2.3) \]

where \( B \) is a non-singular \((n \times n)\) matrix that relates the VAR residuals \((e_t)\) with the structural shocks \((\varepsilon_t)\). Multiplying both sides of Eq.(2.2) by \( B^{-1} \) yields

\[ B^{-1}Y_t = D_1Y_{t-1} + D_2Y_{t-2} + \cdots + D_pY_{t-p} + B^{-1}\alpha X_t + \varepsilon_t. \quad (2.4) \]

Here, \( D_l = B^{-1}A_l \) for all \( l = 1, \ldots , p. \)

Adding \((I_n - B^{-1})Y_t\) to both sides of Eq.(2.4) yields

\[ Y_t = (I_n - B^{-1})Y_t + D_1Y_{t-1} + D_2Y_{t-2} + \cdots + D_pY_{t-p} + B^{-1}\alpha X_t + \varepsilon_t, \quad (2.5) \]

where, \( I \) is an \((n \times n)\) identity matrix. In a recursive VAR, the \( B \) matrix is lower triangular and its diagonal elements are one.

The parametric restriction approach is applied in the SVAR model. Following Dungey & Pagan (2000a), the restrictions placed upon the system are of two types: First, we assume the system as a whole is block recursive. As a small open economy, Bangladesh is affected by various foreign variables such as international prices, but Bangladesh cannot affect international prices. So, there are two blocks in the model: the first block contains foreign variables that are important for Bangladesh, and the second block contains domestic variables. The foreign block is placed ahead of the domestic block to ensure that the latter does not enter the equations of the first block. Second, the recursive structure is assumed inside each of the blocks. Finally, to ensure block exogeneity completely, following Zha (1999) and Dungey & Pagan (2000a), I restrict the domestic variables to affect the foreign variables dynamically (in lag). I do not impose any other restriction in the lagged matrix, unlike Dungey & Pagan (2000a) who also restrict some parameters in the lagged matrix.
Foreign block

Next, I discuss the relevance of the model variables separated into two blocks. The purpose of using a foreign block is to explain movements in domestic variables and not the vice versa. To be parsimonious with the available length of domestic time series, only two foreign variables are included in the model. So the foreign block is represented as $Y^f = (opw, pw)'$, where $opw$ is the international oil price and $pw$ is the CPI of Bangladesh’s major import partner countries. Oil price is a commonly used variable in the monetary policy literature and is considered a proxy for negative and inflationary supply shock (Kim & Roubini 2000), which also contains important business cycle information. Since Bangladesh is a small economy, the CPI of other countries from where Bangladesh imports is assumed to be important in determining domestic price movements. For example, the inflation rate in India, one of Bangladesh’s largest trade partners, has correlations with the inflation rate in Bangladesh (Bangladesh Bank 2014). In this study, the aggregate CPI for Bangladesh’s nine major import partners has been considered based on their weights in total imports over the entire period of study (2003-2014) and included as the foreign price variable. The calculations of weights for each of the import partner countries are given in the Appendix Table A4. The international oil price ($opw$) represents the supply side, and the foreign CPI ($pw$) contains information on prices that Bangladesh’s exporters receive from Bangladesh’s major trading partners. Hence, $pw$ is an important component of foreign demand.

Domestic block

Given, the short period of study, deciding which domestic variables to include is a balance between degrees of freedom and correct model specification. The commonly used variables such as nominal interest rate ($i$), M2 money ($m$), nominal effective exchange rate ($neer$), and output ($y$) are all included in the model. Deposit Money Bank (DMB) credit to the
private sector is considered as the bank lending variable \((cr)\) and the Consumer Price Index (CPI) as the aggregate price \((p)\) variable. Other important candidates, such as import price and export price indices, are not included in the model due to their unavailability in the required frequency for the entire period of study. The model also does not include any variable relating to the asset price channel, such as the share price index or house price index. The stock market index appear less important for Bangladesh, as can be seen from statistics in Table 2.1 and the economy-wide house price index is not available for the entire period in the required frequency. These facts, along with the shorter time span, lead the inclusion of six domestic variables mentioned above in the model.

The main objectives of the Bangladesh Bank as a monetary authority are to maintain the stability of price, exchange rate and the overall financial system of Bangladesh, - this provides the room for frequent intervention in the foreign exchange market. The argument put forward by the ERPT literature on emerging economies is that macroeconomic variables have little explanatory power for exchange rates in the medium to short run (Zorzi et al. 2007). For the baseline model I follow the structure provided by Zorzi et al. (2007) and Bhattacharya et al. (2011) to order similar variables in the domestic block.

The order of the variables in the domestic block is as follows: \(Y^d = (\text{neer}, i, m, cr, y, p)^T\). This ordering implies that the exchange rate captures the international effect first and translates to all other variables including monetary policy rate. I place \(\text{neer}\) ahead of \(i\), assuming that the monetary policy decision is contemporaneously affected by exchange rate but the policy rate cannot contemporaneously affect the exchange rate. The model also assumes that domestic price is affected by external as well as all domestic variables. Bhattacharya et al. (2011) use similar reasoning in ordering their SVECM model on the Indian economy. This ordering also implies that financial sector variables affect real sector variables contemporaneously, but not the other way around. The next subsection contains identification structure.
2.5. Methodology and data

2.5.2 Identification

The contemporaneous matrix of the SVAR model following the block recursive approach of Dungey & Pagan (2000a) is given in Table 2.2. Apart from the zero restrictions, the coefficients representing contemporaneous relations between variables are denote by the stars (*). This structure deviates slightly from the pure recursive SVAR in the sense that the monetary policy reaction function is not contemporaneously affected by the foreign price. It is assumed that the monetary authority does not know the current domestic price nor the foreign price while fixing the monetary policy rate. This information delay assumption is similar to that of Kim & Roubini (2000). I place the domestic money demand (m) after the nominal interest rate (i) assuming that domestic money demand is contemporaneously affected by domestic variables only such as domestic interest rate and nominal exchange rate. Variables in foreign block do not affect money demand contemporaneously. The money demand function estimated by Narayan et al. (2009) also includes these two variables, along with output and foreign interest rate. However, I assume that output affects money demand only dynamically, not contemporaneously.

Table 2.2: Identification: contemporaneous relation matrix

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>opw</th>
<th>pw</th>
<th>neer</th>
<th>i</th>
<th>m</th>
<th>cr</th>
<th>y</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreign block</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil price, opw</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Foreign price, pw</td>
<td>*</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Domestic block</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nominal effective exchange rate, neer</td>
<td>*</td>
<td>*</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Interest rate, i</td>
<td>*</td>
<td>0</td>
<td>*</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Money, m</td>
<td>0</td>
<td>0</td>
<td>*</td>
<td>*</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Credit, cr</td>
<td>*</td>
<td>0</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Output, y</td>
<td>*</td>
<td>0</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Price, p</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

The next equation of the SVAR model is the bank credit equation. From the supply perspective we see that the supply of bank loans is contemporaneously affected by oil price, nominal exchange rate, interest rate and money. The performance of the real sector such as price and output will affect bank credit in the next period. This is understandable from the
Chapter 2. Monetary policy transmission in Bangladesh: exploring the lending channel

real world scenario: during good economic condition, firms’ earnings usually increase and, therefore, the probability of default decreases, and better recovery of loans at the end of the current period affect a bank’s supply of loans in the next period. The reason I put credit ahead of output is because of the assumption of a quick pass through of credit to aggregate demand, following the models of Safaei & Cameron (2003) and Berkelmans (2005). Given the costs of borrowing, firms will be quick to utilize bank credit, which can affect output immediately. The output equation, next to credit, assumes that all variables, except the foreign and domestic prices, contemporaneously affect output. The price equation shows that domestic price is contemporaneously affected by all variables in the two blocks. The contemporaneous response of price to output fluctuation is in contrast to Kim & Roubini (2000) and Bhuiyan (2012) for Bangladesh’s economy. However it is similar to many other studies such as Bernanke & Blinder (1992), Dungey & Pagan (2000a) and Berkelmans (2005). In addition, the block exogeneity restriction, discussed in Subsection 2.5.1, is employed.

2.5.3 Data

Events such as the introduction of the Repo (in 2002) and reverse Repo (in 2003) and the adoption of the floating exchange rate in May, 2003 restrict the time span of this study from June 2003 to February 2014. Because the intention of the study is to analyze the monetary policy channels during the period of market based monetary policy instruments and the floating exchange regime. The monthly data have been collected from various sources, (see Appendix Table A10).

In this study, the 91 day T-bill rate is used, as the short term nominal interest rate and the industrial production index is used as the proxy for output as GDP data is not available in monthly frequency. This data limitation needs to be kept in mind throughout the study because industrial production represents only a small part of GDP (less than 28 percent
of GDP on average) in Bangladesh and no other good proxy for output is available. Hence the impulse response may deviate from what is theoretically expected from the output variable. I use Nominal Effective Exchange Rate (NEER) in this model as the exchange rate variable. Exchange rate is defined in a way that an increase in NEER implies an appreciation of domestic currency against the weighted basket of currency of Bangladesh’s trading partners.

The descriptive statistics of the variables is in Table A5, and stationarity properties and break points are in Table A7 in Appendix. All the data used in the estimation process are in logarithm and seasonally adjusted except the 91 day T-bill rate. Following the general trend of the VAR literature I estimate the model in levels, rather than first differenced variables. By differencing the variables may lose important information in the data, as argued by Sims (1980), Sims et al. (1990) and Sims (1992). However, all the series were de-trended before estimating the model, following the reasons mentioned by Dungey & Pagan (2000a). Thus this study focuses on cyclical components only. In order to separate the trend and the cyclical component from the data, I use the Butterworth filter, as it has some advantages e.g, it can retain important data properties.

### 2.6 Estimation results

Before performing the estimation, I check the information criteria for lag length selection (see Appendix Table A6). Both the SBC and the Hannan-Quinn criteria select lag 1; and AIC, FPE and LR criteria select lag 4 and 8. Because it is an eight variable SVAR model with 129 initial observations, in order to conserve the degrees of freedom and to allow for sufficient dynamics in the model, I choose lag 2 to estimate the model. Another important aspect to check is the stability of the underlying VAR system, before deriving the structural shocks of the SVAR model. I estimate a VAR with two exogenous variables and find that
all the Eigen values lie within the unit circle. This indicates that the VAR satisfies the stability condition and it is safe to go for the Impulse Response Function analysis of the structural model. The contemporaneous relation matrix described in the previous section shows that the SVAR model is over-identified. Thus, we need to check the over-identifying restriction test to test the validity of the identifying restrictions imposed in the model.

LR test of identifying restrictions: $\chi^2(5) = 3.398, \text{Prob} > \chi^2 = 0.639$

The likelihood ratio test shows that the identifying restrictions are valid. In the next subsection, I discuss applications of the estimated model i.e. impulse responses and variance decomposition to various innovations.

### 2.6.1 Impulse responses

Impulse Response Functions (IRFs) provide a summary of relationships between the endogenous variables given by the estimated coefficients of the VAR system. The impact of a shock to any variable on the rest of the variables can be found from the estimated model, but for brevity I report only IRF plots of monetary policy, credit and external shocks on rest of the economy here.

#### 2.6.1.1 Monetary policy shock

Fig.2.7 presents impulses responses to a one standard deviation shock to the interest rate along with the 68 percent (dotted line) and the 95 percent (marked line) confidence bands. In response to an increase in the interest rate, CPI decreases immediately which is significant at 68% level. After a slight recovery, the price falls again and reaches the minimum significantly by an amount less than 0.1 percent at around period four and then increases gradually and returns back to the baseline level within 10 months.
This delayed but significant response pattern of price is theoretically consistent and is similar to that of Bhuiyan (2012) but the timing of response is more rapid. The interest rate shock shows some persistence as it takes almost 10 months to return to the baseline. When there is an increase in interest rate, theoretically the exchange rate is expected to appreciate under the condition of a floating exchange regime and perfect capital mobility. Since the Bangladesh Bank implements a separate foreign exchange intervention policy and the capital account is largely closed, we cannot expect the response of exchange rate to be the same as predicted by theory. The NEER is almost unresponsive to an interest rate shock, implying that the uncovered interest parity (UIP) channel is not working. This is an indication that the exchange rate channel of monetary policy is weak in Bangladesh.

As noted, the demand for money decreases by 0.1 percent immediately after an increase in interest rate which is significant at 68% level. After reaching the minimum, money demand gradually returns to the baseline within nine months. Monetary policy affects aggregate output and credit through two channels (Catao & Pagan 2010). The first is
the intertemporal effect of monetary policy in which a shock to the central bank’s policy rate increases the spread between lending and deposit rates, resulting in a fall in credit. The second is the intratemporal effect in which domestic currency appreciation, due to a tightening monetary policy, improves the balance sheets of firms with high foreign currency denominated debt. Also, currency appreciation makes the relative price favorable to the non-tradable sectors. Hence, the intratemporal effect should boost the domestic credit. However, the latter effect depends on the size of the foreign currency denominated debt of the firms, and the size of the bank dependent non-tradable sector. In this study, we find the intertemporal effect dominates. The credit drops in response to an interest rate shock, although it returns to the base line quickly. Then, we see a slight increase in credit above the steady state – the intratemporal effect – which again gradually returns to the baseline within eight months. This is understandable given the presence of a separate foreign exchange intervention policy that suppresses the NEER, preventing it from rising freely as a result of monetary policy shock. Overall, the credit channel plays a nontrivial role in monetary policy transmission and contributes to the falling price level.

This gradual decline of the private credit in response to a rise in the interest rate is similar to that of many empirical studies. For example, Bernanke & Blinder (1992) for the US, and Garretsen & Swank (1998) for Netherlands find a lagged response of credit to an interest rate shock, while Safaei & Cameron (2003) for Canada and Berkelmans (2005) for Australia find immediate responses by credit. Although response of credit is mostly insignificant, only the maximum response is significant at 68% level. The industrial output shows a volatile response and initially moves in opposite direction (although insignificantly) than our theoretical expectations.\footnote{A possible explanation can be, the price elasticity of demand for industrial product is higher than the interest (cost) elasticity of industrial production in Bangladesh. The hypothesis is, however, subject to data availability and further tests.} This does not give a complete picture of how GDP reacts to an interest rate shock since we do not have monthly (or, even quarterly) data for
GDP. Before concluding this as a sharp contrast to New Keynesian macro prediction, we should keep in mind the data limitation that also was mentioned in Subsection 2.5.3. The impulse responses to a positive interest rate shock generate no price puzzle, liquidity puzzle or exchange rate puzzle, highlighting the correct identification of the model. In sum, the responses to a monetary policy shock appear quick which is, however, not unique, and, overall the system returns to the steady state within a year. For example, the adjustment time of output gap, inflation and real exchange rates to a monetary policy shock in the study by Catao & Pagan (2010) is less than 5 quarters or roughly a year for Chile, which is much faster than the evidence found for developed countries. Although the magnitudes of responses in the current study is different, the response patterns are consistent with several other countries’ experiences.

2.6.1.2 Credit shock

Figure 2.8: Credit shock IRFs with 68% (dotted line) and 95% (marked line) confidence bands.

Fig.2.8 presents the impulse responses to a credit shock and confidence bands similar to
Fig. 2.7. We find some interesting response patterns for exchange rate, price and the central bank. First, credit shock itself is transitory compared to a monetary policy shock, returning to the base level within two to three months. The transitory nature of credit shock is similar to Catao & Pagan (2010) for Brazil and Chile. In response to a sudden credit boom, the central bank responds by increasing the policy rate, which is understandable given its goal of maintaining stability. The initial interest rate response is significant at both 68% and 95% levels. Then, exchange rate starts to respond with a lag by appreciating to a small extent but the response is not significant. Monetary authority may not necessarily respond directly to credit movements; rather, endogenous changes in monetary policy may be due to the movements of other endogenous variables in the system (Berkelmans 2005). The credit shock elicits more demand for money, which is expected. This reflects the fact that firms may demand more cash for businesses as more loans are sanctioned on their behalf. The positive response of M2 found in this study is empirically consistent.

Finally, the increase in credit results in some inflationary pressure on the economy as the price level starts to rise, however, the magnitude is not high and only the maximum response is high at 68% level. Even though the central bank increases interest rate, higher credit availability generates greater money demand and a surge in price. The industrial output becomes more volatile and initially rises. Overall, the responses of price, interest rate, and output to a credit shock are similar to those found by Catao & Pagan (2010) for Brazil and Chile and Berkelmans (2005) for Australia. The short-lived responses of the variables are especially similar to the findings of Catao & Pagan (2010), who also find transitory impacts of the credit shock on other variables, although a monetary aggregate is not included in their model. Thus, in this study the responses of variables to a credit shock are theoretically consistent and have similarities to those for other emerging and developed countries.
2.6.1.3 External shock (Oil price shock)

An oil price hike is one of the major sources of macroeconomic fluctuations and can affect many economies simultaneously; hence economists regard this as a global shock (Blanchard & Gali 2010). Fig. 2.9 presents impulse responses to a rise in the international oil price. A sufficient rise in the oil price is stagflationary, and increases domestic inflation by raising production costs, which is detrimental to economic growth. In Fig. 2.9, we see that the domestic CPI rises immediately after an oil price shock, then continues to rise significantly and reaches a maximum by the fourth period. Price, then starts to drop; later there is a deflationary impact by 10th period and then the price gradually comes back to the baseline.

Figure 2.9: Oil price shock IRFs with 68% (dotted line) and 95% (marked line) confidence bands.

A rise in oil price increases the costs of imports, and, hence demand for foreign exchange is likely to increase. This should have a depreciating impact on the domestic currency. This theoretically expected pattern is visible in the impulse response of NEER. The nominal exchange rate does not respond instantaneously to a rise in oil price, rather it is a lagged response and it takes almost a year to return to the baseline.

Since the rise in oil price affects growth negatively, a central bank with multiple objectives rather than only price stability, is likely to be less harsh in its action. Although
there is a possibility of domestic price rise, we see that the nominal interest rate does not rise immediately; rather it decreases gradually for the first few months after the shock. This reaction by the nominal interest rate appears consistent with the Bangladesh Bank’s objectives of promoting economic growth. The interest rate starts to rise afterwards, in response to the price pressure and rises by 0.1 percentage points in approximately eight months. It returns to the original level by 15 months after the shock.

The demand for domestic money does not respond instantly. It rises slowly by a maximum of 0.1 percent by the fifth period, then gradually returns to the original level. Because of the rising costs of production, firms initially may demand more bank credit. The positive response of bank credit can be considered as demand induced. The initial accommodating behavior by the central bank after an oil price shock can also induce credit rise. Credit starts to fall six months after the shock and gradually returns to the baseline level. The maximum responses of CPI, interest rate and NEER to an oil price shock are all significant at both 68% and 95% levels. The maximum responses of money and credit are, however, significant only at 68% level. There is a striking difference between the responses to an oil price shock and responses to the two domestic aggregate demand shocks: the impact of the oil price shock on the economy is more persistent in general, than the impacts of the aggregate demand side shocks. This feature of the responses is consistent with the theory that the supply shocks are longer lasting than the demand shocks. This theoretical consistency supports the validity of the identification of the SVAR model in this study.

2.6.2 Forecast Error Variance Decomposition

Another application of the estimated SVAR model is the Forecast Error Variance Decomposition (FEVD), which shows the variance in the forecast error for each variable due to innovations to all variables in the system. In Table 2.3, the structural FEVDs of each of the
domestic variables for innovations in both foreign and domestic variables are reported for a month, a quarter, two quarters and a year. In Table 2.3, each column is for one domestic variable and throughout a column summation of the variations due to innovations in the model variables for a particular forecast horizon is hundred (except the rounding errors).

<table>
<thead>
<tr>
<th>Innovations</th>
<th>Proportion of forecast error variance</th>
<th>$i$</th>
<th>$m2$</th>
<th>$cr$</th>
<th>$y$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil price ($opw$)</td>
<td>4 5.9</td>
<td>3.2</td>
<td>0.21</td>
<td>4.5</td>
<td>0.95</td>
<td>26*</td>
</tr>
<tr>
<td>8 21*</td>
<td>7.2</td>
<td>2.9</td>
<td>10.4</td>
<td>1.1</td>
<td>26*</td>
<td></td>
</tr>
<tr>
<td>12 22*</td>
<td>14</td>
<td>3.9</td>
<td>13</td>
<td>1.3</td>
<td>26*</td>
<td></td>
</tr>
<tr>
<td>Foreign price ($pw$)</td>
<td>4 1.8</td>
<td>6.1</td>
<td>3.1</td>
<td>7.2</td>
<td>1.8</td>
<td>1.6</td>
</tr>
<tr>
<td>8 3.8</td>
<td>9</td>
<td>3.9</td>
<td>8.4</td>
<td>1.9</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>12 4.6</td>
<td>8.5</td>
<td>3.8</td>
<td>8.2</td>
<td>1.9</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Nominal</td>
<td>4 79*</td>
<td>1.2</td>
<td>12*</td>
<td>5.7</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>8 62*</td>
<td>4.2</td>
<td>11</td>
<td>5.3</td>
<td>1.3</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>12 61*</td>
<td>3.9</td>
<td>11</td>
<td>5.2</td>
<td>1.4</td>
<td>1.2</td>
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<td>1.4</td>
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<td>1.1</td>
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<td>0.0</td>
<td>0.0</td>
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</tr>
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<td>4 0.0</td>
<td>74*</td>
<td>5.4</td>
<td>1</td>
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<td>3.3</td>
<td></td>
</tr>
<tr>
<td>8 0.0</td>
<td>61*</td>
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<td>1.1</td>
<td>1.4</td>
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<tr>
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<td>56*</td>
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<td>1.1</td>
<td>1.4</td>
<td>4.4</td>
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<td>0.0</td>
<td>85*</td>
<td>36*</td>
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<td>0.41</td>
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<tr>
<td>4 1.9</td>
<td>6</td>
<td>73*</td>
<td>36*</td>
<td>16*</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>8 2</td>
<td>7.3</td>
<td>68*</td>
<td>33*</td>
<td>16*</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>12 2</td>
<td>7.1</td>
<td>68*</td>
<td>32*</td>
<td>16*</td>
<td>1.2</td>
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<tr>
<td>Domestic credit ($cr$)</td>
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<td>0.0</td>
<td>0.0</td>
<td>59*</td>
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<td>1.6</td>
<td>36*</td>
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<tr>
<td>12 0.4</td>
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<td>35*</td>
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<td>0.0</td>
<td>97*</td>
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<tr>
<td>4 10</td>
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<td>4.4</td>
<td>74*</td>
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<td></td>
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<tr>
<td>8 8.2</td>
<td>2.2</td>
<td>6.3</td>
<td>4.7</td>
<td>73*</td>
<td>1.1</td>
<td></td>
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<tr>
<td>12 8</td>
<td>2.4</td>
<td>6.3</td>
<td>4.6</td>
<td>73</td>
<td>1.2</td>
<td></td>
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<tr>
<td>CPI ($p$)</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>91*</td>
</tr>
<tr>
<td>4 1.4</td>
<td>5.5</td>
<td>0.2</td>
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<td>0.0</td>
<td>70*</td>
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<td>0.1</td>
<td>62*</td>
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<td>0.67</td>
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<td>0.1</td>
<td>62*</td>
<td></td>
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</tbody>
</table>

Note: * denotes significant, comparing with the standard errors for the respective point estimates. A point is considered significant if it is at least twice as big as the standard error.

The short term nominal interest rate does not appear to have significant explanatory
power for the variations in the other variables in a given forecast horizon, except for its own variation and for approximately five percent of variations in M2 and CPI. In the longer horizon, both oil price and foreign CPI substantially contribute to the variation in the interest rates movements. The nominal effective exchange rate has significant explanatory power for movements in M2 and for itself. It contributes around five percent of variation in credit, but has no sizable impact on price variation. This is similar to Chowdhury & Siddique (2006) but is in contrast to Akhtaruzzaman (2005) for Bangladesh who finds exchange rates have a significant explanatory power for CPI movements. The nominal interest rate has almost no explanatory power in NEER movements which is understandable from the current exchange rate management of the Bangladesh Bank, and CPI also has no explanatory power for any variables but itself. Oil price and foreign price appear important for the variation in the credit variable in the longer horizon and broad money (M2) is attributable to more than thirty per cent of variations in the credit throughout the time horizons reported. FEVDCs for the sub-sample 2003-2008 and sub-sample 2009-2013 are also reported in the Appendix Table A8 and Table A9. Analyzing the FEVDs, it is clear that foreign factors play important roles in the variation of domestic variables.

2.7 Robustness check

The stability of the VAR model, discussed in Section 2.6, indicates the reliability of the impulse responses to some extent. The SVAR can be quite sensitive to the model’s assumptions and sample length. Thus, common ways to check robustness for an estimated SVAR model are: 1) to estimate the model with alternative assumptions; and 2) the break point test where the series is divided into two parts and the model is estimated in each sub-sample. To confirm the validity of the base model, first I estimate a model with alternative assumptions; and second, I split the sample into two parts – 2003-2008 and 2009-2013 – in
order to estimate the base model in each of these sub-samples.

The first alternative model is where the interest rate is placed ahead of the exchange rate, thus allowing for NEER to be contemporaneously affected by the monetary policy. This implies that a rise in interest rate makes the investment in domestic currency more attractive, and hence the demand for domestic currency rises leading the currency to appreciate against the USD. Impulse responses to a monetary policy shock and a credit shock with this ordering can be found in the Appendix Fig.A10 and Fig.A11. With this ordering, the responses of all variables to the monetary policy shock is qualitatively similar to the baseline model, with the exception of the response of the exchange rate. Instead of appreciating, the exchange rate depreciates in small magnitude instantly – this is called the ‘exchange rate puzzle’ in empirical literature. However it quickly returns to the steady state level. This result from the alternative ordering validates the identification of the baseline model. The impulse responses to a credit shock in this alternative model, in Fig.A11, appear similar to the responses found in the baseline model.

Next we re-estimate the model using the two sub-samples. The first sub-sample (2003-2008) is the period before the global financial crisis and the second sub-sample (2009-2013) is the post-crisis period. Impulse responses to a positive interest rate shock in the two sub-samples can be found in the Appendix Fig... And impulse responses to a positive credit shock in the two sub-samples are presented in the Appendix Fig... In both figures, the black lines (circle marked) represent IRFs for the first sub-sample and blue lines (square marked) represent IRFs for the second sub-sample. In the first sub-sample, a rise in interest rate (tightening monetary policy) has broadly similar impacts on the domestic variables and there appears to be no empirical puzzles. Regarding the magnitude of the response, the initial exchange rate appreciation is now greater than the baseline model. CPI shows a delayed, but directionally the same, response as the base model and the downward effect
becomes significant during the fourth period. In the second sub-sample, monetary policy shock reduces price significantly from the second to the fourth period. Credit and money demand also decline significantly in response to an interest rate shock. NEER initially fluctuates around zero and then depreciates. However, in the second sub-sample, the overall NEER response is insignificant throughout the horizons.

Now I analyze credit shock in the two sub-samples. One interesting finding is that credit shock appears less persistent in the first sample – similar to the full sample model, but it is more persistent during the post-crisis period. Monetary policy reaction is contractionary – similar to the base model; however, the response is insignificant in the post crisis period. There are positive effects on industrial output which becomes significant with lag. The price variable responds positively to a sudden credit boom, similar to the base model. The response of NEER appears different in the two sub-samples. In the first sample, exchange rate depreciates and in the second sample, it appreciates. The response in the first sample has wider confidence intervals, while the maximum response is significant in the second sub-sample, similar to the base model. Overall, the conclusion of the model using the two sub-samples differs little from the base model.

2.8 Conclusion

In this chapter I have investigated Bangladesh’s monetary policy transmission channels with special emphasis on the credit channel during the managed float exchange rate period using monthly data. I have also analyzed the impact of a credit boom and external shocks within the SVAR framework. The impulse responses and the variance decomposition analysis show that the responses of macro aggregates to a monetary policy shock are similar to the empirical regularities found in emerging economies. The model finds that the exchange rate channel is not effective in transmitting monetary policy in order to affect the
price level. This is to be expected in the context of Bangladesh’s highly intervened foreign exchange market. However, monetary policy has a significant role in influencing the domestic price level, and bank credit plays a non-trivial role in the process. The credit shock, on the other hand, influences output and inflation; however, the responses are short-lived compared to the monetary policy shock. The central bank plays a stabilizing role in its responses to a credit shock by raising interest rates to reduce the impact of a credit shock. The study also finds that external factors are important drivers in the movements of the domestic macro aggregates. This study is a preliminary investigation based on a relatively short span of time. Therefore, further research based on a longer time frame can reveal more reliable evidence on the monetary transmission channels of Bangladesh. In sum, the current monetary aggregates targeting framework works effectively in influencing the domestic price level, and this chapter shows explicitly the channels through which monetary policy affects the aggregate price level in Bangladesh.

In contrary to the growing nature of financial sector of Bangladesh, financial sectors in advanced countries are complex and deeply interrelated with the real sectors. The frictions associated with these complexities of the financial sector deserve special attention in analysing the transmission mechanisms of shocks for these countries. Therefore, the critical role played by bank credit in the dynamics of real economy is analysed further in the next chapter in terms of financial frictions and shocks in a general equilibrium framework as this model is capable of working with complex frictions explicitly. The Dynamic Stochastic General Equilibrium (DSGE) framework adopted in the next chapter discusses financial sector’s role as an independent source of shocks as well as amplifier of shocks originating in the real sector in the context of advanced financial markets.
2. Appendix

2. A.1 Output

Table A4: Weights for CPI of major import partner countries of Bangladesh based on imports, 2003-2013.

<table>
<thead>
<tr>
<th>Countries</th>
<th>Weights</th>
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<tbody>
<tr>
<td>China</td>
<td>0.28</td>
</tr>
<tr>
<td>India</td>
<td>0.23</td>
</tr>
<tr>
<td>EU</td>
<td>0.12</td>
</tr>
<tr>
<td>Singapore</td>
<td>0.10</td>
</tr>
<tr>
<td>Japan</td>
<td>0.07</td>
</tr>
<tr>
<td>Malaysia</td>
<td>0.07</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>0.05</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.04</td>
</tr>
<tr>
<td>Indonesia</td>
<td>0.04</td>
</tr>
<tr>
<td>Total</td>
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Note: Author’s own calculations using data from sources in Table A10.

Table A5: Descriptive statistics of data (period: 2003 June - 2014 February)

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<th>opw</th>
<th>pw</th>
<th>neer</th>
<th>i</th>
<th>m in USD</th>
<th>cr in USD</th>
<th>y</th>
<th>p</th>
</tr>
</thead>
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<td>4.56</td>
<td>4.22</td>
<td>6.74</td>
<td>10.56</td>
<td>10.26</td>
<td>4.49</td>
<td>4.49</td>
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<td>Median</td>
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<td>4.55</td>
<td>4.21</td>
<td>7.40</td>
<td>10.56</td>
<td>10.27</td>
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<td>4.47</td>
<td>11.37</td>
<td>11.37</td>
<td>11.03</td>
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<td>4.89</td>
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<td>4.08</td>
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<td>0.45</td>
<td>0.47</td>
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<td>Kurtosis</td>
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<td>1.78</td>
<td>2.51</td>
<td>2.86</td>
<td>1.65</td>
<td>1.60</td>
<td>1.93</td>
<td>1.75</td>
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<tr>
<td>Jarque-Bera</td>
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<td>9.33</td>
<td>5.51</td>
<td>2.87</td>
<td>9.91</td>
<td>10.52</td>
<td>6.41</td>
<td>8.40</td>
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<td>Probability</td>
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<td>(0.01)</td>
<td>(0.06)</td>
<td>(0.24)</td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.04)</td>
<td>(0.02)</td>
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<td>Sum</td>
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<td>588.85</td>
<td>544.31</td>
<td>869.09</td>
<td>1362.40</td>
<td>1323.63</td>
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<td>578.70</td>
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Note: All variables are in logarithm except the 91 day T-bills rate.
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<th>AIC</th>
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<th>SBIC</th>
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Note: Log likelihood (LL), Likelihood ratio (LR), Final prediction error (FPE), Akaike’s information criterion (AIC), the Hannan and Quinn information criterion (HQIC), and Schwarz’s Bayesian information criterion (SBIC). Number of observations = 119.
Table A7: Unit root tests

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<th>Zivot Andrews</th>
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<td>-----------------</td>
<td>-------</td>
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<tr>
<td>$i$ (C)</td>
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<td>-4.58**</td>
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</tr>
<tr>
<td>$cr$ (C&amp;T)</td>
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<td>-13.94**</td>
<td>-2.74</td>
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<tr>
<td>$m$ (C&amp;T)</td>
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<td>-12.48**</td>
<td>-2.22</td>
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<td>$p$ (C&amp;T)</td>
<td>-2.94</td>
<td>-10.69**</td>
<td>-3.15*</td>
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<tr>
<td>$neer$ (C)</td>
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<td>-8.51**</td>
<td>-2.15</td>
</tr>
<tr>
<td>$y$ (C&amp;T)</td>
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<td>-13.23**</td>
<td>-10.4**</td>
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<tr>
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<tr>
<td>$pw$ (C)</td>
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</table>

Note: ** is 1% and * is 10% significance levels. C & T denotes constant and trend. Zivot Andrews test break points are in parenthesis, critical values: C: 1% 5.34, 5% 4.80, 10% 4.58 and C,T: 1% 5.57, 5% 5.08, 10% 4.82.
Table A8: FEVDC during 2003-2008 (in percent)

<table>
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<tr>
<th>Innovations</th>
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<td>0.99</td>
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<td>8</td>
<td>1.77</td>
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<tr>
<td>12</td>
<td>1.92</td>
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<tr>
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Note: The row and column descriptions are same as in Table 2.3.
Table A9: FEVDC during 2009-2013 (in percent)

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Note: The row and column descriptions are same as in Table 2.3.
Figure A10: IRFs to interest rate shock with 95% (broken lines) and 68% (dotted lines) confidence bands in alternative specification.

Figure A11: IRFs to credit shock with 95% (broken lines) and 68% (dotted lines) confidence bands in alternative specification.
Chapter 2. Monetary policy transmission in Bangladesh: exploring the lending channel

Figure A12: Interest rate shock in two sub-samples 2003-2008(s1) and 2009-2013(s2): broken lines are 95% and dotted lines are 68% confidence bands.

Figure A13: Credit shock in two sub-samples 2003-2008(s1) and 2009-2013(s2): broken lines are 95% and dotted lines are 68% confidence bands.
### 2.A.2 Data sources

Table A10: Data Sources

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<td>91day T-bills rate (<em>i</em>)</td>
<td>Bangladesh Bank</td>
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<td>CPI of Bangladesh (<em>p</em>)</td>
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<td>CPI of nine countries (<em>pw</em>)</td>
<td>IFS and CEIC database</td>
</tr>
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<td>Import (fob) values of nine countries</td>
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Chapter 3

The role of financial shocks in business cycles with a liability side financial friction

Abstract

The chapter investigates the role of investment specific technology shock within the particular type of financial friction of Gertler and Karadi (2011) and the impact of direct financial shock into this, such as a net worth shock, using US data. The chapter explicitly shows how the bank balance sheet effect of counter cyclical movement of capital price attenuates such investment shocks and the extent depends on the type of financial shocks included in the model. Because of the construction of capital quality shock in such financial friction model, we need to incorporate a direct net worth shock while analysing the role of financial shock. This highlights finance sector as a fundamental source of shocks apart from amplifier of shocks originating in elsewhere of the economy.

3.1 Introduction

One of the most central questions of modern macroeconomics is, what are the prime sources of business cycles? and economists have not reached any consensus yet on the answers. Neoclassical theories often consider neutral technology shock as the main driver of output movement (King & Rebelo 1999). The seminal work of (Smets & Wouters 2007) concludes
that two ‘supply shocks’ – neutral technology, and wage markup shocks – are the primary sources of variation in output. From the aftermath of the financial crisis of 2007-09, it became vividly apparent that any shocks originating in the financial sector can be disastrous to both financial and real sector variables through a balance sheet channel. The financial friction proposed by Gertler & Karadi (2011) is one among various attempts in the literature to design the real world financial frictions. Gertler & Karadi (2011) introduce an agency problem between bankers and depositors in a way that bankers may divert a fraction of the funds to the households bankers belong to. The introduction of such moral hazard problem is to bring an elegant technique that would put a limit on intermediaries’ ability to expand assets infinitely. This creates an endogenous constraint on the intermediaries’ leverage ratios which ties the overall credit supplies to the equity capital of the intermediaries. In order to analyse the financial crisis scenario, Gertler & Karadi (2011) incorporate a capital quality shock, which is a novel feature of their model.

In this chapter, I incorporate the financial friction proposed by Gertler & Karadi (2011) into the otherwise standard New Keynesian DSGE model in order to empirically analyse US business cycles and the roles of financial and investment specific technology (IST) or Marginal Efficiency of Investment (MEI) shocks. Hence the main research question is, what is the mechanism (hence, role) of investment specific technology or MEI shock in presence of a banker-depositor type financial friction and financial shocks, such as the net worth and capital quality shocks, when the model contains both output and labour price rigidities? In addition, the chapter seeks the relative importance of capital quality and bank net worth shocks, in terms of their ability to explain variations in output and interest spread. The latter part is closely related to the former because it shows which finance based shock is important to be included in the model to identify the true role of MEI and others shocks at business cycles. For this, identification strategy for disentangling the two financial shocks is crucial.
The research questions are interesting in two main dimensions. Since the chapter investigates the balance sheet impacts of financial frictions and shocks on the transmission mechanism of MEI shock, the first dimension relates to the treatment of financial shocks within Gertler & Karadi (2011)’s framework. In their model, capital quality shock enters through the physical capital accumulation process which originates in the non-financial sector (e.g. housing sector) and affects the asset side of bank balance sheets through the change in collateral value. The shock is categorised as financial because of the balance sheet identity between the assets and the liabilities. Here, banks play amplification roles for the shock that originates elsewhere in the economy. The amplification role of banks is well known in the literature and a number of literature suggests that the degree of amplification resulting from credit constraints is empirically limited outside the crisis period (Kocherlakota 2000, Cordoba & Ripoll 2004). The way the capital quality shock is constructed in Gertler & Karadi (2011)’s framework does not rule out the possibility of any physical destruction of capital machineries (including housing). Whether a ‘qualitative’ destruction or a ‘physical’ destruction of capital, the shock is directly related to the physical capital stock of the economy which can affect both bank dependent and less dependent agents strongly. Therefore, this shock is different from any exogenous changes in bank net worth arising directly within the financial sector. Examples of such events can be a sectoral tax on financial intermediation, an increase in the Capital Adequacy Ratio (CAR), an increase in the central bank’s requirements for minimum equity capital, a change in the classification of Tier 1 and Tier 2 capital, or any other events not explicitly included in the model but affect the share price (equity) of the banks. So, I assess and quantify the impacts of bank net worth shock within Gertler & Karadi (2011)’s financial friction along with capital quality shock. Because bank’s role as an independent source of fluctuations deserves separate treatment from the role as amplifier of shocks originating in elsewhere of the economy when estimating financial shocks. The net worth shock, in contrary to
capital quality shock, will compress the profit in the finance sector relative to the broader economy, especially compared to the sector distant from financial intermediation and debt (see Fornari & Stracca 2013 for example).

The second dimension relates to the role of nominal wage rigidities as the calibrated model of Gertler & Karadi (2011) does not incorporate any labour market imperfections. The work of Justiniano et al. (2010) shows the importance of MEI shock in the movements of output in a model without any financial sector. Sanjani (2014) estimated Gertler & Karadi (2011)’s model without labour market imperfections for the US data and found the largest role for capital quality shock while a negligible role for the MEI shock in output variations. Justiniano et al. (2010) argue that ignoring imperfections in the product and labour market is one reason that some early neoclassical studies do not find any significant role played by MEI shock in the business cycles. Due to nominal frictions in the goods and the labour markets, the efficiency condition becomes

\[ \mu \left( L - L^* \right) MRS \left( C, L + \cdot \right) = MPL \left( L \right), \]

where \( C \) is consumption and \( L \) is labour hours (Justiniano et al. 2010). The equation is different from the neoclassical benchmark because of the presence of an endogenous markup term, \( \mu \), which is a summation of the price and the wage markups. Thus, \( \mu \) creates a wedge in the efficiency condition between the marginal rate of substitution (MRS) between \( C \) and \( L \) and the marginal product of \( L \) (MPL). When \( \mu \) is ignored, as in earlier neoclassical models, \( C \) has to decrease if \( L \) increases, to maintain the efficiency condition. With \( \mu \), when a positive investment shock hits the economy, the equilibrium \( L \) can increase without any decrease in \( C \), as both the price and wage markups drop, generating a positive shift in labour demand (see Justiniano et al. 2010 for more). Thus, labour market imperfections and nominal wage rigidities have important role in analysing the impact of MEI shock in a financial friction model.

What is new in my study is that I analyse the transmission mechanism of investment (MEI) shock within a financial friction (Gertler & Karadi 2011) model in presence of
various shocks including financial, and show explicitly what role nominal wage rigidities play in it during the post war period in the US. Most importantly, I show the type of financial shock included in the model has important implications in identifying the role of investment specific shock. Second, I present a comparative analysis whether finance sector is merely an amplification device for collapse of assets value that originate in non-finance sector or, other (fundamental) shock in finance sector, is independently important. Finally, the chapter identifies shock that is the main driver of fluctuations in a bank’s net worth and spread. Thus, the chapter contributes to the literature by revisiting the factors contributing to the US business cycles.

Although a number of literature (Meh & Moran 2010, Gerali et al. 2010, Chen 2001, for example) has analysed the role of bank net worth shock, this chapter highlights the need to disentangle net worth shock from capital quality shock as a finance based shock within the Gertler & Karadi (2011)’s framework and quantify their relative impacts. Meh & Moran (2010) identify the financial shock as a direct exogenous change in bank net worth (such as tax on bank capital). Fornari & Stracca (2013) suggest that bank capital is a key tool of financial intermediaries’ debt production capacity, therefore, the shock may have wider consequences for financing conditions and the real economy. Other studies, apart from Sanjani (2014), have estimated the financial friction model of Gertler & Karadi (2011), however, not all of them estimate the net worth shock and if they do, they find no substantial impact of the net worth shock. For example, Villa & Yang (2011) analyse the empirical properties of the model without labour market heterogeneity with UK data, and find no substantial role for the net worth shock. Another study, Villa (2013), compares the performances of three models (Smets & Wouters 2007, Bernanke et al. 1999b and Gertler & Karadi 2011) while replicating the Euro area business cycles and finds that the Gertler & Karadi (2011)’s model outperforms the other two models in fitting the Euro area data. In order to make the three models comparable, Villa (2013) modifies
the Gertler & Karadi (2011) version and includes only the MEI shock, not the capital quality shock. However, Villa (2014) estimates both MEI and capital quality shocks for the Euro area and the US but not financial net worth shock. Another study containing similar financial frictions is by Görtz & Tsoukalas (2012), who construct a two sectors real economy following Huffman & Wynne (1999), which analyses the impacts of financial news shocks in sectoral and aggregate fluctuations. These gaps in the literature and better fit of Gertler & Karadi (2011)’s model to actual data found in previous estimation examples, along with the interesting facts discussed above, motivate further work with this financial friction.

The main results are that investment specific technology shock is weakened in the long run when the model includes financial friction and the type of finance base shock we include has implications in quantifying this impact. There appears to have benefits in disentangling the net worth and capital quality shock in terms of model’s ability to replicate moments and other business cycle properties, in which net worth shock provides better fit.

The rest of the chapter is organised as follows: The model description is in Section 3.2. The properties of the data, estimation and identification issues are available in Section 3.3. Next, Section 3.4 discusses the estimated parameters, and Section 3.5 analyses fit of the estimated model. Section 3.6 contains the application of the estimated model and Section 3.7 shows the robustness of the baseline estimates. Finally, Section 3.8 concludes the discussion.

3.2 Model

This section contains only brief features of the model and some explanatory notes on transmission mechanisms where needed. A detailed model description and mathematical derivation are skipped where they are well known and same as in the cited literature. All model equations and their log-linearized version are listed in the Appendix Section 3.A.
3.2 Households

There is a continuum of households of measure unity, same as in Gertler & Karadi (2011), except the fact that there is labour market friction in the current model. I include labour market heterogeneity and nominal wage rigidity, following the assumptions of Erceg et al. (2000), for the reasons discussed in introductory section. Households are assumed to be identical with respect to all characteristics except the labour services they supply to the production sector. Households choose consumption \( C_t \), set wages \( W_t(l) \) for the labour supply \( N_t(l) \) where \( l \) is a particular labour type. Households save a fraction of their income as bank deposits or invest in interest bearing assets \( B_t \), pay taxes \( T_t \) and receive transfers (net-transfer) from the ownerships of firms. The household utility function is standard and consists of consumption with habit \( b \) formation and labour supply. In Gertler & Karadi (2011), each period, \( (1 - f) \) fraction of household members are workers and the remaining \( f \) are bankers. The probability that a banker stays a banker in the next period is \( \theta \). So a total measure of \( (1 - \theta)f \) bankers randomly become workers. A representative household’s preferences are denoted by the following utility function:

\[
Max E_t \sum_{s=0}^{\infty} \beta^s \varrho_t \left[ \ln(C_{t+s} - bC_{t+s-1}) - \psi \frac{N_{t+s}(l)^{1+\eta}}{1+\eta} \right].
\] (3.1)

Households maximise utility subject to

\[
\frac{W_t(l)}{P_t}N_t(l) + R_{t+1}B_t - B_{t+1} + nettransfer_t - C_t - T_t = 0
\] (3.2)

and a downward sloping demand for their labour supply from the employment agency. Here, I include \( \varrho_t \) as the inter-temporal preference shock that affects the marginal utility of consumption and marginal dis-utility of labour. We assume this shock follows a mean zero AR(1) process, \( \log \varrho_t = \rho \log \varrho_{t-1} + \varepsilon_{\varrho,t} \) with \( \varepsilon_{\varrho,t} \sim i.i.d(0, \sigma^2_{\varrho}) \). \( P_t \) is the general price level. Deposits and government securities are perfect substitutes which earn gross real interest rate \( R_t \). Here, \( \psi \) is the coefficient of leisure and \( \eta \) is the inverse Frisch elasticity parameter. In each period, there is \( (1 - \phi_w) \) probability that a household can adjust its wage. If it cannot, then it indexes the wage to the lagged inflation at \( \varsigma_w \in (0,1) \). The
importance of nominal wage rigidities is not only for generating hump shaped impulse responses of the macro variables (Christiano et al. 2005), but also for its inherent sluggishness in the US economy. Strong micro level evidence on nominal wage rigidity in the US is provided by Barattieri et al. (2014), based on the Survey of Income and Program Participation data. Nominal wage is very sticky after correcting for measurement errors; and the probability of a wage change is positively correlated with the unemployment rate and consumer price inflation (see Barattieri et al. 2014 for details). The model assumes a time varying wage mark-up, $\epsilon_w t - 1 \mu_w t$, where $\epsilon_w > 1$ is the wage elasticity and $\mu_w t$ is the time varying AR(1) process with persistence $\rho_w$ and a serially uncorrelated shock, $\varepsilon_{w,t}$ such that $\varepsilon_{w,t} \sim iid(0, \sigma_w^2)$. Thus wage mark-up shock is the only representative of the labour market shocks.

### 3.2.2 Financial intermediaries

For detail construction of the financial friction, I refer interested readers to Gertler & Karadi (2011). Here, I present a brief overview of the friction and the net worth shock within such friction. Financial intermediaries consist of the entire banking sector. Bank receives deposits ($B_t$) from households and invests them in financial claims ($S_t$), issued by the intermediate goods sector. There is an agency problem that bankers may shift a fraction, $\lambda_d$, of total bank assets to their own households in the forms of higher bonuses and dividends. The financial claims, are equivalent to the value of physical capital ($K_t$) these firms require into goods production. Bank pays real interest payment $R_{t+1}$ on deposits at time $t + 1$ and earns return $R_{k,t+1}$ on assets. Overtime the bank balance sheet condition implies the growth in equity ($E_t$) as,

$$E_{j,t+1} = R_{t+1}E_{j,t} + (R_{k,t+1} - R_{t+1})Q_tS_{jt}. \quad (3.3)$$

Here, $efp_{t+1} = (R_{k,t+1} - R_{t+1})$, is the external finance premium. Different from Gertler & Karadi (2011), I assume that the intermediaries face a time varying, instead of a constant,
stochastic survival probability \((\theta_t)\) from one period to the next. The assumption suits the empirically observed exogenous events in the finance sector, listed in Section 4.1 for examples, which can affect bank net worth directly. This provides a simple way to bring direct exogenous source of variation to the bank equity capital without much modification to the endogenous balance sheet constraint of Gertler & Karadi (2011). In the model of Nishiyama et al. (2012), the Lehman Brothers collapse is considered as an aggregate net worth shock that affects bank sector’s balance sheets directly. They design both the corporate and financial sectors’ net worth shocks by assuming different time varying survival rates for the entrepreneurs to assess and quantify the role of Lehman shock as a banking sector net worth shock. Thus, the model in this chapter adopts this by assuming a time varying stochastic \(\theta_t\) which follows an \(AR(1)\) process to account for direct exogenous variation in bank net worth. In this financial friction, a negative net worth shock is an increase in the probability that bankers exit. By forcing bankers to exit sooner, when they make profit on average, this shock will reduce the bank share value. When a bank has low franchise value, it requires the bank to reduce leverage in order to satisfy the incentive constraint: \textit{terminal value of bank} \(\geq\) \textit{fraction of divertable assets.} In Gertler & Karadi (2011)’s original set up, the dynamics of \(E_t\) and the terminal wealth, \(V_t\), depend on the endogenously determined return from lending \((R_{k,t})\). But now the model allows variations in net worth exogenously. The banker’s problem is to maximise the expected terminal wealth

\[
V_{j,t} = \max E_i \sum_{i=0}^{\infty} (1 - \theta_{t+1}) \theta_i^{\beta^{i+1}} A_{t,t+1+i} (E_{j,t+1+i}) ,
\]

(3.4)

where, \(\beta^tA_{t,t+i}\) is the stochastic discount factor. As long as \(\beta^{i+1}A_{t,t+1+i}(R_{k,t+1+i} - R_{t+1+i})\) is positive, the intermediary will want to expand its assets indefinitely by borrowing from the households. In order to limit this, the model introduces the moral hazard (or costly enforcement problem) problem. The maximum terminal wealth Eq.(3.4) along with Eq.(3.3)
show that in response to any negative shock that directly affect $E_t$, the premium that a bank can charge must decrease given the asset value. Intuitively, for a given collateral value, in this situation the bank cannot charge a higher premium on its loan. This should raise the demand for loan and asset price; on the other hand, the effect of endogenous balance sheet constraint works in the opposite direction. This later effect surpasses the former effect soon and bank must deleverage as a consequence. When bank starts to deleverage, the premium rises, demand for new assets declines and eventually, $Q_t$ declines.

Summarising across all intermediaries total banking assets can be written as, $Q_tS_t = \phi_tE_t$, where $\phi_t$ is the banking sector leverage. If government intermediates a fraction, $\gamma_t$, of total assets in the market during a crisis, then government assets can be written as,

$$Q_tS_t = \phi_tE_t + \gamma_tQ_tS_t = \phi_{ct}E_t,$$

where, $\phi_{ct} = \frac{1}{1-\gamma_t}\phi_t$.

### 3.2.3 Production sector and the retailers

There is no friction in the process of non-financial firms obtaining funds from banks. The intermediate goods sector issues financial claims, $S_t$, to finance capital accumulation and the return $R_{k,t}$ is determined endogenously within this sector. The arbitrage condition implies that $Q_tS_t = Q_tK_{t+1}$.

Following Gertler & Karadi (2011), the production function is

$$Y_{m,t} = A_t(U_t\xi_tK_t)^{\alpha}N_t^{1-\alpha},$$

where, $A_t$ is the total factor productivity or neutral technology and $\xi_t$ is the quality of capital. Gertler & Karadi (2011) describe $\xi_t$ as providing a source of exogenous variations

Bank loan remains an important source of finance for the non-financial firms. The lengthy continuation of the US quantitative easing from 2008 till 2014 -- aimed at affecting the credit conditions for the households and businesses -- is an indication of this fact. The retained earnings or cash flows in non-financial firms are often used as precautionary balances to meet unexpected business expenses, instead of investing in new investment projects. Also, firms with imperfect access to the formal credit institutions usually rely on cash inflows for new investments; see Gertler & Karadi (2011), Acharya et al. (2010), Sufi (2009) and Yun (2009). An alternative specification can be $Q_tS_t = \Theta Q_tK_{t+1}$, implying that firms borrow only a fraction, $\Theta$, of the total capital cost from the banks. This parameter ($\Theta$) will then affect the return on assets, $R_{k,t}$, which is endogenously determined.
in the quality of capital; this corresponds to an economic depreciation or an obsolescence of capital. It is assumed that both \( A_t \) and \( \xi_t \) follow AR(1) processes with persistence coefficients, \( \rho_a \) and \( \rho_\xi \) and serially uncorrelated shocks such that they are \( iid(0,\sigma_a^2) \), and \( iid(0,\sigma_\xi^2) \) respectively. The nominal wage rate to hire \( N_t \) is \( W_t^P \). Along with \( R_{k,t} \), the capital utilisation rate \( (U_t) \) is also determined here. I keep the capital depreciation rate \( (\delta_t) \) variable with utilisation \( (U_t) \), as in Sanjani (2014) in the following form:

\[
\delta(U_t) = \delta_{ss} + \frac{b_1}{1+\zeta} U_t^{1+\zeta};
\]

where \( \delta_{ss} \) is the steady state fixed depreciation rate and \( \zeta \) is the elasticity of utilisation cost. The intermediate sector is a price taker in its output market. If output price is \( P_{m,t} \) then firm’s optimising behaviour shows that the return to the capital is affected by the exogenous variation in quality of capital:

\[
R_{k,t+1} = \frac{P_{m,t+1} \alpha \frac{Y_{m,t+1}}{K_{t+1}} + (Q_{t+1} - \delta(U_{t+1})) \xi_{t+1}}{Q_t}. \tag{3.8}
\]

A separate retail sector is introduced to bring the nominal price rigidities in the output market following Christiano et al. (2005a). The description of this sector is same as in the standard DSGE literature. Final output price is set on a staggered basis (similar to Calvo 1983). Thus, \( P_{m,t} \) is similar to the marginal cost of production in the retail sector. There is \((1 - \phi_p)\) probability that a retailer can adjust its price in a period. If it cannot, then it indexes price to the lagged inflation \((\Pi_t)\) at \( \zeta_p \in (0,1) \). Final output is a CES aggregate of all retailers output and the price elasticity of demand is \( \epsilon_p > 1 \). The optimal pricing condition of retailers in terms of re-set price inflation \( (\Pi_t^\#) \) is in Appendix. Similar to wage markup, the gross price markup, \( M_{p,t} \), is defined as \( M_{p,t} = \frac{\epsilon_p}{\epsilon_p-1} \mu_p^t \) where, \( \mu_p^t \) is the time-varying component that follows an AR(1) process with persistence coefficient, \( \rho_p \), and a serially uncorrelated shock, \( \epsilon_{p,t} \) such that \( \epsilon_{p,t} \sim iid(0,\sigma_p^2) \).
Chapter 3. The role of financial shocks in business cycles with a liability side financial friction

3.2.4 Capital goods producers

The capital producing firms buy used capital from the intermediate sector and repair the depreciated capital. Competitive capital producing firms also produce new capital and sell the new and refurbished capital to the intermediate firms. Capital price \( Q_t \) is determined by the optimising behaviour of the capital producing firms.

\[
K_{t+1} = Z_t \left( 1 - \frac{\tau}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \right) I_t + \xi_t (1 - \beta (U_t)) K_t. \tag{3.9}
\]

In Eq. (3.9), \( Z_t \), based on the arguments of Justiniano et al. (2010), is the source of exogenous variations in the efficiency with which investment goods are transformed into installed physical capital. The variation in \( Z_t \) arises from either technological factors specific to the production of investment goods or disturbances to the process by which these investment goods are transformed into installed capital (see Greenwood et al. 1996). In this model, \( Z_t \) is the marginal efficiency of investment (MEI) shock that follow AR(1) processes with persistent coefficients \( \rho_Z \) and serially uncorrelated shocks \( \varepsilon_{zt} \) such that \( i.i.d(0, \sigma^2_z) \). Here, \( \tau \) is the inverse elasticity of net investment parameter in quadratic capital adjustment cost.

Capital producers maximise the following discounted profit:

\[
\text{Max}_{<I_t>} \left\{ E_t \sum_{i=t}^{\infty} \beta_i \left[ \frac{\lambda_{t+i}}{\lambda_t} \right] \left\{ Q_i Z_i \left( 1 - \frac{\tau}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \right) I_t - I_i - (\bar{Q}_i - Q_i) K_i \right\} \right\}. \tag{3.10}
\]

The optimal condition of capital producer (Eq. (A54) or its linearised version Eq. (A78)) in Appendix, shows that any negative shock to \( Z_t \) will raise the asset price. The profit maximising behaviour of the capital producers implies that any negative shock to the process of transforming investment goods into installed capital will require the producers to charge higher price. Thus, \( Q_t \) is expected to be counter-cyclical to the MEI shock. An increase in \( Q_t \) affects the intermediaries’ balance sheets through a positive change in the collateral valuation, which strengthens the balance sheet conditions and may increase the banks’ appetites for more financial assets. On the other hand, the linearised capital accumula-
3.2. Model

Equation (Eq. (A79)) shows that a negative shock to $Z_t$ affects the future capital accumulation process negatively. Thus, the shock has negative impacts on the availability of installed capital in the subsequent periods. Therefore, the two opposing effects make the aggregate impacts of a MEI shock weak while affecting the aggregate output in the presence of this type of financial friction. In contrast, $Q_t$ is expected to be pro-cyclical to the capital quality shock. A negative capital quality shock (or expectation of one) reduces $Q_t$ by reducing the effective quantity of capital ($\xi_t K_t$). This affects the valuation of collaterals negatively and the net worth position of intermediaries’ deteriorates. Since, the demand for assets is constrained by net worth, bank’s demand for new assets decreases during a financial crisis. The high leverage ratio in the financial sector can add to the already worsening credit condition and banks are then forced to de-leverage and the required return on loan increases. The rising spread decreases investment expenditures.

3.2.5 Government and the Monetary authority

Government finances its expenditure, $G_t$, by lump-sum tax, $T_t$. Thus, the government budget constraint is $G_t = T_t$. Government spending is subject to a stochastic shock. We can write $G_t = \omega_g^g Y_t$ where,

$$
\log \omega_g^g = (1 - \rho_g) \log \omega_g^g + \rho_g \log \omega_{g,t-1}^g + \varepsilon_{g,t},
$$

and $\omega^g$ is the steady state level of government spending to GDP ratio. The central bank is responsible for monetary policy and the policy is described by the Taylor rule as,

$$
i_t = (1 - \rho_i) i + \rho_i i_{t-1} + (1 - \rho_i) (\phi_\pi (\pi_t - \pi) + \phi_y (\ln Y_t - \ln Y_{t-1})) + \varepsilon_{i,t}
$$

where, $i_t$ is the net nominal interest rate and $\rho_i$ is the interest smoothing parameter. The monetary policy shock is $\varepsilon_{i,t} \sim i.i.d N(0, 1)$. In absence of a severe financial crisis, this interest rate rule is sufficient to influence market interest rates. But during a financial crisis, the government may involve itself in direct intermediation. The Gertler & Karadi (2011) model defines the feedback rule for such unconventional monetary policy as follows:
\[ \gamma_t = \gamma + \kappa E_t \left[ (\log R_{kt+1} - \log R_t) - (\log R_k - \log R) \right], \]

where, \( \gamma \) is the steady state fraction of total intermediated assets and \( \kappa \) is the positive feedback parameter.

### 3.2.6 Aggregation

Aggregating across all retailer’s output and price,

\[ Y_t = Y_{m,t} \ast \nu^p_t. \]  \hspace{1cm} (3.13)

where, \( \nu^p_t \) is the price dispersion term. Finally aggregate resource constraint can be written as,

\[ Y_t = C_t + I_t + G_t + \tau \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 I_t. \]  \hspace{1cm} (3.14)

Thus, Section 3.2 completes the brief model description in this chapter.

### 3.3 Data and estimation

While estimating the model, I observe the US data for seven variables: output, consumption, investment, inflation, nominal interest rate, hours worked and spread for the period 1962:Q2 - 2014:Q4. The baseline estimations are done for the period 1962:Q2 - 2007:Q1 and a robustness check is done for 1962:Q2 - 2014:Q4. Description of these series and sources can be found in Appendix Section 3.A.4. In my estimation, durable consumption expenditure is separated from the total consumption expenditure and is included in the investment expenditure. This is due to the reasons argued by Justiniano et al. (2010) that including the durable consumption expenditures into investment generates more reliable results on the sources of fluctuations than their inclusion in consumption expenditures (e.g Smets & Wouters 2007). Unlike Sanjani (2014), I includes financial data such as interest spread in the estimation. Observing financial variables in estimation has implications for the estimated impacts of the financial shocks.

In the model there are nine structural shocks and all of them, except the monetary policy shock, follow AR(1) processes. As labour market data are inherently noisy and poorly measured (see Justiniano et al. 2013 for an example), I include measurement error.
with hours worked. The measurement error appears in the observation equation only, hence, I do not define any separate process for it. All series are in logarithm. Following literature such as Born & Pfeifer (2014), Jiang (2016), these series are de-trended using the one-sided HP-filter before taking them into estimation. The filtering ensures that all series are mean zero. By such transformation, we directly observe the model variables, hence specifying the observation equations will be redundant.

Considering $M$ as the basic model with six structural shocks, such as neutral technology, monetary policy, preference, government expenditure and wage and price markup shocks, I estimate three main versions of $M$ for the period 1962-2007. First, I estimate $M_{\theta z}$ where $M$ is extended to allow for net worth and MEI shocks, indicated by the subscript. Second, I estimate $M_{\xi z}$ where $M$ is extended for capital quality and MEI shocks. Finally, I estimate $M_{\theta \xi z}$ with all shocks. These estimates can be compared to know which financial shock is important to be included in the model and how they affect MEI shock. In addition, I estimate several other versions of $M$ such as, $M_{\theta}$, $M_{\xi}$, $M_{\theta \xi}$ and $M_{z}$ as experiments and the results are reported in the Appendix Table A8 for interested readers.

The chapter follows the Bayesian estimation technique described by An & Schorfheide (2007) and Fernández-Villaverde (2009) to estimate the non-calibrated parameters. This technique is described as a bridge between calibration and maximum likelihood. In brief, the process begins with providing prior assumptions about the distribution of the parameters. Given the model, the likelihood function is calculated using the Kalman filter from the observed data. The prior information on parameters act as weights on the likelihood function. Next, the posterior kernel is obtained by combining the likelihood function with the priors. By maximizing the posterior kernel, which is a nonlinear and complicated function, with respect to the parameters, we obtain the approximation of the posterior modes. Using these modes, posterior mean for each of the parameters is calculated. A sampling based technique, the Metropolis-Hastings (MH) algorithm (also called Monte Carlo Markov
Chain (MCMC)), is used to get the posterior distributions. Assuming asymptotic normality for each of the parameter spaces, the MH algorithm simulate the posterior kernel. The posterior modes are used as the starting values in the simulation process. The sampling process generates draws from the posterior density which is unknown at the outset, and updates the parameters after each draw. After sufficient draws in each of the parallel MH chains, the posterior density function and the mean and variance of the distribution are obtained.

3.3.1 Calibration and priors

While a range of parameters is estimated, several parameters of the model are fixed. The decision as to which parameters to keep fixed is governed by the model and identification test. Since the model include no trend technology, I estimate parameters that govern cycles, not the parameters that govern long-run path.

The list of calibrated parameters and steady state values are given in Table 3.1. The discount factor ($\beta$) is 0.99 which implies a quarterly real interest rate of one percent. Capital income share ($\alpha$) is 0.33 and the relative weight of labour ($\psi$) is 3.409. Elasticity of substitution in the goods market ($\epsilon_p$) and in the labour market ($\epsilon_w$) is assumed 4.167 which implies a markup of 1.32 approximately in each sector. These parameters are almost same as in Gertler & Karadi (2011).

<table>
<thead>
<tr>
<th>Description</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount factor</td>
<td>$\beta$</td>
<td>0.99</td>
</tr>
<tr>
<td>Capital income share</td>
<td>$\alpha$</td>
<td>0.33</td>
</tr>
<tr>
<td>Relative utility weight of labor</td>
<td>$\psi$</td>
<td>3.409</td>
</tr>
<tr>
<td>Elasticity of substitution in goods market</td>
<td>$\epsilon_p$</td>
<td>4.167</td>
</tr>
<tr>
<td>Elasticity of substitution in labor supply</td>
<td>$\epsilon_w$</td>
<td>4.167</td>
</tr>
<tr>
<td>Proportion of funds given to the new bankers</td>
<td>$\Omega$</td>
<td>0.002</td>
</tr>
<tr>
<td>Bankers average survival rate</td>
<td>$\theta_{ss}$</td>
<td>0.972</td>
</tr>
<tr>
<td>Fund divert rate</td>
<td>$\lambda^d$</td>
<td>0.381</td>
</tr>
<tr>
<td>Steady state fixed depreciation rate</td>
<td>$\delta_{ss}$</td>
<td>0.02</td>
</tr>
<tr>
<td>Government spending-output ratio</td>
<td>$\omega_{gss}$</td>
<td>0.2</td>
</tr>
<tr>
<td>Credit policy feedback parameter</td>
<td>$\kappa$</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3.1: Calibrated parameters
3.3. Data and estimation

Financial sector parameters, such as time varying survival rate of bankers in the next period ($\theta_{ss}$) the fraction of funds given to the new entrant bankers by households ($\Omega$) and the fraction of funds that bankers may divert ($\lambda^d$) are set to achieve the target steady state values for spread, leverage and average horizon of bankers same as in Gertler & Karadi (2011). The steady state fixed depreciation rate is 0.02 and the steady state government spending over GDP ratio ($\omega_{gss}$), is 0.2. The feedback parameter for credit policy or unconventional monetary policy ($\kappa$) is set to 0 in the base line model. An experiment of a moderate level of unconventional monetary policy (with $\kappa = 10$) for period 1962-2014 has been done. Result is skipped but available upon request. The remaining parameters are estimated.

The prior distributions of the estimated parameters are described in Table 3.2. I define most of them along the same line as has been done in the other works on the US economy. The persistence coefficients of the AR(1) processes in the model follow beta distributions and the mean and standard deviations (S.D) are 0.5 and 0.2 respectively. The standard deviations of shocks follow inverse gamma distributions with mean 0.1 and a standard deviation of 2, except for the net worth shock. Following the work of Nishiyama et al. (2012) that also estimate the same shock, I assume a slightly strict prior for net worth shock with mean and standard deviation 0.5 and 1, respectively. I treat the measurement error the same as the other standard errors in the model for reasons explained earlier, containing the same prior information. The remainder are the structural parameters.

The consumption habit ($b$) parameter has a beta distribution with mean 0.7 and S.D. 0.1. The inverse labour elasticity parameter ($\eta$) follows normal distribution with mean 0.33 and a S.D. 0.1, whereas the elasticity parameter for capital utilization ($\zeta$) follows a gamma distribution with mean 7.2 and a S.D. 0.5. The mean and S.D are 1.73 and 0.1 respectively for the investment adjustment cost parameter ($\tau$) which follows gamma distribution. In Taylor rule, the coefficient of the output growth and the coefficient of inflation follow a
normal distribution. The output growth ($\phi_y$) and inflation coefficient ($\phi_\pi$) are assumed to have mean 0.125 with a S.D. 0.1 and mean 1.7 with S.D. 0.3 respectively. This completes the description of prior about the parameters for their Bayesian estimation.
### Table 3.2: Prior distributions and Posteriors

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Distribution</th>
<th>Prior mean (S.D)</th>
<th>Posterior mean and 90% highest posterior density interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Taylor rule: interest smoothing ($\rho_i$)</td>
<td>B</td>
<td>0.6 (0.1)</td>
<td>0.53 [0.48, 0.59]</td>
</tr>
<tr>
<td>Technology ($\rho_a$)</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>0.70 [0.64, 0.76]</td>
</tr>
<tr>
<td>MEI ($\rho_z$)</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>0.16 [0.05, 0.28]</td>
</tr>
<tr>
<td>Net-worth ($\rho_g$)</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>0.95 [0.90, 0.99]</td>
</tr>
<tr>
<td>Capital quality ($\rho_z$)</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>-</td>
</tr>
<tr>
<td>Preference ($\rho_p$)</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>0.41 [0.26, 0.55]</td>
</tr>
<tr>
<td>Govt. expenditure ($\rho_g$)</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>0.65 [0.54, 0.77]</td>
</tr>
<tr>
<td>Wage mark-up ($\rho_w$)</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>0.80 [0.67, 0.93]</td>
</tr>
<tr>
<td>Price mark-up ($\rho_p$)</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>0.15 [0.03, 0.27]</td>
</tr>
<tr>
<td>S.D MP ($\sigma_z$)</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>0.24 [0.21, 0.26]</td>
</tr>
<tr>
<td>S.D technology ($\sigma_a$)</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>0.47 [0.43, 0.52]</td>
</tr>
<tr>
<td>S.D MEI ($\sigma_z$)</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>2.53 [2.18, 2.88]</td>
</tr>
<tr>
<td>S.D net worth ($\sigma_g$)</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>0.12 [0.10, 0.14]</td>
</tr>
<tr>
<td>S.D capital quality ($\sigma_{\xi}$)</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>-</td>
</tr>
<tr>
<td>S.D preference ($\sigma_p$)</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>1.27 [0.91, 1.61]</td>
</tr>
<tr>
<td>S.D Govt. expenditure ($\sigma_g$)</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>1.70 [1.55, 1.85]</td>
</tr>
<tr>
<td>S.D wage markup ($\sigma_w$)</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>1.26 [0.63, 1.89]</td>
</tr>
<tr>
<td>S.D price markup ($\sigma_p$)</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>0.57 [0.45, 0.70]</td>
</tr>
<tr>
<td>S.D N_ME ($\sigma_{NME}$)</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>0.08 [0.02, 0.14]</td>
</tr>
<tr>
<td>Habit ($b$)</td>
<td>B</td>
<td>0.7 (0.1)</td>
<td>0.67 [0.58, 0.77]</td>
</tr>
<tr>
<td>Inverse of Frisch elasticity ($\eta$)</td>
<td>G</td>
<td>0.33 (0.15)</td>
<td>0.42 [0.16, 0.66]</td>
</tr>
<tr>
<td>Elasticity K utilization cost ($\zeta$)</td>
<td>G</td>
<td>7.2 (0.5)</td>
<td>7.06 [6.24, 7.88]</td>
</tr>
<tr>
<td>Investment adj. cost ($\tau$)</td>
<td>G</td>
<td>1.73 (0.1)</td>
<td>1.69 [1.53, 1.84]</td>
</tr>
<tr>
<td>Calvo price ($\phi_p$)</td>
<td>B</td>
<td>0.5 (0.1)</td>
<td>0.71 [0.67, 0.75]</td>
</tr>
<tr>
<td>Calvo wage ($\phi_w$)</td>
<td>B</td>
<td>0.5 (0.1)</td>
<td>0.57 [0.42, 0.72]</td>
</tr>
<tr>
<td>Price indexation ($\zeta_p$)</td>
<td>B</td>
<td>0.5 (0.1)</td>
<td>0.31 [0.19, 0.42]</td>
</tr>
<tr>
<td>Wage indexation ($\zeta_w$)</td>
<td>B</td>
<td>0.5 (0.1)</td>
<td>0.49 [0.33, 0.66]</td>
</tr>
</tbody>
</table>
Table 3.2: Prior distributions and Posteriors

<table>
<thead>
<tr>
<th></th>
<th>distribution</th>
<th>Prior (μ, SD)</th>
<th>Posterior Mean (μ, 5%, 95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taylor rule: output growth (φ_y)</td>
<td>N</td>
<td>0.125 (0.1)</td>
<td>0.29 [0.20, 0.37] 0.32 [0.20, 0.45] 0.29 [0.20, 0.38]</td>
</tr>
<tr>
<td>Taylor rule: inflation (φ_π)</td>
<td>N</td>
<td>1.70 (0.3)</td>
<td>1.72 [1.54, 1.89] 1.83 [1.61, 2.05] 1.71 [1.54, 1.87]</td>
</tr>
</tbody>
</table>

Note: B denotes Beta, IG denotes Inverse Gamma, N denotes Normal, and G denotes Gamma distributions. S.D in parenthesis in column (3) denotes prior standard deviation. N_M E is the measurement error. Posterior mean estimates in column (4) to (6) are with respective 5 and 95 percentiles in square brackets.
3.3. Data and estimation

3.3.2 Identification and estimation

Before discussing the formal identification test results in statistical sense, I present an economic interpretation of the identification of the net worth and capital quality shocks based on impulse responses, as the rest of the shocks in the model are conventional. For this, first, I refer back to the discussion in Section 3.1 that capital quality shock, by design, can be either a valuation shock or a direct loss of capital machineries. Thus, in response to a negative (positive) capital quality shock, we expect an instantaneous decline (increase) of the physical capital stock \( K_t \), similar to the responses to MEI shock. The MEI shock is a shock to the production process of capital goods from investment, and therefore, has an instantaneous impact on \( K_t \). In addition, as Eq.(A78) shows, in response to a negative MEI shock we expect \( Q_t \) to rise. In contrast, there is no reason to believe that \( K_t \) will decline (increase) instantaneously when there is a negative (positive) shock to bank net worth. Because bank net worth shock affects capital accumulation process only gradually overtime through bank’s lending activities of financing capital expenditures in production. The decreased capitalization in banking sector reduces this sector’s capacity to arrange funds for the entrepreneurs (see Meh & Moran 2010 for example). Thus, we expect only a gradual (hump shape) decline, not instantaneous, from \( K_t \) in response to a bank net worth shock.

Both the necessary and sufficient conditions of parameter identification are met in the models. The top panel of Fig.3.1 shows the identification strength of each of the parameters at prior mean of the model containing both capital quality and net worth shocks. Along the x-axis, the parameters are ranked in increasing order of their identification strength. The lower panel of the same figure contains the sensitivity plot, which shows that all the parameters have non-negligible effects on the moments. Both the necessary and the sufficient conditions for identification as discussed by Iskrev (2010), imply that all the parameters are identified in the model and in the moments for the entire prior space. The identification
test was done using the identification routine available in Dynare which strengthens our theoretical expectations about identification. The details of the identification toolbox and the test criteria are described by Ratto & Iskrev (2011) and Iskrev (2010).

Figure 3.1: Identification strength (upper panel) and sensitivity component (lower panel) with asymptotic information matrix (log-scale).

Note: The black and white bars denote measures relative to parameter value and relative to prior standard deviation respectively.

Dynare’s Monte-Carlo based optimisation routine is used to get the posterior modes. For results in the MH stage, 300,000 draws were obtained in each of the three chains. The scale parameter in the jumping distribution was adjusted to ensure the acceptance rate in chains between 25-35% in various model specifications. During estimation, both the univariate and the multivariate convergence diagnostics ensured that convergence was achieved in each case. Brooks & Gelman (1998)’s multivariate convergence diagnostics for model \( M_{92z} \) is reported in Fig.A8 and the rests are skipped but available upon request.
3.4 Results

The posterior mean and corresponding 90 percent Highest Posterior Density (HPD) obtained in the MH algorithm are reported in the last three columns of Table 3.2 for all the three model specifications – $M_{\theta z}$, $M_{\xi z}$ and $M_{\theta \xi z}$. Results for model $M_{\theta z}$ are presented in column (4) where HPD’s are in square bracket with respective estimates. Similarly column (5) and (6) contain results of models $M_{\xi z}$ and $M_{\theta \xi z}$ respectively. A number of observations regarding the exogenous shock processes are worth mentioning.

Data used in the estimation appear quite informative for the parameters including the shock processes. Among the shock persistent coefficients, technology ($\rho_a$) and wage markup ($\rho_w$) shocks have considerable level of persistence across the three models while MEI shock ($\rho_z$) turns out less persistent. A closer look shows that $\rho_a$ (0.84) is higher and $\rho_z$ is much lower (0.06) in $M_{\xi z}$ compared to models with net-worth shock. Both net worth and capital quality shocks are highly persistent in all specifications, however, $\rho_{\theta}$ appears more persistent in $M_{\theta z}$ than models with capital quality shock. The estimated mean of the standard deviations for shocks are at reasonable level and consistent among three specifications. The MEI shock appears highly volatile ($\sigma_z$) and slightly more so in $M_{\xi z}$ compared to the models with net worth shock. The higher persistence coefficients and the lower mean standard deviations for the technology and financial shocks imply that in the long horizons, they are likely to be the strong drivers of business cycles.

The dominance of the wage mark-up and technology shocks in this study is in contrast to Villa (2014) but similar to the findings of Smets & Wouters (2007) and many other estimates in the previous literature on the US. The result for the MEI shock is in contrast to the findings of Justiniano et al. (2010), especially, in the long run. The interesting point to note is, the low persistence and high volatility of MEI shock in all model specifications provide empirical support for the theoretical discussions on the possible replacement of MEI shock by the financial shocks. The persistence and volatility estimates of other shocks are
The estimates of behavioural parameters—habit \((b)\), inverse elasticity of labour supply \((\eta)\), elasticity of \(K\) utilization \((\zeta)\), and investment adjustment costs \((\tau)\) are similar across the three models and not much different than the specified prior mean. Exceptions are the Calvo parameters. A considerable degree of sluggishness in price and nominal wage adjustments is found in this study and price stickiness is higher than the nominal wage stickiness. The estimated Calvo price stickiness \((\phi_p = 0.71)\) in all models implies that firms re-optimize the prices of their products in more than three quarters approximately, similar to the findings of Smets & Wouters (2007) but slightly smaller than Villa (2014). The estimated wage stickiness \((\phi_w = 0.57)\) in \(M_{\theta z}\) and \(M_{\theta z}\) imply that the average duration of a nominal wage contract is above two quarters, which is, however, less than the estimate for the US reported by Barattieri et al. (2014) who find five quarters. The wage stickiness in \(M_{\xi z}\) is much less than the estimates of the other two models. The estimates of the two Calvo parameters show that both the price and the wage adjustments occur within a year.

Estimates of indexation parameters are similar across three models. Estimated \(\zeta_p\) (around 0.30) is lower than its prior value and closer to the estimates of Villa (2014), Smets & Wouters (2007) while \(\zeta_w\) (around 0.49) is higher than Villa (2014) and closer to Smets & Wouters (2007) for the US. The higher value of \(\zeta_w\) than \(\zeta_p\) implies that the endogenous persistence in the labour market is higher relative to the goods market. Among monetary policy parameters, interest rate smoothing and reaction to inflation are slightly higher in \(M_{\xi z}\) than in \(M_{\theta z}\) and \(M_{\theta z}\) and closer to their prior mean. Central bank’s reaction to output growth is higher than the prior mean but consistent across models. This is also higher than the estimates of Villa (2014). This indicates that monetary authority is sensitive not only to inflation fluctuations, but also to the output gap.
3.5 Model fit

The common approaches to check the fit of the estimated DSGE model are to compare the log data densities of the competing models and to compare the theoretical moments of the estimated model to those of the actual data (An & Schorfheide 2007). In this study I check model fit using both approaches.

3.5.1 Relative fit of alternative specifications: Bayes factor

Comparison of posterior odds between the baseline model and other competing models is widely used to check model fit. It has been shown that the posterior odds, under various regularity conditions, favour the DSGE model that is closest to the true data generating process (Phillips 1996, Fernandez-Villaverde & Francisco Rubio-Ramirez 2004, An & Schorfheide 2007).

Table 3.3: Bayes factor comparison

<table>
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<tr>
<th>Model</th>
<th>Log marginal data densities</th>
<th>Bayes factor</th>
</tr>
</thead>
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<tr>
<td>$M_{θξz}$: with all shocks</td>
<td>$-534.96$</td>
<td>1</td>
</tr>
<tr>
<td>$M_{θz}$: net-worth and MEI shocks</td>
<td>$-535.73$</td>
<td>2.16</td>
</tr>
<tr>
<td>$M_{ξz}$: capital quality and MEI shocks</td>
<td>$-556.17$</td>
<td>$1.63 \times 10^9$</td>
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<td>$M_{z}$: MEI shocks</td>
<td>$-629.22$</td>
<td>$8.64 \times 10^{40}$</td>
</tr>
<tr>
<td>$M_{θξ}$: net worth and capital quality shocks</td>
<td>$-593.20$</td>
<td>$1.96 \times 10^{25}$</td>
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</tbody>
</table>

Note: The log marginal data densities were calculated using modified harmonic mean (MHM) approximation, described by Geweke (1998). Bayes factor comparison between $M_{θξz}$ and others.

In terms of marginal data density in Table 3.3, model $M_{θξz}$ is clearly preferred than other model, however, $M_{θz}$ is not less preferred than $M_{θξz}$. It implies that model including net worth shock that arises within the financial sector can represent a better fit of the US economy compared to models that include only capital quality as a financial shock. It is also interesting to note that model that includes both net worth and capital quality shocks

\[ 2 \text{Kass & Raftery (1995) suggest a reference scale to weigh the strength of the evidence in favour of an alternative model with respect to the model in null hypothesis. In this scale, a Bayes factor between '1 to 3' is 'not worth more than a bare mention', '3 to 20' denotes positive and '20 to 125' denotes strong evidence, while a factor greater than 150 is very strong evidence in favour of one of the two models.} \]
Chapter 3. The role of financial shocks in business cycles with a liability side financial friction

\( M_{\theta \xi z} \) performs better than the model \( M_{\xi z} \) considering only capital quality as finance shock.

The respective Bayes factors compared to \( M_{\theta \xi z} \) are calculated in the last column of Table 3.3. The Bayes factor strongly supports \( M_{\theta \xi z} \) and also \( M_{\theta z} \) over \( M_{\xi z} \) and other model specifications including models with no financial shocks \( (M_z) \) and model with no MEI shock \( (M_{\theta \xi}) \). Comparing the log marginal data densities of various experimental models in Table A8 to Table 3.3, we see that the three models in the baseline analysis are still preferred.

### 3.5.2 Absolute fit: moments comparison

In Table 3.4, I present the posterior predictive analysis in which the moments in model generated artificial data are compared to those in actual data. The standard deviations (S.D) and the autocorrelations (AC) of order 1 to 2 reported here are their median values and actual data moments for the period 1962:Q2 -2007:Q1 are in bold face.

The standard deviations of the models show mixed performances. Model \( M_{\theta z} \) performs quite satisfactorily in replicating the volatility of output \( (Y_t) \), consumption \( (C_t) \), inflation \( (\pi_t) \), nominal interest rate \( (i_t) \), hours worked \( (N_t) \) but moderately over predicts for investment \( (I_t) \) and spread \( (efp_t) \). The model’s weak capacity to replicate the volatility of the components of national income accounts is a common problem in the DSGE literature (for example, see von Heideken 2009 on the US). The assumption about the inter-temporal elasticity of substitution parameter \( (\sigma = 1 \text{ in this study}) \) also affects the volatility of these variables.

The fit of volatility of model \( M_{\theta \xi z} \) is closer to model \( M_{\theta z} \). Compared to \( M_{\xi z} \), we see that models with net worth shock provides better fit of the data. If we look at the relative volatility in the lower panel of Table 3.4, we see that the model performs satisfactorily in replicating the relative volatility of all variables.
Table 3.4: Moments comparison: posterior predictive analysis

<table>
<thead>
<tr>
<th></th>
<th>$S.D^{M_{θz}}$</th>
<th>$S.D^{M_{ξz}}$</th>
<th>$S.D^{M_{θξz}}$</th>
<th>$S.D^a$</th>
<th>$AC(1)^{M_{θz}}$</th>
<th>$AC(1)^{M_{θξz}}$</th>
<th>$AC(1)^a$</th>
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<th>$AC(2)^{M_{θξz}}$</th>
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<tr>
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<td>0.83</td>
<td>0.72</td>
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<td>0.94</td>
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<table>
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<th>Relative $S.D^{M_{ξz}}$</th>
<th>Relative $S.D^{M_{θξz}}$</th>
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<td>$efp_t$</td>
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<td>0.13</td>
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<tr>
<td>$N_t$</td>
<td>0.94</td>
<td>0.75</td>
<td>0.84</td>
<td>1.18</td>
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</table>

Note: Standard deviations ($S.D$) for all models and autocorrelations ($AC$) of order 1 and 2 for $M_{θz}$ and $M_{θξz}$ are presented where the superscripts denote respective models and superscript $a$ denotes the actual data statistics. The moments are their median values. Relative S.D means S.D relative to output.
Since the likelihood-based estimator matches the entire covariance matrix of the data, we need to check the other moments, such as the autocorrelations. The autocorrelation coefficients up to order two are reported for $M_{\theta z}$ and $M_{\theta \xi z}$, while $M_{\xi z}$ is skipped for brevity. Except for $i_t$, the models replicate the persistence in data very closely for both the financial and the national income account variables. For $i_t$, both $M_{\theta z}$ and $M_{\theta \xi z}$ under-predict the autocorrelation. Overall, the predicted moments generated by the baseline models are good match for the moments in the actual data.

3.6 Drivers of business cycles

Since the model fits the US macroeconomic data at a reasonable level, next I analyse the main driving forces for the variation in output and other variables through forecast error variance decompositions and the mean impulse responses to the exogenous shocks. These will enable us to revisit the driving forces of the business cycles as well as an empirical evaluation of the transmission process of the financial shocks.

3.6.1 Variance decomposition analysis

In Table 3.5, I report the forecast error variance decompositions (in %) for output ($Y_t$), investment ($I_t$), spread ($efp_t$) and hours worked ($N_t$) over the horizons of one quarter, one year and two years for three models. The unconditional or stationary variance (UV) decompositions are reported in the last row for each of the variables. During the estimation, neutral technology ($e_a$), MEI ($e_z$), capital quality ($e_\xi$) and net worth ($e_\theta$) shocks were defined in a way to produce recessionary situations for an amount of one standard deviation shock. The first point to emphasise is that in the presence of an explicit financial friction, MEI shock ($e_z$) is attenuated in the long run when financial shocks play stronger roles in $Y_t$ variation, although $e_z$ can be important in short run.
### Variance Decomposition (in %)

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<th>$e_z$</th>
<th>$e_\theta$</th>
<th>$e_\xi$</th>
<th>$e_p$</th>
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Note: The reported variances are the mean responses of unconditional or stationary variances (UV) and the conditional variances at horizon 1, 4 and 8 quarters.
The UV decomposition shows that the contribution of MEI shock in $Y_t$ variation decreases from 5% in $M_{\theta z}$ to 2.52% and 1% in $M_{\theta \xi z}$ and $M_{\xi z}$ respectively. This can be understood from the fact that both $e_z$ and $e_\xi$ shocks enter into the model through the capital accumulation process and $e_\xi$ captures the larger portion of output variations when present in the model. In the long run, the contribution of $e_z$ decreases substantially due to the feedback effect from the financial to real sector resulting from the counter cyclical movement of $Q_t$. The UV decomposition of $Y_t$ also shows that $e_\theta$ can explain 33% of variations in model $M_{\theta z}$ and around 17% in $M_{\theta \xi z}$ whereas capital quality shock ($e_\xi$) can explain 29% in model $M_{\theta \xi z}$ and 38% in $M_{\xi z}$, implying the importance of these shocks in output fluctuations. Wage markup shock ($e_w$) turns out to be important in the long run, as shown by the UV decompositions, similar to Smets & Wouters (2007) who also find $e_w$ to be important for the US output variation. Demand side shock such as preference ($e_\varrho$) and government expenditure ($e_g$) shocks have substantial roles in output variation in short run which are robust across models.

For investment ($I_t$) variations, $e_z$ has the highest explanatory power in all models, however in the short run only. Rapid dissemination of investment techniques in today’s world helps to perceive the fact that gains (losses) can be ripped off quickly. This role of $e_z$ for variations in $I_t$ is weakened gradually from model $M_{\theta z}$ to $M_{\theta \xi z}$ to $M_{\xi z}$ in various horizons, while $e_\xi$ takes the opposite role from model $M_{\theta \xi z}$ to $M_{\xi z}$. The highly muted role of MEI shock together with the absence of net worth shock in $M_{\xi z}$ assign larger roles to technology (34%) and capital quality (25%) shocks. Another interesting observation is, UV decompositions show that $e_\theta$ can explain substantial part of $I_t$ variations, 29% in $M_{\theta z}$ and 20% in $M_{\theta \xi z}$. However, this may not be so in the short run, as indicated by the conditional variance decompositions in both models. Monetary policy shock ($e_i$) is also important for the US investment variations and more so in the models with net worth shock.

For spread ($efp_t$), we see that $e_\theta$ and $e_i$ explain the majority part of variations in all
3.6. Drivers of business cycles

horizons across the models. When we do not estimate the pure financial shock separately from the capital quality shock (model $M_{\xi z}$) then $e_\xi$ alone explains up to 46% of variation in spread. Since net worth shock is explained as a direct shock within the financial sector, the percent variations of $efp_t$ due to $e_\theta$ in models $M_{\theta z}$ and $M_{\theta \xi z}$ are expected. Technology shock also has a substantial role to play in $efp_t$ variation.

For hours worked ($N_t$), government expenditure shock, ($e_g$), is an important short run source of fluctuations, demonstrated across the three models. However, overall the wage markup shock ($e_w$) is the most important driver in the employment sector beyond a year, as expected. In model $M_{\theta z}$, $e_\theta$ also appears very important, followed by technology shock. As we include $e_\xi$ in the model, the role of net worth shock decreases and greater variations are explained by neutral technology shock. In $M_{\xi z}$, the two most important shocks, based on UV decomposition of $N_t$, are $e_a$ (38 %) and $e_w$ (27%). Capital quality shock also has a substantial impact (20% in two years horizon) in labour market. The nature of $e_\xi$ shock can give some explanations in this regard. The capital quality shock can include physical as well as valuation change in the capital stock and in case its a physical change in $K_t$, $e_\xi$ will certainly have a big effect on $N_t$ as dictated by the production function. MEI shock is also important for $N_t$ variations and the highest impact of this is in $M_{\theta z}$.

Overall, the experiment with various model specifications thus highlights the importance of disentangling $e_\xi$ and $e_\theta$ shocks to assign true roles to MEI shocks.

It would be interesting to compare these results with Villa (2014) who estimated the same financial friction for the US without estimating any bank net worth shock. The UV decomposition reported in Villa (2014) shows that capital quality shock alone explains 92% of output variation, making it the sole important factor for the US output variation. In contrast, estimating the bank net worth shock distinctly as a finance based shock, such as in this study, shows that although financial shocks ($e_\theta, e_\xi$ in $M_{\theta \xi z}$) account for more than 45% of $Y_t$ variations, other shocks such as technology, monetary policy and wage mark-up can
explain a considerable portion of $Y_t$ variations. This is empirically more consistent. The UV decomposition in model $M_{\varepsilon z}$ in this study appears qualitatively similar to the findings of Sanjani (2014) regarding the dominant roles of $\varepsilon_a$ and $\varepsilon_\xi$ but differs quantitatively for $\varepsilon_z$. Adding labour market heterogeneity into the model increases the role of MEI shock in $Y_t$ variation, supporting the transmission mechanism of MEI shock explained in Justiniano et al. (2010). However, the MEI shock still remains less important for output and labour market variations especially in longer horizon in such financial friction model.

The historical shock decompositions for output ($Y_t$) and bank net worth ($E_t$) over period 1962-2007 in model $M_{\theta z}$ are presented in the Appendix Fig.A10 and Fig.A11 with associated colour codes for various shocks. In the financial friction of Gertler & Karadi (2011), the crucial variable in amplifying the feedback effects from the financial sector to the real economy is the bank leverage. The smoothed leverage series generated by models $M_{\theta z}$ and $M_{\theta \xi z}$ are plotted along with the US recession bar in the Appendix Fig.A9.

### 3.6.2 Impulse responses

The Impulse Response Functions (IRFs) show the future paths of the endogenous variables in response to an exogenous shock occurring at period one. Overall, the qualitative patterns of the IRFs derived from the estimated models of this study are theoretically sensible and similar to many empirical studies, but the response quantities vary.

#### 3.6.2.1 Impulse responses of physical capital

The impulse responses of capital ($K_t$) is particularly interesting as it is linked to the separate identifiability of financial shocks in the model discussed in Subsection 3.3.2. In Fig.3.2, the impulse responses of $K_t$ and asset price ($Q_t$) to net worth, capital quality and MEI shocks are presented for the three model specifications. Although net worth and capital quality shocks affect finance sector’s leverage in the same way, they are different due to their origins and propagation mechanisms which need to be disentangled.
Figure 3.2: IRFS to net worth, MEI and K quality shocks.

Note: Column 1 to 3 represent models $M_{\theta z}$, $M_{\theta\xi z}$ and $M_{\xi z}$ respectively.

Figure 3.3: Comparison between flexible and sticky wages.

Note: Titles with MEI and net worth show responses of the variables to those shocks respectively in model $M_{\theta\xi z}$.
Chapter 3. The role of financial shocks in business cycles with a liability side financial friction

The first row of Fig.3.2 clearly depicts the economic intuition behind identification of financial shock. In response to negative net worth shock (black solid line), $K_t$, in both $M_{\theta z}$ and $M_{\theta \xi z}$, remains unresponsiveness initially and moves down gradually afterwards. On the other hand, in response to a negative capital quality shock (grey marked line) of same magnitude, $K_t$, in both $M_{\theta \xi z}$ and $M_{\xi z}$, falls instantaneously. The fall in $K_t$ due to capital quality shock is deeper in $M_{\xi z}$ compared to $M_{\theta \xi z}$ and similar to the instantaneous response to MEI shocks (blue broken line). This pattern validates the statistical identification of shock parameters (persistence and standard errors) presented earlier. The maximum decline of $K_t$ is much higher in response to a capital quality shock than the other two shocks as it captures both amplification effect by banks and the direct impacts originating in the real sector.

The second row of Fig.3.2 shows the response of capital price, $Q_t$, to MEI and financial shocks. The key point of the hypothesis that MEI shock is attenuated in presence of financial friction is the counter cyclical movement of asset price in response to MEI shock and pro-cyclical movement in response to financial shocks and we see that $Q_t$ shows such responses. In response to a negative MEI shock (blue broken line), $Q_t$ jumps up which affects the bank balance sheet positively through higher collateral valuations. This fact eases credit conditions by lowering the required risk premium on loans which favours investment decisions. Therefore, the balance sheet channel neutralises the negative effects of the MEI shock on output in the medium run, even if it is not so in the short run. In response to net worth shock, although $Q_t$ jumps up but returns back quickly and stays below the steady state level for a while before adjusting back to the steady state. The fall in $Q_t$ is more pronounced for capital quality shock.
3.6.2.2 Comparison between sticky wage and perfectly flexible wage

In order to assess the role played by nominal wage rigidity, I re-estimate the model with all shocks, $M_{\theta\xi z}$, with fully flexible wage (except the wage markup shock). Fig.3.3 juxtaposes the IRFs of variables $Y_t$, $N_t$, $efp_t$ and $E_t$ to MEI shock (in upper row) and net worth shock (in lower row) only for brevity. Here, the black solid lines are the IRFs of model with perfectly flexible wage and the broken lines are for the rigid wage case (the baseline). Fig.3.3 clearly shows that if there is no imperfection and rigidity in labour market, adjustment processes after a shock are quicker in most of the cases. In response to a negative MEI shock, the drop in $Y_t$ under flexible wage is much less and adjustment to steady state is quicker than wage rigidity case. Thus, it validates the arguments of Justiniano et al. (2010) that nominal wage and price rigidities indeed have important roles to play in shock transmission mechanism. However, the depressed $efp_t$ for prolonged time at the same time provides evidence that MEI shock is attenuated by financial friction because financial spread moves pro-cyclically in response. In lower row of Fig.3.3, we see the impacts of net worth shock on $Y_t$ and $E_t$ are much higher under nominal wage rigidity than under flexible wage. The response of $efp_t$ to net worth shock in rigid wage case shows that it drops initially, but returns quickly and remains over the steady state till 25 quarter. The gap between the IRFs under two different labour market assumptions clearly shows the importance of modelling labour market heterogeneity and nominal wage stickiness, as emphasised by Christiano et al. (2005b).

3.6.2.3 Impulse responses to various shocks in model $M_{\theta\xi z}$

Fig.3.4 contains IRFs to MEI, net worth, neutral technology, wage markup and capital quality shocks from the first to the fifth rows respectively for select variables in models $M_{\theta\xi z}$. The shaded regions are 95 percent error bands. In the first row, we find that $Y_t$, $I_t$ and $N_t$, decline in response to a MEI shock which is a one standard deviation negative
innovation in the process of transforming investment into installed capital. Due to counter
cyclical movements in assets price, banks net worth, $E_t$, increases and required spread, 
$e fp_t$, decreases.

Figure 3.4: IRFs to MEI, net worth, technology, wage markup and capital quality shocks 
in $Mθξz$.

Note: The thick black lines are the IRFs and the shaded regions are 95 % error bands in model 
$Mθξz$. The first variable title in every row contains the name of the shock for all variables of that 
row.

IRFs to a negative net worth shock, in the second row, appear more persistent com-
pared to those for MEI shock. Although $e fp_t$ declines initially after the net worth shock, 
rises above the steady state level shortly and remains slightly above the steady state for 
prolonged time. The maximum decline in $Y_t$ occurs in response to neutral technology shock 
and the impact is also persistent.

The impacts of the technology shock on $N_t$ and the associated impacts in the US 
business cycles are debated issues. For example, Gali (1999) and Francis & Ramey (2005) 
argue that because of the factors such as habit, nominal price rigidities and investment
adjustment costs, the impact of a positive technology shock is an immediate fall in $N_t$. In contrast, based on a VAR based specification, Christiano et al. (2003) argue that the response of $N_t$ to a technology shock is not robust and there is some evidence in favour of positive impact. In Smets & Wouters (2007), we see an immediate fall in $N_t$ in response to a positive technology shock, and this becomes positive only after two years. In this chapter, $N_t$ increases instantly but its not persistent. It goes down below the steady state very quickly and takes time to rise back to the steady state. Therefore, the result is broadly consistent with the arguments of Gali (1999). In response to wage markup shock, on the other hand, $N_t$ declines sharply and returns back to steady state by thirty quarters. In response to a negative innovation in the quality of capital, both $Y_t$ and $N_t$ decline; and $E_t$ declines and $efp_t$ rises due to the loss of collateral valuation, depicted in the last row.

3.6.2.4 Impulse responses to various shocks in models $M_{\theta z}$ and $M_{\xi z}$

Figure 3.5: IRFs in $M_{\theta z}$ and $M_{\xi z}$ to MEI, net worth, technology, wage markup and capital quality shocks.

Note: The solid (black) lines are IRFs in $M_{\theta z}$ and the broken (blue) lines are IRFs in $M_{\xi z}$. The first variable title in every row contains the name of the shock for all variables of that row.
Impulse responses for the same list of shocks in model $M_{\theta z}$ and $M_{\xi z}$ are presented together in Fig.3.5 where solid (black) lines are IRFs in $M_{\theta z}$ and broken (blue) lines are IRFs in $M_{\xi z}$. In the first row we see the decline in $Y_t$ to MEI shock is slightly higher in $M_{\theta z}$, compared to $M_{\xi z}$. Over all the responses to MEI shock in the two specifications are not much different. The quantitative difference in responses between two models are more pronounced for technology shock in the second row where $Y_t$, $I_t$ and $N_t$ decline to greater magnitudes and are more persistent in model $M_{\xi z}$.

In response to wage markup shock, these variables decline slightly more in $M_{\xi z}$ than in $M_{\theta z}$. The fourth row depicts responses to net worth shock in $M_{\theta z}$ only which are not much different than the responses to net worth shock in Fig.3.4. The responses to capital quality shock in $M_{\xi z}$ are presented in the last row which are not much different than the same responses in Fig.3.4. Impulse responses to monetary policy, government expenditures, preference and price markup shocks in different models can be found in the Appendix Fig.A12 and Fig.A13.

### 3.7 Robustness of the model

#### 3.7.1 Results with extended time period

The baseline analysis does not include global financial crisis period. Since the zero lower bound can bias the estimates (Gali et al. 2012), I re-estimate all three models for an extended period, 1962:Q2 -2014:Q4. Impulse responses of $Y_t$, $efp_t$ and $E_t$ in the the extended time estimation are presented in Fig.3.6 for neutral technology, MEI, net worth and capital quality shocks. If we compare Fig.3.6 to IRFs in Subsection 3.6.2, we see the magnitudes are not very different between the two sample periods.

The response pattern in extended period is broadly similar to the pattern in pre-global financial criss period. In new sample, $Y_t$ and $E_t$ decline slightly more in $M_{\theta z}$ in response to a net worth shock, denoted by the grey marked lines. The same is true for capital quality shock in both models $M_{\theta z}$ (solid lines) and $M_{\xi z}$ (broken lines).
3.7. Robustness of the model

Figure 3.6: IRFs for extended period (1962-2014) to MEI, net worth and capital quality shocks.

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<th>Table 3.6: Moments and log data density for the extended period (1962-2014).</th>
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I also present volatility (S.D) and log data density in Table 3.6 to compare between three model specifications for the extended period. In extended data set, the ability of $M_{\theta z}$ and $M_{\theta \xi z}$ to fit data remains superior to $M_{\xi z}$, same as in the baseline period. However, all model specifications now relatively over-predict the volatility of national accounts data. The fit is reasonably good for financial and labour market data. In terms of log marginal data density, model $M_{\theta \xi z}$, and also $M_{\theta z}$, are preferable to model $M_{\xi z}$, supporting the robustness of baseline analysis.

3.7.2 Sensitivity to the leverage ratio

The importance of the value of leverage ratio is emphasised in many studies, e.g. Jordà et al. (2011) and Bernanke et al. (1999b), and, of course, Gertler & Karadi (2011). It is important to check the sensitivity of the estimation results to changes in the steady
Chapter 3. The role of financial shocks in business cycles with a liability side financial friction

state value of the leverage ratio. Gertler & Karadi (2011) find that the calibration of the leverage ratio is tricky. Following their calibration, leverage ratio was four in my baseline estimation. To check the sensitivity of the estimated results to various leverage ratios, I re-estimate model $M_{\theta\xi z}$ and present the log marginal data densities for various leverages in Table 3.7.

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Note: MDD are calculated using the Modified Harmonic Mean estimator in $M_{\theta\xi z}$ specification.

Table 3.7 also shows that the marginal data densities change from low to high leverages in terms of over all fit but the impulse responses are qualitatively not different. The IRFs to neutral technology shock with various leverage ratios in $M_{\theta\xi z}$ are also presented in Fig.3.7.

Figure 3.7: IRFs to neutral technology shocks at various leverages in model $M_{\theta\xi z}$.

The IRFs to a negative technology shock with leverage ratios 4 (black solid line), 3 (blue broken line) and 5 (grey marked line) show that response patterns are qualitatively same but slightly different quantitatively, especially for the financial sector variables. For example, the spread ($efp_t$) rises more to a negative technology shock when the financial sector leverage is higher and the associated decline in net worth ($E_t$) is also higher. The differences in IRFs for real sector variables are less pronounced than the financial sector variables. The adjustment timing to steady states are robust across various leverage ratios.
3.8 Conclusion

In this chapter I have analysed the roles of financial frictions in the liability side of a balance sheet, a la Gertler & Karadi (2011) and finance shocks in light of their ability to influence the transmission mechanism of investment specific technology (MEI) and other shocks in driving business cycles with all common forms real and nominal frictions. The analysis also offers an experiment on financial shocks by comparing the bank net worth shock and the capital quality shock. The analysis is strengthened by the experiment of including one financial shock at a time before applying both.

My empirical analysis shows that financial friction indeed replaces the marginal efficiency of investment shock through the bank balance sheet effect of the counter cyclical movement of stock market price of capital. Including nominal price and wage rigidity improves the role of MEI shock but the balance sheet effect is strong enough to weaken the impacts of this shock on output variations in the long run. The MEI shock is muted to a greater extent if only capital quality shock is included as a finance based shock. The result is robust across different model specifications; and for pre and post global financial crisis periods.

When comparing between the bank net worth and capital quality shocks, I find that considering the former as a financial shock or both together in the model can improve the models ability to fit data rather than considering capital quality shock only. To validate the claim I present detail identification mechanism of the two finance based shocks which also shows the importance of disentangling them in the model. This provides an important outlook that designing a shock that reflects exogenous variation in capital price only, rather than the quantity as is the present case for capital quality shock, can be an interesting work.

The business cycles implications of financial frictions are discussed under the assumptions of perfect competition in the financial sector in a closed economy representation. In
practice the financial sectors of many countries are not very competitive as in the US, hence, the financial frictions discussed in this chapter may not be suitable for those countries. This fact raises the following questions: What is the role of imperfectly competitive financial sector in business cycles when we observe high concentration in the bank industry? How does a highly concentrated financial sector affect an economy’s responses to the exogenous events in the rest of the world? Answers to these questions are discussed in the next chapter where I investigate a different type of financial friction arising out of high concentration in bank industry for a small open economy using a DSGE model.

3.A Appendix
3.A.1 Output

Figure A8: Brooks and Gelman’s multivariate convergence diagnostic in base model $M_{\theta z}$.

Figure A9: Smoothed leverage variable in $M_{\theta z}$ and $M_{\theta x}$ along with the US recession bars for years 1962-2007.
3. Appendix

Figure A10: Y - historical shock decomposition in $M_{\theta\xi z}$ for 1962-2007 data.

Figure A11: E - historical shock decomposition in $M_{\theta\xi z}$ for 1962-2007 data.
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Figure A12: IRFs with 95% error bands to monetary policy, preference, price markup, and government expenditure shocks in $M_{\theta \xi z}$ for 1962-2007.

Figure A13: IRFs to monetary policy, preference, price markup, and government expenditure shocks in $M_{\theta z}$ and $M_{\xi z}$ for 1962-2007.
Table A8: Estimates from the model versions $M_\theta$, $M_\xi$, $M_z$, and $M_{\theta,\xi}$

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Distribution</th>
<th>Prior mean (S.D)</th>
<th>Posterior mean and 5 and 95 percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho_e$</td>
<td>B</td>
<td>0.6 (0.1)</td>
<td>$0.61 [0.57, 0.65]$</td>
</tr>
<tr>
<td>$\rho_b$</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>$0.75 [0.69, 0.80]$</td>
</tr>
<tr>
<td>$\rho_z$</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>$0.80 [0.75, 0.85]$</td>
</tr>
<tr>
<td>$\rho_\theta$</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>$0.88 [0.86, 0.90]$</td>
</tr>
<tr>
<td>$\rho_\xi$</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>$0.08 [0.07, 0.10]$</td>
</tr>
<tr>
<td>$\rho_\phi$</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>$0.36 [0.15, 0.57]$</td>
</tr>
<tr>
<td>$\rho_\theta$</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>$0.90 [0.85, 0.95]$</td>
</tr>
<tr>
<td>$\rho_p$</td>
<td>B</td>
<td>0.5 (0.2)</td>
<td>$0.13 [0.02, 0.21]$</td>
</tr>
<tr>
<td>$\sigma_i$</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>$0.22 [0.20, 0.24]$</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>$0.47 [0.42, 0.51]$</td>
</tr>
<tr>
<td>$\sigma_x$</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>$2.07 [1.84, 2.29]$</td>
</tr>
<tr>
<td>$\sigma_g$</td>
<td>IG</td>
<td>0.5 (1)</td>
<td>$2.26 [1.85, 2.69]$</td>
</tr>
<tr>
<td>$\sigma_\xi$</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>-</td>
</tr>
<tr>
<td>$\sigma_\phi$</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>-</td>
</tr>
<tr>
<td>$\sigma_\theta$</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>-</td>
</tr>
<tr>
<td>$\sigma_p$</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>$0.73 [0.61, 0.86]$</td>
</tr>
<tr>
<td>$\sigma_\eta$</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>$0.08 [0.02, 0.16]$</td>
</tr>
<tr>
<td>$\sigma_\zeta$</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>$0.76 [0.69, 0.87]$</td>
</tr>
<tr>
<td>$\sigma_\tau$</td>
<td>IG</td>
<td>0.33 (0.15)</td>
<td>$0.46 [0.20, 0.72]$</td>
</tr>
<tr>
<td>$\sigma_{\eta,\zeta}$</td>
<td>IG</td>
<td>0.1 (2)</td>
<td>$1.73 (0.5)$</td>
</tr>
<tr>
<td>$b$</td>
<td>B</td>
<td>0.7 (0.1)</td>
<td>$0.78 [0.69, 0.87]$</td>
</tr>
<tr>
<td>$\eta$</td>
<td>G</td>
<td>0.33 (0.15)</td>
<td>$0.46 [0.20, 0.72]$</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>G</td>
<td>7.2 (0.5)</td>
<td>$6.96 [6.15, 7.76]$</td>
</tr>
<tr>
<td>$\tau$</td>
<td>G</td>
<td>1.73 (0.1)</td>
<td>$1.50 [1.36, 1.64]$</td>
</tr>
</tbody>
</table>
Table A8: Estimates from the model versions $M_\theta$, $M_\xi$, $M_z$, and $M_{\theta\xi}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model</th>
<th>Estimate</th>
<th>5th Percentile</th>
<th>95th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_p$</td>
<td>B</td>
<td>0.5 (0.1)</td>
<td>[0.65, 0.75]</td>
<td>[0.68, 0.74]</td>
</tr>
<tr>
<td>$\phi_w$</td>
<td>B</td>
<td>0.5 (0.1)</td>
<td>[0.63, 0.80]</td>
<td>[0.12, 0.29]</td>
</tr>
<tr>
<td>$\zeta_p$</td>
<td>B</td>
<td>0.5 (0.1)</td>
<td>[0.30, 0.59]</td>
<td>[0.12, 0.33]</td>
</tr>
<tr>
<td>$\zeta_w$</td>
<td>B</td>
<td>0.5 (0.1)</td>
<td>[0.43, 0.74]</td>
<td>[0.32, 0.66]</td>
</tr>
<tr>
<td>$\phi_y$</td>
<td>N</td>
<td>0.125 (0.1)</td>
<td>[0.05, 0.21]</td>
<td>[0.1, 0.24]</td>
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<tr>
<td>$\phi_x$</td>
<td>N</td>
<td>1.70 (0.3)</td>
<td>[1.65, 2.05]</td>
<td>[1.55, 1.89]</td>
</tr>
</tbody>
</table>

MDD          |       | -605.33  | -713.23        | -629.22         | -593.20         |

Note: Posterior mean estimates for model $M_\theta$, $M_\xi$, $M_z$ and $M_{\theta\xi}$ are in column (4), (5) (6) and (7) respectively with 5 and 95 percentiles in square brackets.
3.A.2 Model equations

Household and labour packer

Households’s optimal conditions:

\[ \lambda_t = \frac{\theta_t}{C_t - bC_{t-1}} - \beta b \frac{\theta_{t+1}}{C_{t+1} - bC_t}, \]  
\[ \lambda_t = \beta \lambda_{t+1} R_{t+1}. \]  

Define ratio of Lagrange multiplier as, \[ \Lambda_{t+1} = \frac{\lambda_{t+1}}{\lambda_t} \]  and combining with Eq. (A16),

\[ 1 = \beta \Lambda_{t+1} R_{t+1}. \]  

The employment agency bundles the heterogeneous labours together and sells to the production firms. The competitive labour agency’s problem is to maximise profit,

\[ \max_{N_t(l)} W_t^P \left( \int_0^1 N_t(l)^{\epsilon_w-1} \frac{\epsilon_w}{\epsilon_w-1} dl \right) - \int_0^1 W_t(l) N_t(l) dl. \]  

The first order condition is

\[ W_t^P \frac{\epsilon_w}{\epsilon_w-1} \left( \int_0^1 N_t(l)^{\epsilon_w-1} \frac{\epsilon_w}{\epsilon_w-1} dl \right)^{-1} - \frac{\epsilon_w}{\epsilon_w-1} N_t(l)^{\epsilon_w-1} = W_t(l) \]  

\[ \Rightarrow N_t(l) \left( \int_0^1 N_t(l)^{\epsilon_w-1} \frac{\epsilon_w}{\epsilon_w-1} dl \right)^{-\epsilon_w} = \left( \frac{W_t(l)}{W_t^P} \right)^{-\epsilon_w} \]  

\[ \Rightarrow N_t(l) = \left( \frac{W_t(l)}{W_t^P} \right)^{-\epsilon_w} N_t. \]  

Similarly, the aggregate wage index can be derived as,

\[ W_t^P N_t = \int_0^1 W_t(l) N_t(l) dl = \int_0^1 W_t(l)^{1-\epsilon_w} W_t^P \epsilon_w N_t dl \]  

\[ \Rightarrow \left( W_t^P \right)^{1-\epsilon_w} = \int_0^1 W_t(l)^{1-\epsilon_w} dl \]  

\[ \Rightarrow W_t^P = \left( \int_0^1 W_t(l)^{1-\epsilon_w} dl \right)^{-\frac{1}{1-\epsilon_w}}. \]  

In each period, we assume there is \((1-\phi_w)\) probability that a household can adjust its wage. If it cannot, then it will index its wage to lagged inflation at \(\varsigma_w \in (0,1)\). At period
Chapter 3. The role of financial shocks in business cycles with a liability side financial friction

Lagrangian of household’s optimisation problem for labour services is:

$W(l)_{t+s} = \Pi_{t-1,t+s-1}^{\epsilon_w} W_t(l)$

where $\Pi_t$ is the gross inflation rate. In real term, this can be written as

$$\frac{W_t(l)_{t+s}}{P_t^{l,s}} = \frac{W_t(l)_{t+s}}{P_t^{l,s}} \Pi_{t-1,t+s-1}^{\epsilon_w} \Rightarrow w_t(l)_{t+s} = w_t(l)_{t+s}^{(1-\epsilon_w)} \Pi_{t-1,t+s-1}^{\epsilon_w}. \quad (A23)$$

Now the household problem becomes dynamic and household disutility of labor will be discounted by the factor $(\beta \phi_w)^s$. We can eliminate labor as a choice by plugging in the demand for labor (Eq.(A21)) and replacing the real wage from (Eq.(A23)). Part of Lagrangian of household’s optimisation problem for labour services is:

$$L = E_0 \sum_{s=0}^{\infty} (\beta \phi_w)^s \left[ -q_{t+s} \psi \left( \frac{w_t(l)_{t+s}^{(1-\epsilon_w)} \Pi_{t-1,t+s-1}^{\epsilon_w}}{\Pi_{t-1,t+s-1}^{\epsilon_w}} \right)^{-\epsilon_w (1+\eta)} N_{t+s}^{1+\eta} + \ldots \right. \right.$$  

$$\left. + \lambda_{t+s} \left( w_t(l)_{t+s}^{(1-\epsilon_w)} \Pi_{t-1,t+s-1}^{\epsilon_w} \left( \frac{w_t(l)_{t+s}^{(1-\epsilon_w)} \Pi_{t-1,t+s-1}^{\epsilon_w}}{w_t(l)_{t+s}} \right)^{-\epsilon_w} \right) \right]. \quad (A24)$$

The first order condition with respect to real wage, $w_t(l)$, is

$$\epsilon_w w_t(l)_{t+s}^{(1-\epsilon_w)} \sum_{s=0}^{\infty} (\beta \phi_w)^s q_{t+s} \psi \Pi_{t-1,t+s-1}^{\epsilon_w} (1+\eta) N_{t+s}^{1+\eta} + (1-\epsilon_w) w_t(l)_{t+s}^{(1-\epsilon_w)} \sum_{s=0}^{\infty} (\beta \phi_w)^s \lambda_{t+s} \Pi_{t-1,t+s-1}^{\epsilon_w} (1-\epsilon_w) N_{t+s}^{1+\eta} = 0. \quad (A25)$$

From here, we can write the common reset wage ($w_t^{(#1)}$) as

$$w_t^{(#1,1+\epsilon_w)} = \frac{\epsilon_w}{\epsilon_w - 1} \frac{E_t}{E_{t+s}} \left( \beta \phi_w ight)^s q_{t+s} \psi w_{t+s}^{(1+\eta)} \Pi_{t-1,t+s-1}^{\epsilon_w} \Pi_{t-1,t+s-1}^{1+\eta} N_{t+s}^{1+\eta}. \quad (A26)$$

In the left hand side of Eq. (A26) nothing depends on $l$. We can write this recursively as,

$$w_t^{(#1,1+\epsilon_w)} = M_{w,t} \frac{f_{1,t}}{f_{2,t}}, \quad (A27)$$

$$M_{w,t} = \frac{\epsilon_w}{\epsilon_w - 1} h_t^{\epsilon_w}. \quad (A28)$$

$$f_{1,t} = q_t \psi w_t^{(1+\eta)} N_t^{1+\eta} + \beta \phi_w w_{t+1}^{(1+\eta)} \Pi_{t-1,t+1}^{\epsilon_w} \Pi_{t-1,t+1}^{1+\eta} f_{1,t+1}, \quad (A29)$$

$$f_{2,t} = \lambda_t w_t^{\epsilon_w} N_t + \beta \phi_w w_{t+1}^{1+\epsilon_w} \Pi_{t-1,t+1}^{\epsilon_w} f_{2,t+1}. \quad (A30)$$

Next, applying the properties of Calvo pricing to the aggregate nominal wage index we
get,
\[
(W_t^p)^{1-\epsilon_w} = (1 - \phi_w)W_t^{#1-\epsilon_w} + \int_{1-\phi_w}^1 (\Pi_{t-1})^{(1-\epsilon_w)}W(l)^{1-\epsilon_w}dl. \tag{A31}
\]

Dividing both sides by \(P_t^{1-\epsilon_w}\) gives the real wage as
\[
(w_t)^{1-\epsilon_w} = (1 - \phi_w)w_t^{#1-\epsilon_w} + (\Pi_{t-1})^{(1-\epsilon_w)}(\Pi_t)^{\epsilon_w-1}\phi_ww_{t-1}^{1-\epsilon_w}. \tag{A32}
\]

### Financial intermediaries

Initial balance sheet condition is, \(Q_tS_t = B_{t+1} + E_t\). Terminal wealth that bankers maximise,
\[
V_{j,t} = \max E_t \sum_{i=0}^\infty (1 - \theta_{t+1}) \beta_{t+1}^i A_{t+1+i}(E_{j,t+1+i}). \tag{A33}
\]

Linear value function of wealth: \(V_{j,t} = \nu_tQ_tS_{j,t} + H_tE_{j,t}\) of which,
\[
\nu_t = E_t \{ (1 - \theta_{t+1})\beta_{t+1}A_{t+1} + \theta_{t+1}\beta_{t+1}m_{t+1} \nu_{t+1} \}, \tag{A34}
\]
\[
H_t = E_t \{ (1 - \theta_{t+1})\beta_{t+1}A_{t+1}R_{t+1} + \beta_{t+1}j_{t+1}H_{t+1} \}, \tag{A35}
\]
\[
m_{t+1} = \frac{Q_{j,t+1}S_{j,t+1}}{Q_tS_{j,t}}, \tag{A36}
\]
\[
j_{t+1} = \frac{E_{jt+1}}{E_{jt}}. \tag{A37}
\]

If the constraint, \(V_{j,t}(S_{j,t}, B_{j,t}) \geq \lambda^dQ_tS_{j,t}\), binds then
\[
Q_tS_{j,t} = \frac{H_t}{\lambda^d - \nu_t}E_{j,t} = \phi_tE_{j,t}. \tag{A38}
\]

Dynamics of the net worth
\[
E_{j,t+1} = [R_{t+1} + (R_{k,t+1} - R_{t+1})\phi_t]E_{j,t}. \tag{A39}
\]

Then, \(m_{t+1} = \frac{\phi_{t+1}E_{j,t+1}}{\phi_tE_{j,t}} = \frac{\phi_{t+1}}{\phi_t}j_{t+1}, \) and \(j_{t+1} = R_{t+1} + (R_{k,t+1} - R_{t+1})\phi_t. \) Aggregating across all banks we get,
\[
Q_tS_t = \phi_tE_t. \tag{A40}
\]

New bankers start up net worth is \(E_{nt} = \Omega \frac{(1 - \theta_t)Q_tS_{t-1}}{1 - \theta_t} = \Omega Q_tS_{t-1}. \) Total net worth in the banking sector,
\[
E_t = E_{et} + E_{nt} = \theta_t [(R_{k,t} - R_t)\phi_{t-1} + R_t] E_{t-1} + \Omega Q_tS_{t-1}. \tag{A41}
\]
Chapter 3. The role of financial shocks in business cycles with a liability side financial friction

Production sector and the Retailers

Optimal conditions of intermediate goods producers:

\[ P_{m,t}(1 - \alpha) \frac{Y_{m,t}}{N_t} = w_t, \]  \hspace{1cm} (A42)
\[ P_{m,t} \alpha \frac{Y_{m,t}}{U_t} = b_1 U_t^\zeta \xi_t K_t, \]  \hspace{1cm} (A43)
\[ R_{k,t+1} = \frac{P_{m,t+1} \alpha \frac{Y_{m+1,t}}{K_{t+1}} + (Q_{t+1} - \delta(U_{t+1})) \xi_{t+1}}{Q_t}. \]  \hspace{1cm} (A44)

Final output is a CES aggregate of all retailers output: \( Y_t = \left[ \int_0^1 \frac{Y_{ft}^{1-\epsilon_p}}{1} \right]^{\frac{1}{1-\epsilon_p}} \) and aggregate price \( P_t = \left[ \int_0^1 P_{ft}^{1-\epsilon_p} df \right]^{\frac{1}{1-\epsilon_p}}. \)

Max
\[ E_t \sum_{s=0}^\infty (\beta \phi_p)^s \Lambda_{t+s} \left( \Pi_{t-1,t+s-1} P_{t}^{1-\epsilon_p} P_{t+s}^{\epsilon_p-1} Y_{t+s} - P_{mt} \Pi_{t-1,t+s-1} P_{t}^{\epsilon_p} P_{t+s}^{\epsilon_p} Y_{t+s} \right) = 0, \]  \hspace{1cm} (A45)

The first order condition is,
\[ (1 - \epsilon_p)P_{ft}^{\epsilon_p-1} E_t \sum_{s=0}^\infty (\beta \phi_p)^s \Lambda_{t+s} \Pi_{t-1,t+s-1} P_{t}^{1-\epsilon_p} P_{t+s}^{\epsilon_p-1} Y_{t+s} \]
\[ + \epsilon_p P_{ft}^{\epsilon_p-1} E_t \sum_{s=0}^\infty (\beta \phi_p)^s \Lambda_{t+s} \Pi_{t-1,t+s-1} P_{mt} P_{t+s}^{\epsilon_p} Y_{t+s} = 0, \]

which can be rearranged as
\[ P_{ft} = \frac{\epsilon_p}{\epsilon_p - 1} \frac{E_t \sum_{s=0}^\infty (\beta \phi_p)^s \Lambda_{t+s} \Pi_{t-1,t+s-1} P_{mt} P_{t+s}^{\epsilon_p} Y_{t+s}}{E_t \sum_{s=0}^\infty (\beta \phi_p)^s \Lambda_{t+s} \Pi_{t-1,t+s-1} P_{t}^{1-\epsilon_p} P_{t+s}^{\epsilon_p-1} Y_{t+s}}. \]  \hspace{1cm} (A46)

After recursively writing, we get the optimal reset price as,
\[ P_t^\# = M_{p,t} \frac{X_{1,t}}{X_{2,t}}, \]  \hspace{1cm} (A47)
\[ M_{p,t} = \frac{\epsilon_p}{\epsilon_p - 1} \mu_t^p, \]  \hspace{1cm} (A48)
\[ X_{1,t} = P_{mt} P_{t}^{\epsilon_p} Y_t + \phi_p \beta \Lambda_{t+1}(\Pi_t)^{1-\epsilon_p} x_{1,t+1}, \]  \hspace{1cm} (A49)
\[ X_{2,t} = P_{t}^{\epsilon_p-1} Y_t + \phi_p \beta \Lambda_{t+1}(\Pi_t)^{\epsilon_p(1-\epsilon_p)} x_{2,t+1}. \]  \hspace{1cm} (A50)

After dividing Eq.(A49) by \( P_t^{\epsilon_p} \) and Eq.(A50) by \( P_t^{\epsilon_p-1} \) and defining \( \frac{X_{1,t+1}}{P_t^{\epsilon_p}} = x_{1,t}, \frac{X_{2,t+1}}{P_t^{\epsilon_p-1}} = x_{2,t} \) and \( \Pi_t^\# \) as the reset price inflation, we get
\[ x_{1,t} = P_{mt} Y_t + \phi_p \beta \Lambda_{t+1}(\Pi_t)^{1-\epsilon_p} x_{1,t+1}, \]  \hspace{1cm} (A51)
\[ x_{2,t} = Y_t + \phi_p \beta \Lambda_{t+1}(\Pi_t)^{\epsilon_p(1-\epsilon_p)} x_{2,t+1}. \]  \hspace{1cm} (A52)
The price dispersion, $Q_t^\theta = M_{p,t}^x z_{1,t}^\theta X_{t}$. (A53)

**Capital goods producers**

\[ Q_t Z_t \left[ 1 - \frac{t}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 - \frac{t}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right) \right] + \beta Q_{t+1} \lambda_{t+1} Z_{t+1} \tau \left( \frac{I_{t+1}}{I_t} - 1 \right) \left( \frac{I_{t+1}}{I_t} \right)^2 = 1. \] (A54)

**Aggregation**

The price dispersion, $\nu_t^p$, is,

\[ \nu_t^p = \phi_p \nu_t^p (\Pi_{t-1})^{-\zeta p} \Pi_t^p + (1 - \phi_p) \left( \frac{1 - \phi_p \Pi_{t-1}^{\phi(1-\phi_p)} \Pi_t^{\phi-1}}{1 - \phi_p} \right)^{-\frac{\zeta p}{\phi p}}. \] (A55)

Evolution of aggregate price is $(P_t)^{1-\epsilon_p} = (1 - \phi_p) P_t^\theta(1-\epsilon_p) + \int_{f-\phi_p}^1 (\Pi_{t-1})^{1-\epsilon_p} P_{f,t-1}^{1-\epsilon_p} df$.

This can be written in terms of the inflation rate:

\[ (P_t)^{1-\epsilon_p} = (1 - \phi_p) (P_t^\theta)^{1-\epsilon_p} + \phi_p (\Pi_{t-1})^{1-\epsilon_p}. \] (A56)

Fisher equation (the link between nominal and real interest rate) can be described as

\[ 1 + \epsilon_t = (R_{t+1}) (\Pi_{t+1}). \]

**3.A.3 Log-linearised equations**

**Household sector and labour market**

\[ \lambda_t = \frac{-1}{(1 - b)(1 - \beta b)} [C_t - bC_{t-1} - \beta (C_{t+1} - bC_t) - (1 - b) (\theta_t - \beta \theta_{t+1})]; \] (A57)

\[ \lambda_{t+1} + R_{t+1} = 0; \] (A58)

\[ \lambda_{t+1} = \lambda_{t+1} - \lambda_t; \] (A59)

\[ (1 + \epsilon w) w_t^\theta = f_{1,t} - f_{2,t} + \mu_t^\nu; \] (A60)

\[ f_{1,t} = \psi w^{\epsilon w} (1 + \eta) \lambda_t + \epsilon w (1 + \eta) \Pi_t + \epsilon w (1 + \eta) \Pi_{t+1} + f_{1,t+1}; \] (A61)

\[ f_{2,t+1} = \psi w^{\epsilon w} (1 + \eta) \lambda_t + \epsilon w \psi f_2 \left[ \lambda_t + \epsilon w (1 + \eta) \Pi_t + (\epsilon w - 1) \Pi_{t+1} + f_{2,t+1} \right]; \] (A62)

\[ w_t = (1 - \epsilon w) w_t^\theta + \phi_w (\zeta w \Pi_{t-1} - \Pi_t + w_{t-1}). \] (A63)

**Financial sector**

\[ \nu \nu_t = (1 - \theta) \beta [(R_t - R) \Lambda_{t+1} + R_t R_{k,t+1} - RR_{t+1}] - \theta \beta (R_t - R) \theta_{t+1} \]

\[ + \beta \theta \nu \psi \Lambda_{t+1} + \epsilon_t + m_{t+1} + \epsilon_{t+1}; \] (A64)

\[ H H_t = (1 - \theta) \beta R (\Lambda_{t+1} + R_{t+1}) - \beta \theta R \theta_{t+1} + \beta \psi J \Lambda_{t+1} + \epsilon_{t+1} + H_{t+1} + \theta_{t+1}; \] (A65)

\[ \nu \psi \phi \phi_{t-1} - \psi \nu (\epsilon_{t-1} + \epsilon_t) = H H_t; \] (A66)

\[ m_{t+1} = \psi \phi_{t+1} - \phi_t + \epsilon_{t+1}; \] (A67)

\[ j j_t = \phi \phi_{t-1} (R_t - R) + \psi (R_t R_{k,t} - RR_t) + RR_t; \] (A68)
Chapter 3. The role of financial shocks in business cycles with a liability side financial friction

\[ E_t = \frac{E_e}{E} E_{e,t} + \frac{E_a}{E} E_{n,t}; \quad (A69) \]
\[ E_{e,t} = j_t + E_{t-1}; \quad (A70) \]
\[ E_{n,t} = Q_t + k_t + \xi_t; \quad (A71) \]
\[ efp_t = R_{kt+1} - R_{t+1}. \quad (A72) \]

**Intermediate goods sector**

\[ w_t = P_{m,t} + Y_{m,t} - N_t; \quad (A73) \]
\[ R_k K (R_{k,t+1} + Q_t + K_{t+1}) = \alpha Y_{m,t} P_m (P_{m,t+1} + Y_{m,t+1}) + K (Q_{t+1} + \xi_{t+1} + K_{t+1}) - \delta K (\delta_{t+1} + \xi_{t+1} + K_{t+1}); \quad (A74) \]
\[ Y_{m,t} = \Lambda_t + \alpha U_t + \alpha \xi_t + \alpha K_t + (1 - \alpha) N_t; \quad (A75) \]
\[ \delta \overline{\delta - \delta ss} \delta_t = (1 + \zeta) U_t; \quad (A76) \]
\[ P_{m,t} + Y_{m,t} - U_t = \zeta U_t + \xi_t + K_t. \quad (A77) \]

**Capital producer**

\[ Q_t = \tau (I_t - I_{t-1}) - \beta \tau (I_{t+1} - I_t) - z_t; \quad (A78) \]
\[ KK_{t+1} = I (z_t + I_t) + K (\xi_t + K_t) - \delta K (\delta(U)_t + \xi_t + K_t). \quad (A79) \]

**Retail sector**

\[ Y_t = Y_{m,t} + \nu_t^p; \quad (A80) \]
\[ \nu_t^p = \phi_p (\nu_{t-1}^p - \zeta p \epsilon_p \Pi_{t-1} + \epsilon_p \Pi_t) + \epsilon_p \phi_p \frac{1}{\phi_p} \{(1 - \phi_p) \zeta p \Pi_{t-1} + (\phi_p - 1) \Pi_t\}; \quad (A81) \]
\[ x_{11,t} = Y P_m (Y_t + P_{m,t}) + \beta \phi_p x_{11} [\Lambda_{t+1} + x_{11,t+1} + \zeta p \epsilon_p \Pi_t + \epsilon_p \Pi_{t+1}]; \quad (A82) \]
\[ x_{22,t} = YY_t + \beta \phi_p x_2 [\phi_p (1 - \epsilon_p) \Pi_t + \Lambda_{t+1} + x_{22,t+1} + (\epsilon_p - 1) \Pi_{t+1}]; \quad (A83) \]
\[ \Pi_t^\# = x_{11,t} - x_{22,t} + \Pi_t + \mu_t^p; \quad (A84) \]
\[ \Pi_t = \phi_p \delta \Pi_{t-1} + (1 - \phi_p) \Pi_t^\#. \quad (A85) \]

**Government, monetary policy and others**

\[ G_t = \omega_t^q + Y_t; \quad (A86) \]
\[ YY_t = CC_t + \Pi_t + 0.2Y (Y_t + \omega_t^q); \quad (A87) \]
\[ \iota_t = R_{t+1} + \Pi_{t+1}; \quad (A88) \]
\[ \iota_t = \rho \iota_{t-1} + (1 - \rho) [\phi \Pi_t + \phi Y (Y_t - Y_{t-1}) + \epsilon_{t,t}]; \quad (A89) \]
\[ efp_t = R_{kt+1} - R_{t+1}; \quad (A90) \]
\[ \gamma \gamma_t = \kappa efp_t; \quad (A91) \]
\[ q_t + K_{t+1} = \phi c_t + E_t; \quad (A92) \]
\[ \phi c_t + \gamma_t = \phi_t. \quad (A93) \]

### 3.A.4 Data construction

Details of the data construction to match with the model variables are as follows:

Output: Nominal GDP (Line 1, Table 1.1.5 BEA) is divided by civilian non-institutional population (CNP) (BLS Series: LNU00000000) and GDP deflator (Line 1, Table 1.1.4 BEA).
Consumption: Personal consumption expenditure (Line 5 & 6, Table 1.1.5 BEA) including non-durable goods and services divided by CNP and GDP deflator.

Investment: Non residential and residential fixed investment (Line 9, 12, Table 1.1.5 BEA) and consumption expenditure on durable goods (Line 4, Table 1.1.5 BEA) are considered as investment which is then divided by CNP and GDP deflator.

Hours worked: Total hours worked in non-farm business sector (Series PRS85006033 BLS) divided by CNP.

Inflation: Computed as log difference of the GDP deflator (Line 1, Table 1.1.4 BEA).

Nominal interest rate: Effective Federal Funds Rate (Series FEDFUNDS, FRED database-FED St.Louis) divided by four to make quarterly rate.

Spread: The proxy for spread or external finance premium is the difference between Moody’s seasoned BAA corporate bond yield and the long term government bond yield (FRED database-FED St.Louis).
Chapter 3. The role of financial shocks in business cycles with a liability side financial friction
Chapter 4

Oligopolistic financial sector in a small open economy

Abstract

The chapter constructs a small open-economy model with an oligopolistic banking sector. Imperfect competition among banks is measured through mark ups in lending rates which depend on the number of competing banks. The number of banks in turn is determined endogenously. Using Australian data, the estimated model implies a countercyclical interest mark-up that varies inversely with the number of banks. The market power of banks often amplifies business cycles, depending on the type of shock. Such competition in the banking sector has a distinct shock propagation mechanism that is worthy of serious consideration by economists and policymakers.

4.1 Introduction

Financial sector is understudied in DSGE model with oligopolistic competition. Although a number of studies discuss such competition effect for goods production sector in business cycle literature, structural models with financial sector are often muted about the strategic interaction between banks, endogeneity of the number of competitors and the impact of new bank entry on the strategic interactions. These are particularly important for countries where financial sector is highly concentrated.
Figure 4.1: 5-bank asset concentration (1996-2014)

Source: The chart is produced from Fred Economic data.
Among OECD countries, the 5-Bank asset concentration ratio presented in Fig. 4.1, shows that five banks hold more than 80 percent of total bank assets in Australia, Canada, New Zealand and in Euro area. In contrast, asset market is less concentrated in the USA, UK and Japan. A highly concentrated and oligopolistic bank industry, through strategic interaction between the banks, can affect loan pricing, volume and other non-interest charges in a way that make banking services expensive and at suboptimal level.

An oligopolistic bank model with endogenous entry suggests a causality that an increasing mass of banks leads to declining market shares of the existing banks. During an economic boom, greater profit opportunities and lower entry costs may encourage new banks to enter the market which in turn lowers the concentration ratio. Reduced market share of each bank weakens a bank’s ability to charge high interest mark ups. This indicates that the incumbent banks enjoy more market power in recessions as weaker banks exit the market or are taken over by the big banks (e.g. St. George bank being taken over by Westpac bank in Australia in December 2008). In Australian data, although the number of banks operating in the market is pro-cyclical, its correlation with output is not high as shown in Table 4.1.

<table>
<thead>
<tr>
<th></th>
<th>Mark up</th>
<th>Output</th>
<th>No. of banks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mark up</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>-0.1516</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>No. of banks</td>
<td>-0.2143</td>
<td>0.1199</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Author’s calculation from Australian Prudential Regulation Authority (APRA) and Reserve Bank of Australia (RBA) statistics. Correlations are in de-trended data.

In Australia, the top four banks hold more than eighty percent of total deposits and loans. Fig. 4.2 shows, starting from 2004, that the top four banks’ shares were declining slightly from 80 percent level and then rising steadily above 80 percent after September 2008.
Figure 4.2: Market share of the big four banks* in Australia (2004-2016)

Source: Author's calculation from Australian Prudential Regulation Authority (APRA) statistics. * The banks are ANZ Bank, Commonwealth Bank, National Australia Bank, and Westpac Bank
4.1. Introduction

Given the growth condition before 2008, the growing entry of smaller banks facilitated the decline in share of big four banks which was sharply reversed when the global financial crisis unfolded. The trend is similar for total bank assets and liabilities. If more banks enter the market, then existing banks’ ability to set higher interest mark ups is curbed.

Perfect competition assumption commonly held in DSGE models with financial frictions can be inappropriate for some countries. High profitability of the oligopolistic banks ensures large capital bases and strong balance sheet positions compared to the perfectly competitive banks. Therefore, the roles of banks as accelerators and the endogenous bank balance sheet constraint discussed in Chapter 3 may be different under oligopolistic competition. Also, greater power in loan market may deter the incumbent banks from sufficiently responding to monetary policy changes, making the ground difficult for monetary policy to influence retail lending rates.

Different from the analysis of financial frictions in the literature (Bernanke et al. 1999a, Gertler & Karadi 2011 and Gerali et al. 2010 for example), this chapter examines the financial sector in terms of its market competition structure in a DSGE model. Hence, the chapter is related to the literature of endogenous firm entry and imperfect competition, mainly monopolistic competition, as in Ghironi & Melitz (2005) and Bilbiie et al. (2008). Based on these studies, the work of Etro & Colciago (2010) analyses strategic interaction and endogenous firm entry in terms of both Bertrand competition and Cournot competition for goods production market. The contributions of oligopolistic models such as, Etro & Colciago (2010), Faia (2012) and others feature supply side strategic complementarities in which the dependence between mark up and the number of firms arises from oligopolistic competition.

Influenced by the work of Etro & Colciago (2010) and others on the product market, I bring such oligopolistic (Bertrand) competition in the finance sector where banks are
able to set the prices (lending rates) of their products (i.e. loans) based on their market power. Although empirical studies investigate monopolistically competitive finance sector (e.g. Gerali et al. 2010), the literature (except Totzek 2011, to the best of my knowledge) has not expanded much in the direction of a scenario where loan mark up depends inversely on the number of competing banks. Totzek (2011) applies this theory to the bank sector in a calibrated DSGE model where bank loans are created to finance wage bills. The close economy model of Totzek (2011) has no capital accumulation, hence the model is not suitable to investigate the role of oligopolistic bank competition on investment and capital dynamics as well as impacts of financial shocks relating to the asset market.

Therefore, main objective of Chapter 4 is to construct a DSGE model to study the oligopolistic bank sector from the macro perspective of a small open economy in which bank loans are used to finance capital expenditures. To assess whether oligopolistic banks amplify or neutralise foreign shock impacts, the model is expanded with standard open economy features along the lines of Adolfson et al. (2007) for the Euro area and Jasskela & Nimark (2011) for Australia. Then, a Bayesian estimation of the model is carried out with Australian data as the country is characterised by such a bank sector. So, this study contributes to the literature by answering following questions: whether frictions arising from oligopolistic competition among banks are important in modelling an economy with highly concentrated bank industry; and how such financial frictions affect the transmission mechanisms of various real sector shocks arising in domestic and external economies? The issues are also analysed by comparing these results with those from a competitive finance sector case. From a modelling perspective, the departure point is the model described in Chapter 3, which is reconstructed to capture the oligopolistic competition in the financial sector. This is purely a supply side friction, similar to Gertler & Karadi (2011), but the source of friction is market power of the banks rather than any agency problem between depositors and bankers.
The main contributions of this chapter are: it captures strategic interactions among financial intermediaries in an estimated DSGE model and thereby studies the links between the endogeneity of the intermediaries and the business cycles properties of an open economy. Additionally, the chapter compares the role of oligopolistic bank sector to a perfectly competitive case to filter out the imperfect competition effects. Second, the chapter redesigns the firm entry condition in case of bank sector where a prospective bank requires a fixed sunk entry cost (deposits or other household resources) and the overall entry cost is inversely affected by the neutral technology shock. A positive technology shock is expected to reduce the costs of new entrants and thereby facilitates banks to enter into the market. This is a novel feature of the model and thus, neutral technology shock is truly an economy wide shock in the model. Third, the bank loan is linked to the real sector through financing capital expenditures (including housing) instead of working capital (wage cost) of domestic production. This allows us to study the impacts of oligopolistic banks on capital accumulation and investment dynamics, and shocks therein. Fourth, external shocks are highly emphasised in open economy VAR based studies, hence, this chapter analyses whether oligopolistic banks act as cushions or amplifiers to such shocks. Finally, given that there are few estimation examples of endogenous firm entry models, the estimation of the current study aims to help future research in this line. No study to date analyses the imperfect competition of Australian bank sector from a macro perspective. The official model of the Reserve Bank of Australia (RBA) (Rees et al. 2016), contains a separate resource sector but does not consider any financial sector in it.

The main results suggest that oligopolistic competition with endogenous bank entry can produce empirically stylised facts such as counter cyclical mark ups in lending rates. However, the response is estimated to be small for Australia. Second, financial sector may act as an accelerator for some but not for every shock. Foreign shocks, along with domestic shocks, are important for both output and employment variations while monetary policy
has a smaller role.

The remainder of the chapter is organised as follows: Section 4.2 contains the model description while Section 4.3 describes data and estimation details. Fit of the estimated model is discussed in Section 4.4. Model applications and a comparison with competitive bank sector are discussed in Section 4.5. The sensitivity of the baseline estimation is presented in Section 4.6. Finally, Section 4.7 concludes the discussion.

4.2 Model

This section contains the construction of the model economy that has an oligopolistically competitive financial sector. The model in built upon the model in Chapter 3 by expanding it to two important dimensions: financial frictions due to oligopolistic competition, and trade and financial flows with the rest of the world. All model equations and their log-linearized version are listed in the Appendix Section 4.A.

4.2.1 Households

There is a continuum of households of measure unity and their characteristics, including labour supply decisions, are similar to Chapter 3. Now, households save a fraction of their income as domestic bank deposits ($B_t$) and in foreign bonds ($B^*_t$), pay taxes ($T_t$) and receive transfers (net-transfer) from the ownerships of firms. Household’s consumption basket ($C_t$) is a CES aggregate of domestic ($C_{d,t}$) and imported ($C_{m,t}$) consumption goods. Banks are owned by households, so, they hold bank shares $x_t$ at value $\nu_t$. The number of total banks in any period is $N_{B,t}^h = N_{B,t} + N_{BE,t}$. Here, $N_{B,t}$ is the mass of banks that are in operation and gives dividend income $d_t$. Newly entrant banks, $N_{BE,t}$, are assumed to take some time to start banking operation after entering the market. Assuming $\delta^b$ as the probability that a bank may die/exit, the evolution of banks occur as,

$$N_{B,t+1} = \left(1 - \delta^b\right) \left(N_{B,t} + N_{BE,t}\right). \quad (4.1)$$
The household utility function is standard and consists of consumption with habit \((b)\) formation and labour supply as,

\[
E \sum_{s=0}^{\infty} \beta^s q_{t+s} \left[ \ln(C_{t+s} - bC_{t+s-1}) - \psi \frac{N_{t+s}(l)^{1+\eta}}{1+\eta} \right].
\]

Households maximise utility subject to

\[
\frac{W_t(l)}{P_t} N_t(l) + (1 + i_t) \frac{B_t}{P_t} - \frac{B_{t+1}}{P_t} + (1 + i_{t+1}^* \Phi \left( f_{a_t, \tilde{\varrho}_t} \right) \frac{S_t B_{t+1}}{P_t} - \frac{S_t B_{t+1}^*}{P_t} + B^*_t \left( S_t - S_{t-1} \right) + \nu_t x_{t+1} + \text{net} transfer_t - \frac{x_t}{(d_t + \nu_t)} - \frac{P_{c,t}}{P_t} C_t - T_t = 0 \quad (4.3)
\]

and a downward sloping labour demand curve from the employment agency. Here, \(q_t\) is the inter-temporal preference shock that affects the marginal utility of consumption and marginal dis-utility of labour and follows a mean zero AR(1) process, \(\log q_t = \rho \log q_{t-1} + \varepsilon_{\varrho,t} \sim i.i.d(0, \sigma^2_{\varrho})\). Similar to Adolfson et al. (2007), \(\Phi \left( f_{a_t, \tilde{\varrho}_t} \right)\) is a premium on foreign bond holdings. The premium depends on the real aggregate net foreign asset \(\left( f_{a_t} \right)\) position of the domestic economy, defined as \(f_{a_t} \equiv \frac{S_t B_{t+1}^*}{P_t}\), and on \(\tilde{\varrho}_t\) which is a shock to the risk premium. Here, \(P_t\) is the domestic production price and \(P_{c,t}\) is the consumer price (CPI). Deposits earn net interest rate \(i_t\) in domestic market, whereas interest rate in the foreign market is \(i_{t+1}^*\). Here, \(\psi\) is the coefficient of leisure and \(\eta\) is the inverse Frisch elasticity parameter. In each period, there is \((1 - \phi_w)\) probability that a household can adjust its wage. If it cannot, then it indexes the wage to the lagged inflation at rate \(\psi_w(0,1)\). The optimal conditions are:

\[
\frac{P_{c,t}}{P_t} \lambda_t = \frac{\varrho_t}{C_t - bC_{t-1}} - \frac{\beta b \varrho_{t+1}}{C_{t+1} - bC_t},
\]

\[
\lambda_t \nu_t = \beta \lambda_{t+1} \frac{1}{(d_{t+1} + \nu_{t+1})},
\]

\[
1 = \beta \lambda_{t+1} R_{t+1},
\]

\[
\lambda_t \frac{S_t}{P_t} = \beta \lambda_{t+1} + (1 + i_{t+1}^*) \Phi \left( f_{a_t, \tilde{\varrho}_t} \right) + \beta \lambda_{t+1} \left( S_{t+1} - S_t \right) \frac{P_{c,t}}{P_{t+1}},
\]

\[
\epsilon_w w_t(l)^{-\epsilon_w(1+\eta)-1} \sum_{s=0}^{\infty} (\beta \phi_w)^s \varrho_t \psi w_{t+s}^{\epsilon_w(1+\eta)} \Pi_{t,l,t+s}^{\epsilon_w(1+\eta)} \Pi_{c,l-1,t+s-1}^{\epsilon_w(1+\eta)} N_{t+s}^{1+\eta} + (1 - \epsilon_w) w_t(l)^{-\epsilon_w} \sum_{s=0}^{\infty} (\beta \phi_w)^s \lambda_{t+s} \Pi_{t,l,t+s}^{\epsilon_w-1} \Pi_{c,l-1,t+s-1}^{\epsilon_w(1+\eta)} w_{t+s}^{\epsilon_w} N_{t+s} = 0.
\]
Here, I define $A_{t+1} = \frac{\lambda_{t+1}}{\lambda_t}$ in Eq.(4.6) and $R_t$ is the real interest rate coming from Fisher relation. Eq.(4.6) and Eq.(4.7) imply,

$$1 = \frac{S_{t+1}}{S_t} \left(1 + i_t^* \right) \Phi \left( \tilde{u}_t, \tilde{\phi}_t \right) + \frac{1}{(1 + i_t)^2} \left( \frac{S_{t+1}}{S_t} - 1 \right). \quad (4.9)$$

In Eq.(4.8), the model assumes a time varying wage mark-up, $\frac{\epsilon_{w_t}}{\epsilon_{w_t} - 1} \mu_t^p$, similar to Chapter 3 but now $\Pi_t$ is domestic producers price inflation and $\Pi_{c,t}$ is consumer price inflation.

### 4.2.2 Financial intermediaries

Banks collect deposits from domestic households without facing any competition in deposit collection and lend these funds to the intermediate production sector for acquiring capital machineries (including housing etc. as in Chapter 3). Thus, market power is analysed for the loan market only, not for deposits since Olivero (2010) and references therein find little evidence for market power in deposit market. In the model, bank loan is connected to the real sector’s need for financing capital expenditures, in order to find the impacts of oligopolistic bank competition on capital accumulation directly for investment and capital related shocks. This is different from the model of Totzek (2011) which has no capital accumulation and bank loan is used to finance working capital loans. Here, banking sector is assumed not directly to be connected to the rest of the world and activities are limited within the domestic economy for simplicity. This is a reasonable assumption in case of Australia, given that the Australian banks have smaller exposure to the international financial market which is even shrinking recently (RBA April 2017). For simplicity, I also assume there is no regulatory cash reserve requirement, hence, banks can use the entire deposits and/or money market credits to make loans. Bank customers are loyal and reluctant to switch to other banks frequently, which is a reasonable assumption for Australia (see more on banking habit in Australia in Fear et al. 2010).

Higher profit opportunities during economic boom attract more banks to enter the
market and increase the number of banks. This results in a decrease in the market share of each single bank operating in the market and thereby decreases the power to charge mark ups higher above the marginal costs of making loans. Reduced interest mark ups will decrease the marginal costs of domestic production sector and may increase the demand for capital machineries for more production activities. As a feedback effect, the increased demand for capital increases the stock market price of capital which in turn improves the bank balance sheet condition through collateral valuation channel. Improved balance sheet condition tends to ease credit market condition further, accelerating the economic boom. Therefore, increased demand for loans and greater profit opportunities in bank sector indicate financial accelerator effects. In contrary, if barriers to entry is high in terms of high entry costs, bigger profit opportunities can make existing oligopolistic banks stronger in terms of balance sheet positions, compared to the competitive banks. It implies greater financial stability under oligopolistic competition that goes in opposite direction of the accelerator effect. However, financial stability is dependent on loan default probability along with many other factors which the model does not deal with to maintain simplicity.

The linear loan production function of a particular bank $j$ is, $o_{j,t} = F_{j,t}$, where loan $o_{j,t}$ is created out of funds $F_{j,t}$ which consists of deposits and money market credits. Similar to Hulsewig et al. (2009) and Totzek (2011) it is assumed that deposits ($B_t$) and money market credit ($m_t$) are perfect substitute and banks pay same return $i_t$ for them. This also implies that central bank’s policy rate ($i_t$) and money market rate ($i^M_t$) are equal: $i_t = i^M_t$. So banks pay competitive rates in deposit market but act strategically in loan market (with symmetric equilibria). If $N_{B,t} > 1$ is the mass of banks in the market, then real aggregate loan, $O_t$, using Dixit-Stiglitz aggregator is,

$$O_t = \left[ \int_0^{N_{B,t}} \frac{\epsilon_{b}^{\epsilon_{b}-1}}{\epsilon_{b}} \right]^{\epsilon_{b}}$$

(4.10)

where, $\epsilon_{b} > 1$ is the intra-temporal elasticity between loans. Aggregate loan $O_t = Q_{t-1}K_t$
where, $Q_{t-1}$ is the price of capital $K_t$. We assume, there are only few banks in the market, therefore, each bank $j$ can control the return $r_{kj,t}$ on its loans depending on its market share. Therefore, aggregate loan rate ($R_{k,t}$) is,

$$R_{k,t} = \left[ \int_0^{N_B} \frac{1}{r_{kj,t}^1 - \epsilon_b} \right]^{1/\epsilon_b}.$$  \hspace{1cm} (4.11)

This results in a downward sloping loan demand function faced by an individual bank $j$:

$$o_{j,t} = \left( \frac{r_{kj,t}}{R_{k,t}} \right)^{-\epsilon_b} O_t.$$ \hspace{1cm} (4.12)

The individual bank $j$’s profit function per period can be written as

$$d_{j,t} = r_{kj,t} o_{j,t} - (1 + i_t) B_{j,t} - (1 + i_t^M) m_{j,t} = r_{kj,t} o_{j,t} - (1 + i_t) (B_{j,t} + m_{j,t}) = [r_{kj,t} - (1 + i_t)] o_{j,t},$$ \hspace{1cm} (4.13)

where, $m_{j,t}$ is the net position in the money market. Thus a bank maximises profit

$$\text{Max}_{r_{kj,t}} d_{j,t} = [r_{kj,t} - (1 + i_t)] o_{j,t}$$ \hspace{1cm} (4.14)

subject to the loan demand Eq.(4.12). It is assumed that total lending is equalised between banks by their customers and this is also perceived as given by the banks. Each bank $j$ chooses $r_{kj,t}$ to maximise its profit taken into account the rates of other banks. The optimal condition with respect to $r_{kj,t}$:

$$\frac{\delta d_{j,t}}{\delta r_{kj,t}} = o_{j,t} + r_{kj,t} \frac{\delta o_{j,t}}{\delta r_{kj,t}} - (1 + i_t) \frac{\delta o_{j,t}}{\delta r_{kj,t}} = 0.$$ \hspace{1cm} (4.15)

Under strategic rate setting, the effect of a change in lending rate on demand for loan can be decomposed into:

$$\frac{\delta o_{j,t}}{\delta r_{kj,t}} = -\epsilon_b \frac{1}{r_{kj,t}^1 - \epsilon_b} O_t + \epsilon_b \left( \frac{r_{kj,t}}{R_{k,t}} \right)^{-\epsilon_b} \frac{1}{R_{k,t} - O_t} \frac{\delta R_{k,t}}{\delta r_{kj,t}}$$ \hspace{1cm} (4.16)

where, $\frac{\delta R_{k,t}}{\delta r_{kj,t}} = \left( \frac{r_{kj,t}}{R_{k,t}} \right)^{-\epsilon_b}$. Individual loan rate $r_{kj,t}$ affects the aggregate loan rate $R_{k,t}$ directly and thereby quantity of loan. This is in contrast to monopolistic competition.

Applying Eq.(4.12) we get the following:

$$\frac{\delta R_{k,t}}{\delta r_{kj,t}} = \frac{o_{j,t}}{O_t}.$$ \hspace{1cm} (4.17)

We can define the market share of an individual bank $j$ as $\varsigma_{jt} \equiv \frac{r_{kj,t} o_{j,t}}{R_{k,t} O_t}$ and insert
4.2. Model

Eq. (4.17) into Eq. (4.16) to get how an individual loan rate affects the demand for loan:

\[
\frac{\delta o_{jt}}{\delta r_{k,jt}} = \epsilon_b \frac{o_{jt}}{r_{k,jt}} (\varsigma_{jt} - 1).
\] (4.18)

We can solve the first order condition (Eq. (4.15)) further using Eq. (4.18) as,

\[
r_{k,jt} = \frac{(1 - \varsigma_{jt}) \epsilon_b}{(1 - \varsigma_{jt}) \epsilon_b - 1} (1 + i_t) = \mu_{jt} (1 + i_t),
\] (4.19)

where,

\[
\mu_{jt} = \frac{(1 - \varsigma_{jt}) \epsilon_b}{(1 - \varsigma_{jt}) \epsilon_b - 1} = \frac{\epsilon_b}{\epsilon_b - \frac{1}{1 - \varsigma_{jt}}}. \tag{4.20}
\]

Eq. (4.20) suggests that mark up, \(\mu_{jt}\), of bank \(j\) depends on its market share \((\varsigma_{jt})\) and intratemporal elasticity \((\epsilon_b)\). This mark up condition, Eq. (4.20), is similar to other studies in oligopolistic competition and endogenous firm entry literature such as Faia (2012) for the production sector and Totzek (2011) for the finance sector. As, \(\varsigma_{jt} \to 0\), then mark up \(\mu_{jt} \to \frac{\epsilon_b}{\epsilon_b - 1}\) which is a constant. If there are numerous banks in the market that each holding very little market share, then mark up depends only on the elasticity \((\epsilon_b)\), similar to the monopolistic competition. Assuming symmetry between \(N_{B,t}\) banks implies, \(o_{jt} = o_t\) and \(r_{k,jt} = r_{k,t}\). Then Eq. (4.12) and Eq. (4.11) can be written as,

\[
O_t = N_{B,t}^{1-\epsilon_b} o_t, \tag{4.21}
\]

\[
R_{k,t} = N_{B,t}^{1-\epsilon_b} r_{k,t}. \tag{4.22}
\]

Eq. (4.21) and Eq. (4.22) suggest that if the mass of banks increases, aggregate loan in the market increases too with a decrease in lending rate. Under symmetry between banks, the definition of market share can also be expressed as \(\varsigma_{jt} = \varsigma_t = \frac{r_{k,t} o_t}{R_{k,t} O_t} = \frac{1}{N_{B,t}}\). This allows us to write the mark up Eq. (4.20) and optimal condition Eq. (4.19) respectively as,

\[
\mu_t = \frac{(N_{B,t} - 1) \epsilon_b}{(N_{B,t} - 1) \epsilon_b - N_{B,t}}, \tag{4.23}
\]

\[
r_{k,t} = \frac{(N_{B,t} - 1) \epsilon_b}{(N_{B,t} - 1) \epsilon_b - N_{B,t}} (1 + i_t) = \mu_t (1 + i_t). \tag{4.24}
\]

Eq. (4.24) is the optimal condition with the assumption that banks face no adjustment costs in changing loan rates. Alternatively, we can assume that banks face quadratic
adjustment costs as in Rotemberg (1982) style, when changing loan rates:

$$\Omega = \frac{\kappa_b}{2} \left( \frac{r_{k,t}}{r_{k,t-1}} - 1 \right)^2 O_t, \quad (4.25)$$

where, \( \kappa_b \) is the adjustment cost (e.g menu costs) parameter. If \( \kappa_b = 0 \), we end up with the flexible rate case Eq.(4.24). Bank’s profit and optimal condition with such adjustment cost change to

$$d_{j,t} = (r_{k,j,t} - (1 + i_t)) o_{j,t} - \frac{\kappa_b}{2} \left( \frac{r_{k,j,t}}{r_{k,t-1}} - 1 \right)^2 O_t, \quad (4.26)$$

$$r_{kj,t} = \frac{(1 - \varsigma_{jt}) \epsilon_b}{(1 - \varsigma_{jt}) \epsilon_b - 1} (1 + i_t) - \frac{\kappa_b}{(1 - \varsigma_{jt}) \epsilon_b - 1} \theta_{j,t}, \quad (4.27)$$

where,

$$\theta_{j,t} = \left( \frac{r_{k,j,t}}{r_{k,j,t-1}} - 1 \right) \frac{r_{k,t} o_{j,t}}{r_{k,j,t} o_{j,t}} - \beta A_{t+1} \left( \frac{r_{k,j,t+1}}{r_{k,j,t}} - 1 \right) \frac{r_{k,j,t+1} O_{t+1}}{r_{k,j,t} O_{j,t}}. \quad (4.28)$$

**Bank entry**

The endogenous bank entry condition relates to the firm entry model such as Etro & Colciago (2010) and Bilbiie et al. (2008). The number of banks in the economy evolves according to Eq.(4.1). The number of new banks entering each period, \( N_{BE,t} \), is determined by an entry condition. It is assumed that entry requires a fixed cost of loan production in units of deposits. The loan production function suggests that costs of one dollar loan is \( i_t \) that earns a gross return \( R_{k,t} \). So, a spending of \( 1 + i_t \) produces a gross loan including return \( R_{k,t} \). Normalising the deposit cost by lending rate gives the marginal cost of one dollar gross loan, \( \frac{1+i_t}{R_{k,t}} \). Before entering the market, banks incur a fixed sunk cost, \( fe \) (as in Bilbiie et al. 2012) which is proportional to the real marginal cost of its loan. Here, I assume \( fe \) as fixed in the base line model. If the sunk cost is high, entry becomes difficult for new entrants. I further assume that the neutral technology shock, \( A_t \), affects the productivity of the resources required to set up a bank, and therefore, affects the overall costs of entry inversely. For example, a positive technology shock is likely to make the resources more effective that reduces the required sunk costs, thus, facilitating bank entry. Hence, the assumption that this shock affects the productivity of resources in the goods production and also in bank creation appears reasonable. This makes neutral technology \( A_t \) a truly
4.2. Model

4.2. Model 123

An economy-wide shock in this model. Hence, different from Totzek (2011), the bank entry cost is defined as,

$$Cost_{BE,t} = f_e \frac{1 + i_t}{A_t R_{k,t}}. \quad (4.29)$$

Bilbiie et al. (2012) describes entry costs as development and set-up cost for new firms. Given the nature of the banking firms, the required fixed sunk cost is expected to be much higher than that required in the goods production sector which should be reflected in the calibration of the model. New banking firms want to enter the market if entry is profitable. Entry condition dictates that new banks enter into the market until the value of a bank ($\nu_t$) is equal to the entry costs:

$$\nu_t = f_e \frac{1 + i_t}{A_t R_{k,t}}. \quad (4.30)$$

Applying Fisher equation and Eq.(4.19), bank entry condition reduces to

$$\nu_t = f_e \frac{R_{t+1} \Pi_{c,t+1}}{A_t r_{k,t} N_{B,t}^{1-\gamma_b}} = f_e \frac{R_{t+1} \Pi_{c,t+1}}{A_t (\mu_t (1 + i_t)) N_{B,t}^{1-\gamma_b}} = f_e \frac{R_{t+1} \Pi_{c,t+1}}{A_t (\mu_t R_{t+1} \Pi_{c,t+1}) N_{B,t}^{1-\gamma_b}} = f_e \frac{1}{A_t \mu_t} N_{B,t}^{\gamma_b-1}. \quad (4.31)$$

Here, the bank value $\nu_t$ is given by the Euler equation for bank share (Eq.(4.5)):

$$\nu_t = \left(1 - \delta^b\right) \beta A_{t+1} \frac{1}{(d_{t+1} + \nu_{t+1})}. \quad (4.32)$$

4.2.3 Domestic production sector

Domestic intermediate goods producers borrow from banks in a frictionless manner to finance capital expenditures $(Q_t K_{t+1})$ and pay interest rate $R_{k,t}$ charged by the banks. The production function is

$$Y_{m,t} = A_t (u_t \xi_t K_t)^\alpha N_t^{1-\alpha}, \quad (4.33)$$

where, $\xi_t$ is a source of exogenous variations in the quality of capital as described in Chapter 3. Although Gertler & Karadi (2011) introduced $\xi_t$ to replicate the US housing market collapse, the shock cannot distinguish between exogenous changes in asset price
and physical destruction of capital (see Afrin 2017 for details). Nevertheless, it serves as an important shock which has not been analysed for Australia. It is assumed that both $A_t$ and $\xi_t$ follow $AR(1)$ processes similar to Chapter 3. I keep the capital depreciation rate ($\delta_t$) variable with utilisation rate ($u_t$), as in Born et al. (2013):

$$\delta (u_t) = \delta_0 + \delta_1 (u_t - 1) + \frac{\delta_2}{2} (u_t - 1)^2; \quad (4.34)$$

where $\delta_0$ is the steady state fixed depreciation rate. The intermediate goods sector is a price taker in its output market. If output price is $P_{m,t}$ then firm’s optimising behaviour shows that the return to the capital is affected by the exogenous variation in quality of capital:

$$R_{k,t+1} = P_{m,t+1} + (Q_{t+1} - \delta (u_{t+1})) \xi_{t+1}. \quad (4.35)$$

A separate retail sector, similar to Chapter 3 is considered to bring the nominal price rigidities in the domestic output market. The optimal pricing condition of domestic retailers in terms of re-set price inflation ($\Pi^i_t$) is in Appendix.

### 4.2.4 Capital goods producers

Domestic and foreign investment goods are related by CES aggregation:

$$I_{t+s} = \left[ (1 - \omega_i)^{\frac{1}{\eta_i}} I_{d,t+s}^{\eta_i - 1} + \omega_i^{\frac{1}{\eta_i}} I_{m,t+s}^{\eta_i - 1} \right]^{\frac{\eta_i}{\eta_i - 1}}, \quad (4.36)$$

where $\omega_i$ is the share of imported investment in $I_t$ and $\eta_i$ is the elasticity of substitution between them. Aggregate price for investment goods: $P_{i,t} = \left[ (1 - \omega_i) P_{t}^{1-\eta_i} + \omega_i P_{m,t}^{1-\eta_i} \right]^{\frac{1}{1-\eta_i}}$.

The capital producing firms buy used capital from the intermediate sector and repair the depreciated capital. Competitive capital producing firms also produce new capital goods and sell the new and refurbished capital machinery to the intermediate firms. Aggregate capital accumulation process can be described as,

$$K_{t+1} = Z_t \left( 1 - \frac{\tau}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \right) I_t + \xi_t (1 - \delta (u_t)) K_t. \quad (4.37)$$
Here, $Z_t$ is the marginal efficiency of investment (MEI) or investment specific technology shock that follow $AR(1)$ process with parameterisation as in Chapter 3. Here, $\tau$ is the inverse elasticity of net investment parameter in quadratic capital adjustment cost. Capital price, $Q_t \equiv \tilde{Q}_{t+1}$, is determined by the optimising behaviour of the capital producing firms.

Capital producers maximise the following discounted profit in real term:

$$\max \ E_t \sum_{s=0}^{\infty} \beta^s \frac{\lambda_{t+s}}{\lambda_{t+s-1}} \left\{ \frac{Q_{t+s}}{P_{t+s}} \tilde{Z}_{t+s} \left( 1 - \frac{\tau}{2} \left( \frac{I_{t+s}}{I_{t+s-1}} - 1 \right)^2 \right) I_{t+s} - \frac{P_{t+s}}{P_{t+s}} I_{t+s} - \frac{(Q_{t+s} - Q_{t+s-1})}{P_{t+s}} K_{t+s} \right\}.$$

(4.38)

The optimal condition is,

$$\frac{\tilde{Q}_t}{P_{t,t}} Z_t \left[ 1 - \frac{\tau}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 - \tau \left( \frac{I_{t+1}}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] + \beta \frac{Q_{t+1}}{P_{t+1}} \frac{\lambda_{t+1}}{\lambda_{t}} Z_{t+1} \tau \left( \frac{I_{t+1}}{I_t} - 1 \right) \left( \frac{I_{t+1}}{I_t} \right)^2 = 1.$$

(4.39)

### 4.2.5 Imports, Exports and Balance of Payments

The trade features of the model economy are standard and have conceptual similarities to Adolffson et al. (2007), hence the detail description is skipped. One of the differences from Adolffson et al. (2007) is that I do not incorporate any trend inflation in any of the sectors for simplicity, hence, my model is stationary. Also the external sector is structural, not a VAR specification. In addition, the assumptions relating to depreciation, capital utilisation, and investment adjustment costs in previous subsections are different from Adolffson et al. (2007). Importers of consumption ($C_{m,t}$) and investment ($I_{m,t}$) goods are assumed to be monopolistically competitive. Calvo price set up, similar to domestic retailers, is assumed.

There is a $(1 - \phi_{mc})$ probability that a consumption goods importer can change price in a period. If it cannot, it indexes price to last year’s inflation. Thus, $P_{mc,t+1} = \pi_{mc,t} P_{mc,t}$.

The profit function of the consumption importer:

$$\max \ E_t \sum_{s=0}^{\infty} \beta^s (\beta \phi_{mc})^s \lambda_{t+s}$$

$$< P_{mc,t}^j >$$
where, marginal cost \( mc_{mc,t+s} = P_{mc,t+s}^* + S_t \) and foreign currency price \( P_t^* \) is multiplied by the nominal exchange rate \( S_t \). Here, \( \epsilon_{mc} \) is the elasticity of demand for \( C_{m,t} \). The reset price inflation \( (\pi^#_{mc,t}) \) and aggregate inflation dynamics for imported consumption are listed in the Appendix. Similarly, we can derive the reset price inflation \( (\pi^#_{mi,t}) \) and subsequent other equations for imported investment goods sector.

Export firms buy domestic final goods at domestic producers price \( P_t \) and after brand naming sell them to foreign households. It is assumed that the export prices are sticky in the foreign currency price, \( P_{x,t}^* \). This is applied using Calvo setup to allow for incomplete exchange rate pass through. The linearized optimal condition of export firm is same as in Adolfson et al. (2007), except that I do not model trend inflation for exports. Export inflation equation is expressed in terms of mark up, not in terms of elasticities as in import sectors. Since the home economy is small compared to rest of the world, foreign demand for domestic consumption and investment goods are \( C_{x,t} = \left[ \frac{P_{x,t}}{P_t^*} \right]^{-\eta_{f}} C_{t}^* \) and \( I_{x,t} = \left[ \frac{P_{x,t}}{P_t^*} \right]^{-\eta_{f}} I_{t}^* \), where \( \eta_{f} \) is the foreign substitution elasticity. Thus, \( C_{x,t} + I_{x,t} = \left[ \frac{P_{x,t}}{P_t^*} \right]^{-\eta_{f}} Y_{t}^* \).

Evolution of net foreign assets at aggregate level:

\[
S_t B_{t+1}^* = S_t P_{x,t} (C_{x,t} + I_{x,t}) - S_t P_{t}^* (C_{m,t} + I_{m,t}) + (1 + i_{t}^*) \Phi \left( f_{a_{t-1}}, \tilde{\phi}_{t-1} \right) S_t B_{t}^*. \tag{4.41}
\]

Here, \( (1 + i_{t}^*) \Phi \left( f_{a_{t-1}}, \tilde{\phi}_{t-1} \right) \) is the risk adjusted gross nominal interest rate. The linearized net foreign asset equation can be expressed as,

\[
f_{\hat{a}_t} = \hat{X}_t - Y^* m_{c,t} + (C_m + I_m) \hat{\gamma}_{f,t} + C_m \left[ -\eta_{c} \left( 1 - \omega_{c} \right) \hat{\gamma}_{cd}^{-\left(1-\eta_{c}\right)} \hat{\gamma}_{mcd,t} + \hat{C}_{t} \right] + I_{m} \left[ -\eta_{i} \left( 1 - \omega_{i} \right) \hat{\gamma}_{id}^{-\left(1-\eta_{i}\right)} \hat{\gamma}_{mid,t} + \hat{I}_{t} \right] + R \left( \hat{f}_{a_{t-1}} \right). \tag{4.42}
\]
4.2.6 Government and the Monetary authority

Government finances its expenditures, \( G_t \), by lump-sum tax, \( T_t \). Thus, government budget constraint is \( G_t = T_t \). Government spending is assumed as an exogenous AR(1) process and subject to stochastic shock \( \varepsilon_{g,t} \). The central bank is responsible for monetary policy. Monetary policy is described by the Taylor rule in linearized form as,

\[
\hat{i}_t = \rho_i \hat{i}_{t-1} + (1 - \rho_i) \left( \phi_{\pi^*} \hat{\pi}^* + \phi_y \hat{Y}_t \right) + \phi_{dy}(\hat{Y}_t - \hat{Y}_{t-1}) + \phi_{rS} \left( rS_t - r\hat{S}_{t-1} \right) + \varepsilon_{i,t}. 
\]

(4.43)

where, \( \hat{i}_t \) is the net nominal interest rate, \( \rho_i \) is the interest smoothing parameter and \( rS_t \equiv \frac{S_t P_t^*}{P_{c,t}} \) is the real exchange rate. The monetary policy shock is \( \varepsilon_{i,t} \sim i.i.dN(0,1) \).

4.2.7 Aggregation and price ratios

Aggregating across all retailer’s output and price,

\[
Y_t = Y_{m,t} \nu_t^p. 
\]

(4.44)

where, \( \nu_t^p \) is the price dispersion term. Goods market clearing can be written as,

\[
Y_t = C_t + I_t + G_t + X_t - M_t. 
\]

(4.45)

The aggregate resource constraint of the economy can be written as,

\[
Y_t + \nu_t N_{BE,t} = w_t N_t + R_{t+1} Q_{t-1} u_t K_t + N_{Bl} d_t. 
\]

(4.46)

4.2.8 External sector

A structural foreign economy sector, similar to Rees et al. (2016) is considered. Hence, the log-linearised equations are presented directly without detail discussion. Foreign inflation Phillips curve, IS curve and monetary policy describe the external sector as,

\[
\hat{\pi}_t^* = \beta \hat{\pi}_{t+1}^* + \frac{\kappa}{100} \hat{Y}_t^* + \varepsilon_{i,t}; 
\]

(4.47)

\[
Y_t^* = Y_{t+1}^* + \hat{\pi}_{t+1}^* - \hat{\pi}_{t+1}^* + \varepsilon_{y^*,t+1} - \varepsilon_{y^*,t}; 
\]

(4.48)

\[
\hat{i}_t^* = \rho_i \hat{i}_{t-1}^* + (1 - \rho_i) \left( \phi_{\pi^*} \hat{\pi}_t^* + \phi_y \hat{Y}_t^* + \phi_{dY^*} \left( \hat{Y}_t^* - \hat{Y}_{t-1}^* \right) \right) + \varepsilon_{i^*,t}. 
\]

(4.49)

\[
\varepsilon_{i^*,t} = \rho_{\pi^*} \varepsilon_{i^*,t-1} + \varepsilon_{i^*,t} 
\]

(4.50)
\[ \varepsilon_{y^*, t} = \rho \pi^{*} \varepsilon_{y^*, t-1} + \varepsilon_{y^*, t} \]  

(4.51)

In Eq.(4.49), \( \varepsilon_{y^*, t} \) is an iid shock denoting foreign monetary policy shock. Eq.(4.50) and Eq.(4.51) are two AR(1) processes where, \( \varepsilon_{\pi^*, t} \) and \( \varepsilon_{y^*, t} \) represent the foreign inflation and output shocks respectively.

### 4.3 Data and estimation

The model is estimated using quarterly Australian data over period 1993:Q1 -2015:Q4. The observed domestic variables include non firm GDP, consumption, investment, CPI inflation, cash rate, average lending rates (average of business and housing sector rates), hours worked, exports, imports and trade weighted real exchange rates. Data used to estimate the foreign sector are weighted GDP of Australia’s major trading partners, federal funds rate as foreign interest rate, and a weighted CPI inflation of major trade partners as foreign inflation. Construction and description of these series are available in Appendix 4.A.4. Following literature such as Born & Pfeifer (2014), Jiang (2016), these series are de-trended using the one-sided HP-filter before taking them into estimation. The filtering ensures that all series are mean zero. By such transformation, we directly observe the model variables, hence, specifying the observation equations will be redundant. I include measurement errors in observation equations for \( Y_t, C_t, I_t, X_t, M_t \) and \( \pi_{c,t} \). Measurement error is also considered for observation equation of \( N_t \) as labour market data is inherently noisy. The measurement errors appear in the observation equations only, hence, I do not define any separate processes for them. The chapter follows the Bayesian estimation technique described by An & Schorfheide (2007) and Fernández-Villaverde (2009) to estimate the non-calibrated parameters.
4.3. Data and estimation

4.3.1 Calibrated parameters

While a range of parameters is estimated, several parameters of the model are fixed. They are listed in Table 4.2. The calibration is mostly based on two studies on Australia (Jasskela & Nimark 2011 and Rees et al. 2016) and in some cases Adolfson et al. (2007) and sample data. The discount factor ($\beta$) is calibrated closer to the sample average of real interest rate and capital income share ($\alpha$) is similar to Jasskela & Nimark (2011). Discount factor for the foreign sector is assumed same as in the domestic sector. Labour dis-utility parameter ($\psi$) is 7.5 which implies agents spend around 30 percent of their time to work in steady state.

Table 4.2: Calibrated parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount factor</td>
<td>$\beta$</td>
<td>0.999</td>
</tr>
<tr>
<td>Capital income share</td>
<td>$\alpha$</td>
<td>0.29</td>
</tr>
<tr>
<td>Relative utility weight of labour</td>
<td>$\psi$</td>
<td>7.5</td>
</tr>
<tr>
<td>Elasticity of substitution in goods market</td>
<td>$\epsilon_p$</td>
<td>6</td>
</tr>
<tr>
<td>Elasticity of substitution in labour supply</td>
<td>$\epsilon_w$</td>
<td>6</td>
</tr>
<tr>
<td>Intra-temporal loan elasticity</td>
<td>$\epsilon_b$</td>
<td>3.5</td>
</tr>
<tr>
<td>Inverse of Frisch labour elasticity</td>
<td>$\eta$</td>
<td>1</td>
</tr>
<tr>
<td>Death probability of a bank</td>
<td>$\delta^b$</td>
<td>0.01</td>
</tr>
<tr>
<td>Steady state fixed depreciation rate</td>
<td>$\delta_0$</td>
<td>0.0175</td>
</tr>
<tr>
<td>G/Y ratio</td>
<td>$gr$</td>
<td>0.2</td>
</tr>
<tr>
<td>Share of imports in $C$</td>
<td>$\omega_c$</td>
<td>0.2</td>
</tr>
<tr>
<td>Share of imports in $I$</td>
<td>$\omega_i$</td>
<td>0.5</td>
</tr>
<tr>
<td>Elasticity of imported $C$</td>
<td>$\epsilon_{mc}$</td>
<td>6</td>
</tr>
<tr>
<td>Elasticity of imported $I$</td>
<td>$\epsilon_{mi}$</td>
<td>6</td>
</tr>
<tr>
<td>Substitution elasticity $C$</td>
<td>$\eta_c$</td>
<td>1.5</td>
</tr>
<tr>
<td>Substitution elasticity $I$</td>
<td>$\eta_i$</td>
<td>1.5</td>
</tr>
<tr>
<td>Substitution elasticity foreign</td>
<td>$\eta_f$</td>
<td>1.5</td>
</tr>
<tr>
<td>Ratio of $K$ utilisation parameters</td>
<td>$\delta_2/\delta_1$</td>
<td>2</td>
</tr>
</tbody>
</table>

Some steady state ratios and targets

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital utilisation</td>
<td>$u_{ss}$</td>
</tr>
<tr>
<td>Loan mark up</td>
<td>$\mu_{ss}$</td>
</tr>
<tr>
<td>Sunk cost of bank entry</td>
<td>$fe_{ss}$</td>
</tr>
<tr>
<td>Net foreign assets</td>
<td>$fu_{ss}$</td>
</tr>
<tr>
<td>Steady state gross inflation</td>
<td>$\Pi_c$</td>
</tr>
<tr>
<td>Mark up in imported $I$ sector</td>
<td>1.2</td>
</tr>
<tr>
<td>Mark up in export sector</td>
<td>1</td>
</tr>
<tr>
<td>Mark up in imported $C$ sector</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Inverse of Frisch labour elasticity ($\eta$) is calibrated to a standard value in the literature and
closer to estimates on Australian economy (Justiniano & Preston 2010).

Elasticity of substitution in domestic goods \((\epsilon_p)\) market and in labour market \((\epsilon_w)\) are both set to 6 which imply steady state mark ups of 1.2. In addition, elasticities for the import consumption \((\epsilon_{mc})\) and import investment \((\epsilon_{mi})\) are assumed to have the same values as in the domestic goods sector, implying the same mark ups. The intra-temporal elasticity of loan demand \((\epsilon_b)\) is calibrated to have a lower value than the goods market. Also, given the steady state interest mark up \((\mu_{ss})\) of 1.675 (from data), \(\epsilon_b\) is calibrated in a way to have a steady state number of banks in between 3 to 4. The value of \(\epsilon_b\) in this study is similar to Gerali et al. (2010) for loan to entrepreneurs. The death or exit probability of bank \((\delta_b)\) is calibrated to be slightly smaller than the probability for the US economy. Since no study on bank death rate for Australia is available, it is chosen in a way to reflect a smaller probability. The fixed sunk cost \((f_{e_{ss}})\) value is set similar to Totzek (2011), but higher than the value in Etro & Colciago (2010) for goods market, as sunk cost for the financial sector is expected to be higher than for the goods market. Some sensitivity analysis have been done with alternative values of \(\delta_b\) and \(f_{e_{ss}}\) in Section 4.6.

The steady depreciation \((\delta_0)\) and government expenditure to output ratio \((gr)\) are based on Australian data which are also similar to the two studies on Australian. Further, the ratio of capital utilisation parameters \(\left(\frac{\delta_2}{\delta_1}\right)\) is set to 2 which is consistent to other literature. The share of imports in total household consumption \((\omega_c)\) and in total investment \((\omega_c)\) are chosen similar to Jasskela & Nimark (2011). Similar to Adolfson et al. (2007) and unlike Jasskela & Nimark (2011), I choose to calibrate the elasticity of substitution between domestic and imported consumption \((\eta_c)\) to 1.5 which is a standard value in macroeconomic literature (Chari et al. 2002 for example). I also calibrate the substitution elasticity of investment goods \((\eta_i)\) and foreign goods \((\eta_f)\) to 1.5 in the baseline estimations. Although estimated \(\eta_c\) for Australian data doesn’t jump too high, as reported by Adolfson et al.
(2007) for Euro area data in that study, it creates some shocks to jump to high values. Also if I estimate all these three substitution elasticities, there are convergence problems in MH stage for some parameters such as the risk premium shock, and import sector sticky parameters ($\phi_{mc}$ and $\phi_{mi}$). Hence, I choose to calibrate them in the baseline estimations. The exercise that include estimation of these three substitution elasticities are reported in the Appendix Table A9.

For convenience, the baseline model with flexible lending rate is denoted as $M_{flex}$ while the baseline model with lending rate adjustment costs is denoted as $M_{sticky}$.

### 4.3.2 Prior distribution of the estimated parameters

In order to avoid the common problem of over predicting variances by the estimated model, following Christiano et al. (2011) I use endogenous prior (also see Del-Negro & Schorfheide 2008 for details ) which is motivated by sequential Bayesian learning. The process begins with initial priors that are unrelated to the data and the standard deviations observed in a ‘pre-sample’ are used to update the initial set of priors. The product of the initial priors and the likelihood of standard deviations in the pre-sample forms the endogenous priors. In practice, actual data is used to compute the standard deviations due to unavailability of suitable data as ‘pre-sample’.

The initial prior distributions are presented in Table 4.3. The prior specifications largely correspond to Adolfson et al. (2007) and Rees et al. (2016) and other related studies. Parameters bounded between 0 and 1, such as shock persistences, habit, Calvo sticky parameters, indexations and interest smoothing parameter in Taylor rule are specified with Beta (B) distribution. Shocks that are allowed to be serially correlated have prior mean 0.6 for autoregressive coefficients and are slightly higher than those in Rees et al. (2016) and lower than in Adolfson et al. (2007).

The standard deviations of all shocks and the risk premium parameter are assumed
to have Inverse Gamma (IG) distribution, as they are expected to be positive. The prior mean of stationary technology shock is 0.7 while the prior mean of the interest rate shock is 0.3. The estimation in Adolfson et al. (2007) assumes 0.15 as the prior mean of interest rate shock. Rees et al. (2016) assumes 0.5 as prior mean for all shocks. Smaller prior mean is chosen for risk premium shock (0.05) and risk premium parameter (0.01) based on Adolfson et al. (2007) and Jasskela & Nimark (2011). The rest of the shocks have prior mean 0.5. Shocks for which there are no clear guidance in the literature for Australia, such as the bank value and capital quality, are set in line with the rest of the shocks. All shocks are assigned with wide prior to account for greater uncertainty.

Among structural parameters, prior mean for consumption habit ($b$) is set to a standard value in the macroeconomic literature. Investment adjustment cost ($\tau$) has normal (N) distribution with prior mean 1.5 and standard deviation 0.5. The prior mean of this adjustment cost is chosen greater than 1 to account for higher model implied volatility of aggregate investment. Following Gerali et al. (2010), in $M_{sticky}$ specification, the prior mean for loan rate adjustment costs ($\kappa_b$) is set to 5 with a narrower standard deviation of 0.5. This value of $\kappa_b$ implies a quick bank pass through. Both Calvo price ($\phi_p$) and wage stickiness ($\phi_w$) parameters have prior mean 0.75 implying domestic goods price and wages are adjusted in every 4 quarters on average.

The Calvo parameters in export ($\phi_x$) and import sectors ($\phi_{mc}, \phi_{mi}$), however, have slightly lower prior mean 0.5 to get reasonable exchange rate pass through. The prior standard deviations of these trade stickiness parameters are twice as large as domestic sectors assuming greater parameter uncertainties, similar to Adolfson et al. (2007).
Table 4.3: Prior and Posteriors

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Prior distribution</th>
<th>Posterior distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distr</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shock persistence: Technology ((\rho_a))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>MEI ((\rho_b))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>Capital quality ((\rho_c))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>Preference ((\rho_d))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>Govt. expenditure ((\rho_g))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>Wage mark up ((\rho_w))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>Price mark up ((\rho_p))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>Risk premium ((\rho_{rpf}))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>Import consumption mark up ((\rho_{mc}))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>Import investment mark up ((\rho_{mi}))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>Export mark up ((\rho_X))</td>
<td>B</td>
<td>0.6</td>
</tr>
<tr>
<td>S.D interest rate ((\sigma_t))</td>
<td>IG</td>
<td>0.15</td>
</tr>
<tr>
<td>S.D technology ((\sigma_a))</td>
<td>IG</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D bank value ((\sigma_b))</td>
<td>IG</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D MEI ((\sigma_z))</td>
<td>IG</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D capital quality ((\sigma_X))</td>
<td>IG</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D preference ((\sigma_g))</td>
<td>IG</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D Govt. expenditure ((\sigma_g))</td>
<td>IG</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D wage mark up ((\sigma_w))</td>
<td>IG</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D price mark up ((\sigma_p))</td>
<td>IG</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D foreign risk premium ((\sigma_{rpf}))</td>
<td>IG</td>
<td>0.05</td>
</tr>
<tr>
<td>S.D import consumption ((\sigma_{mc}))</td>
<td>IG</td>
<td>0.3</td>
</tr>
<tr>
<td>S.D import investment ((\sigma_{mi}))</td>
<td>IG</td>
<td>0.3</td>
</tr>
<tr>
<td>S.D export ((\sigma_X))</td>
<td>IG</td>
<td>0.3</td>
</tr>
<tr>
<td>Habit ((b))</td>
<td>B</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Table 4.3: Prior and Posteriors

<table>
<thead>
<tr>
<th>Parameter Description</th>
<th>Distribution</th>
<th>Prior</th>
<th>Posterior</th>
<th>Prior</th>
<th>Posterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment adj. cost ($\tau$)</td>
<td>N</td>
<td>1.5</td>
<td>0.5</td>
<td>2.55</td>
<td>[1.95, 3.13]</td>
</tr>
<tr>
<td>Loan rate adjustment costs ($\kappa_b$)</td>
<td>G</td>
<td>5.0</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Risk premium parameter ($\phi_a$)</td>
<td>IG</td>
<td>0.01</td>
<td>0.001</td>
<td>0.011</td>
<td>[0.01, 0.013]</td>
</tr>
<tr>
<td>Calvo price probability ($\phi_p$)</td>
<td>B</td>
<td>0.75</td>
<td>0.05</td>
<td>0.745</td>
<td>[0.69, 0.81]</td>
</tr>
<tr>
<td>Calvo wage ($\phi_w$)</td>
<td>B</td>
<td>0.75</td>
<td>0.05</td>
<td>0.71</td>
<td>[0.65, 0.76]</td>
</tr>
<tr>
<td>Calvo $C_m$ price ($\phi_{mc}$)</td>
<td>B</td>
<td>0.5</td>
<td>0.10</td>
<td>0.79</td>
<td>[0.68, 0.89]</td>
</tr>
<tr>
<td>Calvo $I_m$ price ($\phi_{mi}$)</td>
<td>B</td>
<td>0.5</td>
<td>0.10</td>
<td>0.46</td>
<td>[0.33, 0.59]</td>
</tr>
<tr>
<td>Calvo $X$ price ($\phi_X$)</td>
<td>B</td>
<td>0.5</td>
<td>0.10</td>
<td>0.51</td>
<td>[0.36, 0.66]</td>
</tr>
<tr>
<td>Domestic price indexation ($\zeta_p$)</td>
<td>B</td>
<td>0.5</td>
<td>0.10</td>
<td>0.34</td>
<td>[0.20, 0.48]</td>
</tr>
<tr>
<td>Wage indexation ($\zeta_w$)</td>
<td>B</td>
<td>0.5</td>
<td>0.10</td>
<td>0.55</td>
<td>[0.39, 0.72]</td>
</tr>
<tr>
<td>$C_m$ price indexation ($\zeta_{mc}$)</td>
<td>B</td>
<td>0.5</td>
<td>0.15</td>
<td>0.439</td>
<td>[0.19, 0.69]</td>
</tr>
<tr>
<td>$I_m$ price indexation ($\zeta_{mi}$)</td>
<td>B</td>
<td>0.5</td>
<td>0.15</td>
<td>0.49</td>
<td>[0.25, 0.73]</td>
</tr>
<tr>
<td>Export price indexation ($\zeta_X$)</td>
<td>B</td>
<td>0.5</td>
<td>0.15</td>
<td>0.489</td>
<td>[0.25, 0.72]</td>
</tr>
<tr>
<td>Interest rule (IR): interest smoothing ($\rho_i$)</td>
<td>B</td>
<td>0.80</td>
<td>0.05</td>
<td>0.598</td>
<td>[0.55, 0.65]</td>
</tr>
<tr>
<td>IR: inflation ($\phi_\pi$)</td>
<td>N</td>
<td>1.70</td>
<td>0.10</td>
<td>1.11</td>
<td>[1.07, 1.14]</td>
</tr>
<tr>
<td>IR: output ($\phi_Y$)</td>
<td>N</td>
<td>0.125</td>
<td>0.05</td>
<td>0.028</td>
<td>[0.013, 0.04]</td>
</tr>
<tr>
<td>IR: output growth ($\phi_{dy}$)</td>
<td>N</td>
<td>0.0001</td>
<td>0.025</td>
<td>0.049</td>
<td>[0.02, 0.08]</td>
</tr>
<tr>
<td>IR: real exchange rate growth ($\phi_{rS}$)</td>
<td>N</td>
<td>0.0001</td>
<td>0.05</td>
<td>-0.012</td>
<td>[-0.013, -0.01]</td>
</tr>
<tr>
<td>Measurement errors: Output ($me_Y$)</td>
<td>IG</td>
<td>0.1</td>
<td>2</td>
<td>0.27</td>
<td>[0.21, 0.33]</td>
</tr>
<tr>
<td>: Consumption ($me_C$)</td>
<td>IG</td>
<td>0.1</td>
<td>2</td>
<td>0.11</td>
<td>[0.03, 0.17]</td>
</tr>
<tr>
<td>: Investment ($me_I$)</td>
<td>IG</td>
<td>0.1</td>
<td>2</td>
<td>1.63</td>
<td>[1.38, 1.87]</td>
</tr>
<tr>
<td>: Exports ($me_X$)</td>
<td>IG</td>
<td>0.1</td>
<td>2</td>
<td>1.26</td>
<td>[1.01, 1.52]</td>
</tr>
<tr>
<td>: Imports ($me_M$)</td>
<td>IG</td>
<td>0.1</td>
<td>2</td>
<td>0.17</td>
<td>[0.02, 0.46]</td>
</tr>
<tr>
<td>: Hours worked ($me_N$)</td>
<td>IG</td>
<td>0.1</td>
<td>2</td>
<td>0.72</td>
<td>[0.61, 0.82]</td>
</tr>
<tr>
<td>: CPI inflation ($me_{\pi}$)</td>
<td>IG</td>
<td>0.1</td>
<td>2</td>
<td>0.40</td>
<td>[0.35, 0.44]</td>
</tr>
<tr>
<td>Marginal data density*</td>
<td>-977.52</td>
<td>-1049.72</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: B denotes Beta, IG denotes Inverse Gamma, N denotes Normal, and G denotes Gamma distributions. S.D means standard deviation. *Modified harmonic mean.
Prior mean for all indexation parameters are 0.5, assuming same endogenous persistence in all sectors. Prior standard deviations for imports ($\zeta_{mc}, \zeta_{mi}$) and exports ($\zeta_X$) indexations are slightly higher than those for domestic price and wages.

Except interest smoothing, monetary policy parameters follow normal distribution (N). Reaction coefficients of output growth ($\phi_dY$) and real exchange rate growth ($\phi_{rS}$) have smaller prior mean, assuming from Rees et al. (2016) that monetary policy cares less about output growth and exchange rate growth. The prior mean for central bank’s reaction coefficients to inflation ($\phi_\pi$) and output ($\phi_y$) are similar to Jasskela & Nimark (2011) for Australia and Adolfson et al. (2007). In Taylor rule the coefficient of output of 0.125 per quarter implies a standard response of 0.5 for annualised interest rate. Measurement errors are included as exogenous shocks with prior mean 0.1 that implies 10% anomalies between model variable and actual data, with prior standard deviations 2.

### Table 4.4: Prior and the posterior estimates of the external sector

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Distribution</th>
<th>Mean</th>
<th>S.D</th>
<th>Posterior mean</th>
<th>90% HPDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistent of inflation shock ($\rho_{\pi^*}$)</td>
<td>B</td>
<td>0.5</td>
<td>0.1</td>
<td>0.45</td>
<td>[0.35, 0.54]</td>
</tr>
<tr>
<td>Persistent of output shock ($\rho_{Y^*}$)</td>
<td>B</td>
<td>0.5</td>
<td>0.1</td>
<td>0.76</td>
<td>[0.68, 0.84]</td>
</tr>
<tr>
<td>Slope of Phillips curve ($\kappa^*$)</td>
<td>G</td>
<td>1</td>
<td>0.8</td>
<td>0.96</td>
<td>[0.05, 1.82]</td>
</tr>
<tr>
<td>S.D inflation shock ($\sigma_{\pi^*}$)</td>
<td>IG</td>
<td>0.5</td>
<td>0.4</td>
<td>0.14</td>
<td>[0.11, 0.17]</td>
</tr>
<tr>
<td>S.D output shock ($\sigma_{Y^*}$)</td>
<td>IG</td>
<td>0.5</td>
<td>0.4</td>
<td>0.503</td>
<td>[0.42, 0.58]</td>
</tr>
<tr>
<td>S.D Monetary policy shock ($\sigma_{\pi^*}$)</td>
<td>IG</td>
<td>0.2</td>
<td>0.4</td>
<td>0.05</td>
<td>[0.04, 0.06]</td>
</tr>
<tr>
<td>S.D measurement error $\pi^<em>$ ($me_{\pi^</em>}$)</td>
<td>IG</td>
<td>0.1</td>
<td>0.4</td>
<td>0.66</td>
<td>[0.57, 0.76]</td>
</tr>
<tr>
<td>S.D measurement error $Y^<em>$ ($me_{Y^</em>}$)</td>
<td>IG</td>
<td>0.1</td>
<td>0.4</td>
<td>0.06</td>
<td>[0.03, 0.09]</td>
</tr>
<tr>
<td>Taylor rule: interest smoothing ($\rho_\pi$)</td>
<td>B</td>
<td>0.8</td>
<td>0.05</td>
<td>0.801</td>
<td>[0.76, 0.84]</td>
</tr>
<tr>
<td>Taylor rule: reaction inflation ($\phi_\pi^*$)</td>
<td>N</td>
<td>1.50</td>
<td>0.10</td>
<td>1.48</td>
<td>[1.32, 1.64]</td>
</tr>
<tr>
<td>Taylor rule: reaction output ($\phi_Y^*$)</td>
<td>N</td>
<td>0.125</td>
<td>0.05</td>
<td>0.067</td>
<td>[0.014, 0.12]</td>
</tr>
<tr>
<td>Taylor rule: reaction output growth ($\phi_dY^*$)</td>
<td>N</td>
<td>0.0001</td>
<td>0.025</td>
<td>0.0019</td>
<td>[-0.04, 0.04]</td>
</tr>
</tbody>
</table>

Note: $B$ denotes Beta, $IG$ denotes Inverse Gamma, $N$ denotes Normal, and $G$ denotes Gamma distributions.

The foreign sector is only a representation of a group of countries important for Australia and it is hard to set prior to a particular country level. Since I take the external
block from Rees et al. (2016) and the time span of my baseline study is not substantially different, I adopt prior specifications of the same study for the foreign block, presented in Table 4.4.

4.3.3 Estimation and posterior distributions

The estimation is done in two stages: the foreign block is estimated first and these estimates are taken as calibrated parameters in the domestic block which is estimated in the second stage. Before estimation, an identification test for parameters was done using the identification routine available in Dynare program. Both the necessary and the sufficient conditions for identification, as discussed by Iskrev (2010) are satisfied, implying that all the parameters are identified in the model and in the moments for the entire prior space. For brevity, I skip reporting this output. The results for external sector estimation is presented in Table 4.4. In this block, I estimate 12 parameters for data over period 1997Q1-2015Q4. The estimated persistent parameter of output shock \( \rho_{Y^*} \) appears higher than that of inflation shock. The rest of the estimates including foreign monetary policy parameters are all plausible and consistent to the literature.

The domestic block estimation results are in the last four columns of Table 4.3. The posterior mean and corresponding 90 percent Highest Posterior Density (HPD) obtained in the Metropolis Hastings (MH) algorithm are reported for both \( M_{flex} \) and \( M_{sticky} \) specifications. The number of draws in MH algorithm is one million in each of the three chains. Univariate convergence is achieved for all parameters in both specifications. Multivariate convergence which is like a summary of univarite convergences is reported in Fig.A10. The marginal data density appears to favour the model with flexible lending rate, \( M_{flex} \), more. In the baseline, I estimate 50 parameters in \( M_{flex} \) and one more parameter in \( M_{sticky} \) specifications. I estimate the measurement errors as exogenous shocks, unlike Rees et al. (2016) which calibrates measurement errors. The estimated parameters in the current
model are not exactly comparable to the estimates of Jasskela & Nimark (2011) and Rees et al. (2016), because these literature include trend technology in model, hence their data are non-stationary. In contrary, I remove the trend from the data since the model is a stationary one.

Posterior mean of the several persistent parameters in the AR (1) processes appear high such as neutral technology shock ($\rho_a$), government expenditures ($\rho_g$) and foreign sector related shocks such as risk premium shock. Also domestic price and import consumption mark up shocks appear persistent in $M_{\text{sticky}}$ specifications. The estimated persistent coefficients of MEI ($\rho_z$) and capital quality ($\rho_{\xi}$) appear smaller than other shocks. Data does not appear very informative for the autoregressive parameters of all shocks, because posterior mean of some shocks are closer to the specified prior mean. Among posterior mean of shock standard deviations, MEI shock ($\sigma_z$) and import investment shock ($\sigma_{mi}$) appear highly volatile in both specifications. The posterior mean standard deviations for technology ($\sigma_a$), bank value ($\sigma_b$) and monetary policy ($\sigma_i$) shocks are estimated to be higher in $M_{\text{sticky}}$ than in $M_{\text{flex}}$.

For behavioural parameters, data appear more informative. Their is a substantial degree of consumption inertia, as indicated by the posterior mean of habit ($b$) which is slightly smaller than the estimates in Jasskela & Nimark (2011) and Rees et al. (2016). The investment adjustment cost ($\tau$) is much higher than the specified prior mean. Since aggregate investment is a composite of imported ($\omega_i = 0.5$) and domestic ($1-\omega_i$) investment goods and the elasticity ($\eta_i$) between them is calibrated as 1.5, $\tau$ is the only parameter that captures the high volatility of investment and imports data by taking a larger value. The high estimated value of $\tau$ indicates that the stock market effect of capital price can be high. The estimate is higher than the same estimate of Rees et al. (2016) which does not distinguish between domestic and imported investment goods. The posterior mean of loan rate adjustment cost ($\kappa_b$) appears closer to the specified prior mean.
Among the Calvo parameters, domestic price ($\phi_p$), wage ($\phi_w$) and import consumption ($\phi_{mc}$) show high degree of stickiness. The estimated $\phi_p = 0.745$ implies domestic producers re-optimize prices of their products in around 4 quarters which is higher than Jasskela & Nimark (2011) but lower than Rees et al. (2016). The estimated $\phi_w = 0.71$ implies that average duration of nominal wage contract lasts around 3.5 quarters which is around 4 quarters in $M_{sticky}$. The stickiest sector is the import consumption sector ($\phi_{mc} = 0.79$) where price is re-optimized in 5 quarters approximately. The estimated stickiness in import investment ($\phi_{mi} = 0.46$) and export sector ($\phi_{mc} = 0.51$) are relatively smaller, where prices are re-optimized in every 2 quarters. Since the Calvo stickiness parameters are the only source of incomplete exchange rate pass through in the model, these estimated parameters imply that around 21% (55%) of an exchange rate movement is passed through to the price of import consumption (investment) goods. The actual degree of exchange rate pass through may vary depending on what type of shock hits the economy. These stickiness parameters in import sectors with Australian data appear opposite of the findings of Adolfson et al. (2007) for Euro area data where stickiness in import investment (4 quarters) is higher than import consumption (2 quarters) sector.

The estimated domestic price and wage indexations in this study are slightly lower than those in Jasskela & Nimark (2011) but closer to other studies such as Adolfson et al. (2007). Indexation parameters in two imports and export sectors, in contrary, are higher than those found in Jasskela & Nimark (2011) and consistent with other literature. The higher indexation in wage setting ($\zeta_w = 0.55$) compared to domestic price ($\zeta_p = 0.34$) implies that endogenous persistence in labour market is higher than in domestic goods market.

The posterior mean of interest smoothing parameter in Taylor rule appears smaller than the prior mean in both specifications and compared to the estimate in Rees et al. (2016). The monetary policy’s reaction to inflation ($\phi_{\pi}$) is much higher in the $M_{sticky}$ specification
than in the $M_{flex}$. The model does not find any strong reaction of monetary policy to output and real exchange rate growth, especially for output in $M_{sticky}$. Although quantitatively smaller, the fact that monetary policy response to output growth ($\phi_{dY} = 0.049$) is larger than output level ($\phi_Y = 0.03$) is similar to the findings of Justiniano & Preston (2010) for Australia. Although Rees et al. (2016) find no response of monetary policy to real exchange rate, the current study finds a smaller response ($\phi_{rS} = -0.012$) of monetary policy to real exchange rate growths. The sign and magnitude are consistent with the findings of Adolfson et al. (2007).

### 4.4 Model fit

This section presents the ability of the model with oligopolistic banks to fit the actual data. A common approach to check the fit of the estimated DSGE model is to compare the theoretical moments of the estimated model to those of the actual data (An & Schorfheide 2007). This is the absolute fit of the model.

<table>
<thead>
<tr>
<th>Variables</th>
<th>$S.D_{flex}$</th>
<th>$S.D_{sticky}$</th>
<th>$S.D^a$</th>
<th>Relative $S.D_{flex}$</th>
<th>Relative $S.D_{sticky}$</th>
<th>Relative $S.D^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output $Y_t$</td>
<td>0.67</td>
<td>0.69</td>
<td>0.66</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Consumption $C_t$</td>
<td>0.88</td>
<td>1.00</td>
<td>0.86</td>
<td>1.31</td>
<td>1.45</td>
<td>1.30</td>
</tr>
<tr>
<td>Investment $I_t$</td>
<td>4.61</td>
<td>5.31</td>
<td>4.34</td>
<td>6.88</td>
<td>7.70</td>
<td>6.53</td>
</tr>
<tr>
<td>CPI inflation $\pi_{c,t}$</td>
<td>0.19</td>
<td>0.10</td>
<td>0.44</td>
<td>0.28</td>
<td>0.15</td>
<td>0.66</td>
</tr>
<tr>
<td>Cash rate $i_t$</td>
<td>0.20</td>
<td>0.22</td>
<td>0.18</td>
<td>0.30</td>
<td>0.32</td>
<td>0.27</td>
</tr>
<tr>
<td>Lending rate $R_{k,t}$</td>
<td>0.18</td>
<td>0.18</td>
<td>0.15</td>
<td>0.28</td>
<td>0.26</td>
<td>0.23</td>
</tr>
<tr>
<td>Hours worked $N_t$</td>
<td>0.66</td>
<td>0.73</td>
<td>0.90</td>
<td>0.99</td>
<td>1.06</td>
<td>1.36</td>
</tr>
<tr>
<td>Real exchange rates</td>
<td>6.75</td>
<td>8.39</td>
<td>5.47</td>
<td>10.08</td>
<td>12.17</td>
<td>8.24</td>
</tr>
<tr>
<td>$rS_t$</td>
<td>6.75</td>
<td>8.39</td>
<td>5.47</td>
<td>10.08</td>
<td>12.17</td>
<td>8.24</td>
</tr>
<tr>
<td>Exports $X_t$</td>
<td>2.39</td>
<td>2.15</td>
<td>2.38</td>
<td>3.57</td>
<td>3.12</td>
<td>3.59</td>
</tr>
<tr>
<td>Imports $M_t$</td>
<td>5.50</td>
<td>5.98</td>
<td>4.10</td>
<td>8.20</td>
<td>8.68</td>
<td>6.18</td>
</tr>
</tbody>
</table>

Note: Standard deviations for flexible ($S.D_{flex}$) and sticky lending rates ($S.D_{sticky}$) models are presented where the superscripts denote respective models and superscript $a$ denotes the actual data statistics. The moments are their median values. Relative S.D means S.D relative to output.

In Table 4.5, I present such posterior predictive analysis in which the standard deviations in model generated artificial data are compared to those in actual data. The standard
deviations (S.D) reported here are their median values and actual data moments for the period 1993:Q1 - 2015:Q4. The last three columns of Table 4.5 provide S.Ds relative to S.D of output. The model under-predicts the volatility of CPI inflation and hours worked whereas slightly over-predicts the volatility of real exchange rate and imports. Model implied volatilities for rest of the variables are quite close to the volatilities in actual data. Overall, the predicted volatilities are fairly close to those in data, hence, we can rely on the applications of the model such as variance decompositions and impulse response functions. Comparing two model specifications, the flexible lending rate model provides better fit for some variables.

4.5 Application of the model

This section contains various applications of the estimated models to analyse the impacts of oligopolistic banks on growth and dynamics of the economy. This is done in four ways. First, the variance decomposition analysis which tells us the driving forces of business cycles. Second, plots of Impulse Response Functions (IRFs) that depict transmission of shocks and adjustment dynamics of the economy towards steady state. Third, comparisons of IRFs between the oligopolistic bank model and a perfectly competitive bank model. Fourth, historical decompositions to show contributions of shocks to movements of Australian output and employment.

4.5.1 Drivers of business cycles: variance decomposition analysis

Table 4.6 contains the conditional forecast error variance decompositions (in %) for output ($Y_t$), investment ($I_t$), exports ($X_t$), real exchange rates ($rS_t$) and hours worked ($N_t$) over the horizons of one quarter, one year, two and five years for the model with flexible loan rate. Thus, factors driving business cycles in short (1 to 4 quarters), medium (8 quarters) and long (20 quarters) runs can be analysed. The unconditional or stationary variance (UV) decompositions are also reported in the last row for each of the variables. The sixteen
shocks are categorised into seven groups as: monetary policy (interest rate) shock, supply side or mark up (domestic price, wage, import consumption, import investment and export mark ups) shocks, two finance based shocks such as bank value and capital quality (asset side) shocks, demand side (preference and government expenditure) shocks, technology (stationary technology and marginal efficiency of investment) shocks, and foreign (risk premium, world inflation, interest rate and output) shocks.

For evolution of output \(Y_t\) in the short run, demand shocks explain 37-27% of variations whereas supply side or mark up shocks explain 21-25% of variations. The substantial contribution by the demand side in short run output variations is empirically consistent as these shocks are expected to be short lived compared to the supply and technology shocks. From medium to long run, technology shocks explain more than 19-24% and mark up shocks explain around 21-18% of output variations. Gradually, demand shocks become weaker and technology shocks become stronger. In terms of unconditional variance (UV), the role of demand side is smaller and the role of mark ups is bigger compared to the findings of Rees et al. (2016) for \(Y_t\) variations. A smaller role of monetary policy in output dynamics in this study is similar to the finding of Jasskela & Nimark (2011), Justiniano & Preston (2010) and Rees et al. (2016). Interestingly, this study finds that foreign shocks explain a substantial part of output variations (32-22% from short to long run) which is similar to Jasskela & Nimark (2011) but in contrast to Justiniano & Preston (2010) and Rees et al. (2016). This study supports the findings of VAR based literature on small open economy (Dungey & Pagan 2009b, Liu 2010 for example) which usually find larger role of external shocks to variations of macro variables.

For investment \(I_t\), the technology shock group appears as the single most important factor in short run, explaining 95-86% of variations. More specifically, MEI shock is the most important factor contributing to \(I_t\) dynamics. However, external sector also influences
investment substantially over time in this study. In the long run, external sector shocks contribute more than 35% of Australian investment variations whereas technology shock group is still the dominating factor explaining 48% of the variations.

Table 4.6: Variance decomposition (in percent)

<table>
<thead>
<tr>
<th>Shocks</th>
<th>Interest rate</th>
<th>Mark ups</th>
<th>Bank value</th>
<th>Capital quality</th>
<th>Demand</th>
<th>Technology</th>
<th>Foreign</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_t$</td>
<td>1 1.14</td>
<td>20.50</td>
<td>0.09</td>
<td>1.01</td>
<td>36.75</td>
<td>8.54</td>
<td>31.96</td>
</tr>
<tr>
<td></td>
<td>4 1.37</td>
<td>24.58</td>
<td>0.38</td>
<td>3.67</td>
<td>27.33</td>
<td>13.61</td>
<td>29.05</td>
</tr>
<tr>
<td></td>
<td>8 1.22</td>
<td>21.12</td>
<td>0.37</td>
<td>9.06</td>
<td>22.26</td>
<td>19.23</td>
<td>26.75</td>
</tr>
<tr>
<td></td>
<td>20 1.00</td>
<td>17.53</td>
<td>0.31</td>
<td>16.12</td>
<td>19.04</td>
<td>23.80</td>
<td>22.20</td>
</tr>
<tr>
<td></td>
<td>UV 0.87</td>
<td>15.30</td>
<td>0.27</td>
<td>20.68</td>
<td>17.21</td>
<td>24.18</td>
<td>21.48</td>
</tr>
<tr>
<td>$I_t$</td>
<td>1 0.30</td>
<td>1.06</td>
<td>0.16</td>
<td>0.50</td>
<td>1.50</td>
<td>94.79</td>
<td>1.69</td>
</tr>
<tr>
<td></td>
<td>4 0.32</td>
<td>1.55</td>
<td>0.17</td>
<td>0.52</td>
<td>3.86</td>
<td>86.20</td>
<td>7.37</td>
</tr>
<tr>
<td></td>
<td>8 0.27</td>
<td>1.42</td>
<td>0.15</td>
<td>0.44</td>
<td>5.84</td>
<td>71.79</td>
<td>20.09</td>
</tr>
<tr>
<td></td>
<td>20 0.20</td>
<td>1.32</td>
<td>0.11</td>
<td>3.04</td>
<td>5.97</td>
<td>54.25</td>
<td>35.13</td>
</tr>
<tr>
<td></td>
<td>UV 0.17</td>
<td>1.19</td>
<td>0.09</td>
<td>10.15</td>
<td>5.20</td>
<td>47.94</td>
<td>35.26</td>
</tr>
<tr>
<td>$X_t$</td>
<td>1 0.24</td>
<td>30.81</td>
<td>0.01</td>
<td>0.00</td>
<td>0.04</td>
<td>0.08</td>
<td>68.82</td>
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<td></td>
<td>4 0.35</td>
<td>41.55</td>
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<td>0.07</td>
<td>0.15</td>
<td>0.42</td>
<td>57.38</td>
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<td></td>
<td>8 0.32</td>
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<td>0.22</td>
<td>1.11</td>
<td>57.95</td>
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<tr>
<td></td>
<td>20 0.25</td>
<td>33.05</td>
<td>0.07</td>
<td>0.62</td>
<td>0.18</td>
<td>2.75</td>
<td>63.08</td>
</tr>
<tr>
<td></td>
<td>UV 0.23</td>
<td>31.33</td>
<td>0.06</td>
<td>0.75</td>
<td>0.18</td>
<td>3.35</td>
<td>64.09</td>
</tr>
<tr>
<td>$rS_t$</td>
<td>1 7.89</td>
<td>10.52</td>
<td>53.39</td>
<td>7.57</td>
<td>1.05</td>
<td>18.78</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>4 7.87</td>
<td>10.50</td>
<td>52.99</td>
<td>7.51</td>
<td>1.05</td>
<td>18.65</td>
<td>1.43</td>
</tr>
<tr>
<td></td>
<td>8 7.85</td>
<td>10.51</td>
<td>52.89</td>
<td>7.51</td>
<td>1.05</td>
<td>18.64</td>
<td>1.56</td>
</tr>
<tr>
<td></td>
<td>20 7.83</td>
<td>10.52</td>
<td>52.77</td>
<td>7.5</td>
<td>1.04</td>
<td>18.67</td>
<td>1.65</td>
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<tr>
<td></td>
<td>UV 7.81</td>
<td>10.49</td>
<td>52.64</td>
<td>7.49</td>
<td>1.04</td>
<td>18.66</td>
<td>1.85</td>
</tr>
<tr>
<td>$N_t$</td>
<td>1 1.27</td>
<td>22.31</td>
<td>0.37</td>
<td>7.63</td>
<td>25.18</td>
<td>12.90</td>
<td>30.34</td>
</tr>
<tr>
<td></td>
<td>4 1.46</td>
<td>25.74</td>
<td>0.40</td>
<td>0.34</td>
<td>30.28</td>
<td>9.86</td>
<td>31.90</td>
</tr>
<tr>
<td></td>
<td>8 1.44</td>
<td>24.83</td>
<td>0.42</td>
<td>0.37</td>
<td>28.11</td>
<td>12.10</td>
<td>32.72</td>
</tr>
<tr>
<td></td>
<td>20 1.39</td>
<td>24.24</td>
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<td>1.76</td>
<td>27.09</td>
<td>12.38</td>
<td>32.73</td>
</tr>
<tr>
<td></td>
<td>UV 1.09</td>
<td>9.96</td>
<td>0.43</td>
<td>12.9</td>
<td>40.84</td>
<td>10.45</td>
<td>24.32</td>
</tr>
</tbody>
</table>

Note: The reported variances are the mean responses of unconditional or stationary variances (UV) and the conditional variances at horizons 1, 4, 8 and 20 quarters.

In terms of the UV decomposition, the findings are more similar to Rees et al. (2016) which finds technology shock (91%) is the single most important driver of $I_t$ variations. In contrary, Jasskela & Nimark (2011) reports external and mark up shocks are the two most important drivers of Australian investment. In UV decomposition, capital quality shock also influences $I_t$ dynamics substantially in the current study.

As a commodity exporting country, the fact that the largest part (69-58% from short
to medium run) of Australian export ($X_t$) variations explained by shocks developed in external sector is not surprising. This is because commodity markets are largely independent of the developments in the individual exporting countries (Chen et al. 2010, Jasskela & Nimark 2011). Mark up shocks, predominantly the export mark up shock, also appear very important (42-33%) for $X_t$ variations. Interestingly the work of Rees et al. (2016), in its multi sector model, finds resource price shock explains only 6% and world shocks explain only 7% of export variations different from the current study.

For real exchange rate ($rS_t$) movements, monetary policy appears to have considerable amount of contributions (around 8%). The higher contributions of bank value shock and lower contributions of foreign shocks appear puzzling. Chen et al. (2010) states that exchange rate-commodity price linkage can operate through the asset markets and portfolio channel. For example, higher commodity price can attract funds into commodity exporting countries implying an additional empirical relationship between equity market behaviour and world commodity price. Since the current model does not design separate commodity exporting sector, the shock to the stock market value of bank firms may capture this fact to explain greater variations in $rS_t$. Technology and mark up shocks also explain substantial part of exchange rate variations in the current study.

For hours worked ($N_t$) variations, foreign shocks, and demand and supply side shocks are dominant which is of no surprise. External shocks can explain around 30-34% of variations in $N_t$, highlighting the importance of the developments in rest of the world for Australian labour market emphasised by the VAR based literature. The demand shocks explain more than 25% of short run variations and 28% of medium and long run variations in $N_t$. Consumption preference shock, in particular from the demand side, is the most important contributor to employment dynamics. Mark up shocks have explanatory power closer to the demand shocks for $N_t$ variations. The bigger role of mark up shock group in the current study is similar to Jasskela & Nimark (2011) in which mark up shock is the
single most important driver of employment variations.

### 4.5.2 Impulse responses

The Impulse Response Functions (IRFs) show the future paths of the endogenous variables of the model in response to an exogenous shock occurring at period one. The transmission mechanisms of various real sector shocks and dynamics of the economy in presence of strategic bank behaviour can be observed from the plots of IRFs of the endogenous variables. The solid (black) lines are the IRFs of $M_{flex}$ specification and the surrounding dotted lines are 95% posterior density intervals. The broken (blue) lines are the IRFs of $M_{sticky}$ specifications.

#### 4.5.2.1 Impulse responses to Monetary policy shock

Fig. 4.3 contains IRFs to a positive (contractionary) monetary policy shock. Output ($Y_t$), investment ($I_t$), inflation ($\pi_c,t$) and hours worked ($N_t$) — all show anticipated negative responses. However, the responses of the real sector variables are smaller in magnitudes. The real wage ($w_t$) also decreases but the response is not significant in $M_{flex}$. When monetary policy is contractionary, the model suggests that the entry cost of prospective bank firm increases due to an increase in the marginal costs of funds. Thus, bank entry channel implies a gradual drop in the mass of banks ($N_{B,t}$) in a hump shape manner. Then, the market share under control of surviving banks increases and thereby greater market power leads them to charge higher interest mark ups ($\mu_t$). Thus, oligopolistic banks with endogenous entry suggest a new channel that produces countercyclical movements in mark up.

The gross commercial lending rate, $R_{k,t}$, increases by 0.06 percentage points. This reduces the demand for loans. Lending rate increases for two reasons - first is the rise in deposit costs and second is the rise in $\mu_t$ due to increased market power of existing banks. If banks face rate adjustment costs, $R_{k,t}$ increases but not instantly. In this situation, the
decline in $Y_t$ and $N_t$ are slightly less than the flexible rate case. The tighter condition in the credit market is reflected by a drop in asset price $Q_t$. 

Figure 4.3: Interest rate shock

Figure 4.4: Stationary technology shock

Note: The black (solid) lines are mean IRFs of $M_{flex}$ specification and area within dotted lines are their 95% posterior density interval. The blue (broken) lines are IRFs of $M_{sticky}$ specification.
We see that aggregate exports \((X_t)\) also decrease in response to a monetary tightening. The depreciation of real exchange rate \(rS_t\) is not counter intuitive, rather suggests a strong stock market effect (see open economy model of Gavin 1989 for detail). If the link between stock market price and aggregate demand is important enough, the impact of monetary policy on real exchange rate can be reversed. When the stock market effect is very strong, the negative relation between \(i_t\) and \(Q_t\) implies a reverse over-shooting, hence, \(rS_t\) depreciates. This depreciation improves trade balance and moderates the conractionary effect of monetary policy on aggregate demand.

The extent of maximum responses of the real sector variables in the current study are smaller than those found in Jasskela & Nimark (2011). But this is similar to the findings of Dungey & Pagan (2009b) which finds smaller responses of real variables compared to the earlier study Dungey & Pagan (2000b). Comparing with Jasskela & Nimark (2011), we see that adjustment process in the current study is slower. It takes almost 3 years for the output to return to the steady state whereas it takes only 5 quarters in Jasskela & Nimark (2011). Introducing adjustment costs in retail lending rate does not produce substantially different IRFs to a monetary policy shock.

### 4.5.2.2 Impulse responses to technology shock

In response to a positive neutral technology shock in Fig.4.4, both \(Y_t\) and \(I_t\) increase as anticipated and the responses are persistent. Higher productivity in the labour market increases real wage \((w_t)\). Hence, hours worked \((N_t)\) decrease initially. But increased economic activity in the supply side gradually increases the demand for labour, hence, \(N_t\) increases. Increase in \(w_t\) is much higher in \(M_{\text{sticky}}\) model. CPI inflation, \(\pi_{c,t}\), decreases rapidly and remains below the steady state level for a considerable period of time in \(M_{\text{flex}}\). Ideally, monetary policy would not respond to technology shock but, as stated in Dungey & Pagan (2009b), it is hard for monetary authority to separate out technology shocks from
demand induced rises in output. The estimated parameters in the study suggest that the monetary authority places less emphasis on output fluctuations than inflation. In response to a technology shock, a transitory rise in cash rate \( (i_t) \) is soon followed by a drop to reach below the steady state. Then it takes 10 quarters to return.

The technology shock is expected to be transmitted through the financial sector to the real economy in two ways. First, through the bank entry channel by facilitating new entry and thereby, reducing bank sector concentration and mark ups. The model generates a positive response for \( N_{B,t} \) but the magnitude is small in \( M_{flex} \). In contrary, lending rate stickiness implies that immediately after the shock, the banking sector profitability remains much higher in \( M_{sticky} \) specification than in \( M_{flex} \). Higher profitability attracts more banks in the market. Therefore, the bank entry channel is stronger under sticky lending rate case, amplifying the overall shock impacts more on the real economy. Second, through the balance sheet channel due to change in collateral valuation. As resources become more profitable and production activities increases, \( Q_t \) increases. Increase in \( Q_t \) is a gain to bank balance sheets through gain in collateral valuations. However, the second effect is expected not to be higher than that in case of perfectly competitive banks. This finding is consistent with the empirical observation on Australian banking industry.

The big four banks in Australia are dominating the market for more than a decade and, given the regulatory regime, the shocks are quantitatively not large enough to guarantee new entry that can take over substantial market shares from the existing big four banks. In practice there are entry and exit of small local banks and foreign banks with limited market exposures which are small enough to make substantial differences in market concentration. The decrease in \( \mu_t \) results in a drop in lending rates by 0.06 percentage points in \( M_{flex} \) and the drop is slightly more in \( M_{sticky} \). The decrease in borrowing costs increases the demand for capital machineries leading to a surge in capital price \( (Q_t) \) as depicted in Fig.4.4.

The falling price in the domestic goods market due to positive technology shock in-
increases exports ($X_t$) as domestic goods become cheaper in the world market. Here, $rS_t$ appreciates instantly, similar to the findings of Dungey & Pagan (2000b) in which shocks are transitory. However, the finding is opposite to Dungey & Pagan (2009b) in which shocks are permanent. Bringing stickiness in the lending rate adjustment produces similar IRFs but the magnitudes of procyclicality are greater for some variables than those found in $M_{flex}$ specification. So, the oligopolistic competition among banks appears to amplify the effects when a technology shock hits the economy.

4.5.2.3 Impulse responses to investment specific technology (MEI) shock

The MEI shock appears to play a large role in $Y_t$ and $I_t$ dynamics in both specifications. In response to a negative MEI shock, in the first two rows of Fig.4.5, $Y_t$ decreases by 0.12% and investment decreases by 1.5% at the maximum impact. As this is a negative shock to the production process of capital, $Q_t$ rises instantly and returns to the steady state only gradually, displaying a persistent impact of the shock. The high stock market price of capital leads to an appreciation of $rS_t$. Here, we see $rS_t$ remains at an appreciating stage for a considerable period of time and the initial transitory depreciation is not significant. This has negative consequences on exports. $X_t$ declines by more than 0.1% at the maximum impact.

A rise in $Q_t$ improves the bank balance sheet condition and thereby, reduces spread or markup ($\mu_t$) in a competitive bank industry as shown in Chapter 3. Given the strategic bank behaviour in this study, $\mu_t$ still shows anticipated negative response but the magnitude is too small to have sizeable impacts on $I_t$ and $Y_t$. Since, investment specific technology shock has no direct impact on entry costs, the bank entry channel is less effective. This implies that balance sheet effect of change in $Q_t$ on mark up is weaker under oligopolistic competition, leaving a larger role for MEI shock as emphasised by Justiniano et al. (2010). Here, MEI shock has strong negative and persistent effects on $Y_t$ and $I_t$, different from the
findings of Afrin (2017) for the US where bank industry is more competitive.

Figure 4.5: MEI and capital quality shocks

Note: The black (solid) lines are mean IRFs of $M_{flex}$ specification and shaded regions are their 95% posterior density interval. The blue (broken) lines are IRFs of $M_{sticky}$ specification. The first variable contains the name of the shock for the entire row.

The price of domestic goods rises as domestic production is negatively affected by the shock. Although currency appreciation reduces import costs, inflation rises because domestic goods are the largest part in the consumption basket. Since monetary policy places more importance on inflation stability, cash rate ($i_t$) rises following the dynamics of $\pi_{c,t}$. The dampening production activity reduces both $N_t$ and $w_t$ but adjustments in $N_t$ is quicker than $w_t$ which displays a sluggish adjustment toward steady state. Overall the responses are consistent with the IRFs in Adolfson et al. (2007). The IRFs in sticky loan rate model are qualitatively similar and quantitatively different only marginally. The maximum decrease in $\mu_t$ is smaller in $M_{sticky}$ than that in $M_{flex}$. The overall impact on
4.5. Application of the model

$Y_t$ is not substantially different between the two specifications.

4.5.2.4 Impulse responses to capital quality shock

IRFs to a negative capital quality shock are depicted in the last two rows of Fig.4.5. After the shock, $Y_t$ decreases and starts to move upward after 8 quarters. With the same specification, $I_t$ decreases for a short time. Fast adjustment leads $I_t$ to cross the steady state line by 8 quarters and remains over it for a considerable period of time. The reason for high persistence of the impact on $Y_t$ can be due to the fact that investment requires time to build and replenish the capital stock to the steady state level. Capital price $Q_t$ declines sharply by 0.2% which returns to the steady state in 10 quarters. The maximum impacts on $Y_t$, $I_t$, $\pi_{c,t}$ and $\mu_t$ are higher in the flexible specification than in $M_{sticky}$.

It is interesting to compare the results to the estimates of Gertler & Karadi (2011)’s financial friction model for the US in Afrin (2017) where loss in collateral valuation leads to deterioration of bank balance sheet and net worth. The loss of bank equity in turn raises interest spread due to endogenous balance sheet constraint and shrinks credit availability. In contrary, under oligopolistic set up in which banks do not face the endogenous balance sheet constraints, mark up ($\mu_t$) declines. The declining mark up fuels investment and mitigates the fall in output. Since oligopolistic banks are likely to have high retained profits and capital, the negative balance sheet effects of a capital quality shock on the real economy are anticipated to be less severe. Financial sector responds to the loss of capital or valuation of capital by providing more investment. Capital quality shock is less likely to be amplified under oligopolistic set up where banks are unlikely to face endogenous balance sheet constraint that competitive banks face. Although is not explicit in the current model, . Thus, oligopolistic banks may not always act as accelerators to shocks originating in the real sector.
4.5.2.5 Impulse responses to other shocks

IRFs for rest of the shocks are presented in Section 4.A. In response to an export markup shock in Fig.A11, $Y_t$ and $\pi_{c,t}$ decline and $rS_t$ shows the anticipated negative response (depreciation). There is no significant response from the mass of banks or interest mark up to export mark up shock. In Fig.A12 in response to a positive consumption preference shock, $Y_t$ increases due to a surge in consumption and $I_t$ decreases due to households’ increased preferences towards consumption. Consequently, both $N_t$ and $\pi_{c,t}$ increase. Reduced demand for $I_t$ results in a decrease in interest mark up ($\mu_t$). The rest of the variables show theoretically and empirically intuitive responses similar to Adolfson et al. (2007). IRFs to a positive risk premium shock in Fig.A13 appear qualitatively consistent to Rees et al. (2016) and other Australian studies. However, the impacts are quantitatively smaller, similar to the findings of Justiniano & Preston (2010).

Foreign shocks can be seen in Fig.4.7 in Subsection 4.5.3. Foreign inflation shock has positive impacts on domestic $Y_t$ and $I_t$ and as a consequence $N_t$ increases. In contrary, a negative shock to foreign output has negative impacts on domestic $Y_t$, and $I_t$. For a contractionary foreign monetary policy shock, domestic $Y_t$ appears fluctuating but both $I_t$ and $Q_t$ rise.

Overall, the IRFs derived from the estimated models are theoretically sensible and similar to many empirical studies qualitatively, but the response quantities vary. The models of empirical studies that have been used to compare the results with are not exactly nested to the oligopolistic bank model of this study. We should not put much emphasis on quantity comparison also because the estimation in this study uses de-trended data. These facts are to be kept in mind when comparing the IRFs to other studies.
4.5.3 Comparison with a benchmark of no oligopolistic competition

In order to highlight the impacts of oligopolistic competition further, results of the baseline estimates are compared to those of a benchmark model in which banks are perfectly competitive. This is a purely hypothetical financial sector for the sake of comparison only and to filter out the oligopolistic competition effects. The benchmark model implies that there are numerous banks in the industry and they are normalized to one ($N_{B,t} = 1$). Each bank’s market share is too small to influence its lending rate. There is no interest mark up, hence, $r_{k,t} = R_{k,t} = i_t$. This competitive benchmark model is estimated with the same prior as the baseline models.

Figure 4.6: Comparison to benchmark model for domestic shocks

![Comparison to benchmark model for domestic shocks](image)

Note: The red (solid) lines are mean IRFs of the benchmark model with perfectly competitive banks and the black and blue (broken) lines are mean IRFs of the $M_{flex}$ and $M_{sticky}$ specifications in the baseline respectively.

The first row in Fig.4.6 shows comparison of IRFs to a negative MEI shock. The impacts of MEI shock is larger under oligopolistic banks compared to the benchmark model. Although asset price rises more in the baseline models, balance sheet channel is less effective in reducing lending rates due to strategic behaviour among banks, already depicted in Fig.4.5. The effect of positive collateral valuation on $\mu_t$ is weakened also by the bank entry channel. The bank entry channel, although not directly affected by the MEI
shock, implies that the mass of banks may decrease and existing banks may gain more
market power that deter them to reduce lending rates sufficiently to compensate the fall
in $I_t$. The moderate increase in $Q_t$ in the benchmark model is due to a greater increase in
nominal interest rate compared to the baseline specifications. Hence, the behaviour of $i_t$
has a critical role to play.

For positive technology shock, in Fig.4.6, $Y_t$ and $I_t$ increase more when banks are
oligopolistic with sticky loan rate, compared to the benchmark case. It implies that the
imperfect bank pass through in oligopolistic set up plays an important role in accelerating
shock effects through the bank entry channel.

The comparison for monetary policy shock is presented in the last row of Fig.4.6.
The drop in $Q_t$ to a rise in cash rate is much higher in the baseline models than in the
benchmark model. It implies that the stock market effect can be very strong in aggregate
demand through its effect on real exchange rates in oligopolistic models. Although mark
up in lending rate rises which amplifies monetary policy effect but the stock market effect
is strong enough to moderate the fall in $Y_t$. This is consistent with the findings of Gavin
(1989)’s model that share price in the stock market substitutes for the real interest rate
in the determination of aggregate demand. For Australian data, the stock market effect is
much stronger in presence of oligopolistic banks which nullifies the other - counter cyclical
mark up - effect of monetary policy. Thus, $Y_t$ and $I_t$ decline more to a contractionary
monetary policy in benchmark model than in the oligopolistic bank models.

Therefore, this study finds a different transmission mechanism of monetary policy under
oligopolistic banks. This also suggests that when monetary policy wishes to be more
accommodative, the existence of a highly concentrated bank sector makes it difficult to
achieve the monetary policy goals.
Figure 4.7: Foreign inflation, output and interest rate shocks for benchmark and baseline models

Note: The red (solid) lines are IRFs of the benchmark model with perfectly competitive banks and the black and blue (broken) lines are IRFs of the $M_{flex}$ and $M_{sticky}$ specifications respectively.

Fig. 4.7 shows the impulse responses of real economy to foreign inflation, foreign output, and foreign monetary policy shocks when the domestic banking sector is oligopolistic and when it is not. Oligopolistic banks mostly accelerate the external shock impacts on the real economy. The responses are not much different between flexible and sticky lending rates specifications. However, in response to a foreign inflation shock, domestic $I_t$ rises initially, while they decrease in the benchmark model with perfectly competitive banks. The response of $Y_t$ to a rise in foreign interest rate is fluctuating in oligopolistic bank models while it is rising after a transitory drop in the benchmark model.

Overall, the comparisons of domestic and foreign shocks imply that oligopolistic banking sector may not necessarily act as accelerator to all shocks rather it depends on which shock hits the economy.

4.5.4 Australian output and employment: historical decompositions

Historical shock decompositions for output ($Y_t$) and hours worked ($N_t$) are presented in Fig. 4.8 and Fig. 4.9 to analyse the sources of Australian business cycles, over the inflation targeting era. These figures show the contributions of various shocks to output and em-
ployment deviations from their steady states over time. I apply same shock groupings as in the variance decomposition analysis to make the figures easily interpretable. According to the business cycles dating by Melbourne Institute, Australian economy went through expansionary phases in mid and late 1990s (peaks October 1994, December 1997), and mid 2000s (peaks November 2002, May 2007) within the time frame of this study. The contractionary phases are identified as early 2000s and during the Global Financial Crisis (troughs July 1996, November 2001, June 2003 and May 2009).

The model replicates the empirical peaks and troughs very well and identifies demand side, technology, capital quality and foreign shocks as the main contributing factors to the evolution of output. The expansionary phase during 1994 was driven by positive technology, especially the investment specific technology shocks and the positive demand side shocks. The economic booms during late 1997 and early 1998 on the other hand are driven by positive variations in the quality of capital (including housing). House price boom of 1996-2003, one of the four house booms between 1973-2003 identified by Abelson et al. (2005) for Australia, suggests the dominance of capital quality shock in recovering output during this period.

The large positive capital quality shock after 1996 along with the positive external factors helped the economy came out of the depression and reached a peak in the end of 1997. The model attributes the expansion in mid 2000s (first half of both 2004 and 2007 in particular) to positive demand shocks and positive external shocks. Since the model does not include resource price separately, the household preference shock in the demand side may capture some part of the resource price boom as increased household expenditures.

Monetary policy seems to have some contribution in the downturn of the economy after the expansion phase in 1994. In order to put a limit on an anticipated rise in inflation, RBA increased interest rates by 275 basis points between August and December 1994 (Rees et al. 2016).
Figure 4.8: Output, $Y_t$: historical shock decomposition (group wise) based on $M_{flex}$.

Figure 4.9: Hours worked, $N_t$: historical shock decomposition (group wise) based on $M_{flex}$.
Largely negative demand, and also supply shocks resulted in the depressed economic condition until it reached a trough in the second half of 1996. For the downturn in the early 2000s, the model identifies large negative technology shock, investment shock in particular, as the main factor. These shocks were associated by negative mark up shocks implied by the model. These negative domestic shocks offset the positive external sector shocks in early 2000s. Introduction of goods and service tax in July 2000 may be captured to some extent by the mark up shocks and by the negative demand shocks in between 2001-2002. The work of Rees et al. (2016) stated that the dominance of investment shocks together with this tax are responsible for the contraction of this period and indicated this fact as a model misspecification. The authors suggest that the tax induced huge building investment to be brought forward in the first half of 2000 and consequent reduction in the second half of that year. As the model of this chapter does not feature any tax other than lump sum tax, it assigns the tax effects to the investment shocks, being unable to account for the tax explicitly.

The downturn during the GFC was mainly caused more by the domestic factors rather than by the global factors themselves. The downfall was initiated by large negative demand and then by negative technology shocks. These findings are consistent with the observation that the consumer confidence was dropped by the bad news from other economies and economic regions that time. This fact is captured by the demand and investment shocks by the model. Post GFC recovery was fuelled by demand and technology shocks. If we look at the recent years after 2013, the growth is slowed down by falling technology (investment) and capital quality shocks. Hours worked ($N_t$) also follow the cyclical patterns of output. Demand side, technology and foreign shocks contribute most to the evolution of hours worked over different times.
4.6 Sensitivity analysis

A list of sensitivity analysis has been done to check the robustness of the findings in baseline estimations. Here, the findings are analysed in terms of $M_{flex}$ specification. For brevity, Table 4.7 contains the marginal data densities (MDD) based on modified harmonic mean (MHM) estimator of the various estimated models along with the MDD of the baseline estimation for comparison. However, we should not put much emphasis on the marginal likelihood as they can be very sensitive to prior specifications. The estimated results do not appear much different than the baseline case.

<table>
<thead>
<tr>
<th>Sensitivity to</th>
<th>$f_{ess} = 4$</th>
<th>$f_{ess} = 8$</th>
<th>Baseline ($M_{flex}$)</th>
<th>$\delta^b = 0.0125$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marginal Data Density (MDD*)</td>
<td>-1010.98</td>
<td>-974.60</td>
<td>-977.52</td>
<td>-977.20</td>
</tr>
</tbody>
</table>

Note: Modified harmonic mean MDD based on $M_{flex}$ specification.

The fixed sunk cost ($f_{ess}$) associated with bank entry and the bank exit rate ($\delta^b$) affect the steady state of the model. Since there is no guide in the literature for these parameters in the context of Australia, I re-estimate $M_{flex}$ with a lower ($f_{ess} = 4$) and a higher ($f_{ess} = 8$) values of sunk entry costs than the baseline to check the sensitivity of the baseline results. From column (1) and (2) of Table 4.7, we see that overall, marginal data densities are not substantially different and models with higher sunk costs are preferred only slightly. However, estimation with $f_{ess} = 4$ creates convergence problem in MH stage for several parameters, although model dynamics remain similar to the baseline case. The values of $f_{ess}$ as or above the baseline can solve this problem. This finding, therefore, validates the choice of $f_{ess}$ in this study.

Next, I re-estimate the model with slightly higher bank death/exit rate $\delta^b = 0.0125$. The MDD of the estimated model in column (4) of Table 4.7 suggests that this choice is not more favoured than the baseline case. The estimated results are not reported here but
the higher exit rate does not produce much different parameter estimates, at least with this much increase in $\delta^b$.

In Table 4.8 I report posterior mean of select parameters from the estimated models with two different assumptions to check the sensitivity of baseline results. The first robustness check I have performed is the assumption regarding correlated bank value shock ($\varepsilon^b$). This is specified as uncorrelated in the baseline specifications. I check whether correlated bank value shock has any substantial impacts on the remaining parameter estimates. Columns (2) in Table 4.8 has posterior mean from the model with correlated bank value shock. The estimates are not very different from the baseline $M_{flex}$ estimates. The autocorrelation coefficient of bank value ($\rho^b$) shock does not appear much persistent.

Table 4.8: Correlated bank value shock model, and modified bank entry condition model: select posterior mean.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Correlated shock $\varepsilon^b$</th>
<th>No $A_t$ in bank entry</th>
<th>Parameters</th>
<th>Correlated shock $\varepsilon^b$</th>
<th>No $A_t$ in bank entry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) (2) (3)</td>
<td></td>
<td>(1)</td>
<td>(2) (3)</td>
<td></td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>0.74</td>
<td>0.68</td>
<td>$\sigma_a$</td>
<td>0.044</td>
<td>0.43</td>
</tr>
<tr>
<td>$\rho_b$</td>
<td>0.14</td>
<td>-</td>
<td>$\sigma_b$</td>
<td>0.081</td>
<td>0.082</td>
</tr>
<tr>
<td>$\rho_z$</td>
<td>0.42</td>
<td>0.44</td>
<td>$\sigma_z$</td>
<td>2.30</td>
<td>2.24</td>
</tr>
<tr>
<td>$\rho_\xi$</td>
<td>0.45</td>
<td>0.53</td>
<td>$\sigma_\xi$</td>
<td>0.29</td>
<td>0.26</td>
</tr>
<tr>
<td>$\rho_{rpf}$</td>
<td>0.59</td>
<td>0.61</td>
<td>$\sigma_{rpf}$</td>
<td>0.15</td>
<td>0.29</td>
</tr>
<tr>
<td>$\phi_p$</td>
<td>0.73</td>
<td>0.80</td>
<td>$\zeta_p$</td>
<td>0.34</td>
<td>0.22</td>
</tr>
<tr>
<td>$\phi_w$</td>
<td>0.72</td>
<td>0.72</td>
<td>$\zeta_w$</td>
<td>0.52</td>
<td>0.49</td>
</tr>
<tr>
<td>$\phi_{mc}$</td>
<td>0.81</td>
<td>0.84</td>
<td>$\zeta_{mc}$</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>$\phi_{mi}$</td>
<td>0.49</td>
<td>0.49</td>
<td>$\zeta_{mi}$</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>$\phi_X$</td>
<td>0.54</td>
<td>0.53</td>
<td>$\zeta_X$</td>
<td>0.48</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Marginal Data Density (MDD): -1000.97 -932.61

Next, the entry condition assumption that stationary technology shock does not enter into the bank entry costs is tested. This assumption is similar to the calibrated model Totzek (2011). Column (3) of Table 4.8 contains posterior mean estimates for this experiment. The posterior mean of key parameters are not substantially different compared to the results in Table 4.3. In this experiment, the model dynamics is mostly similar to the baseline case, however, the impulse response of $\mu_t$ to a stationary technology shock is no
longer countercyclical and the magnitude of response is very small. The estimation result of $M_{flex}$ specification when all parameter are estimated is reported in Table A9. The MDD of this estimation is not much different than the MDD of the baseline model.

Overall, various sensitivity analysis validate the results of the baseline specification of the study.

4.7 Conclusion

In this chapter I have analysed the role of financial frictions arising from the oligopolistic competition in the finance sector by implications of various shocks and frictions in an estimated DSGE model, motivated by the highly concentrated banking industry in some countries. So, the chapter is an application of imperfect competition and endogenous firm entry theory within the class of general equilibrium model for finance sector, estimated with Australian data. The model consists of standard open economy features and analyses the role of oligopolistic banks to external shocks as external shocks are important for a small open economy like Australia. I constructed a modified bank entry condition to endogenize the number of banks. The proposed model considers strategic bank behaviour for loan market only and measures this imperfect competition through mark up in lending rate.

The estimated model produces countercyclical interest mark ups, however, the magnitudes of cyclical responses to some shocks are smaller for Australian data. The countercyclical movements in interest mark ups amplify some shocks originating in domestic economy and in the external sector. Monetary policy shock appears to have smaller role in output fluctuations in presence of oligopolistic banks. The oligopolistic bank model finds higher stock market responses to shocks when comparing with the competitive bank sector case. Also MEI shock impacts on output appears higher under oligopolistic set up in contrast to the findings of Chapter 3 for MEI shock. Strategic behaviour among banks and absence of endogenous balance sheet constraint, leave a larger room for MEI shock
to affect output and employment. Demand side shocks, technology shocks, particularly investment specific technology shock, and foreign shocks appear as important drivers of Australian output and employment fluctuations during the period of this study. Oligopolistic competition among banks play an amplification role for some real sector shocks but act as better shock absorber for finance sector shocks such as capital quality shock.

Therefore, the study finds distinct shock propagation mechanisms arising from the strategic behaviour and endogenous entry of banks with important implications for policymakers. The findings of this chapter highlight the importance of incorporating financial frictions arising from oligopolistic competition among banks while modelling an economy with highly concentrated financial sector. The next chapter summarises policy implications implied by the findings of Chapter 2 to 4. In addition, the next chapter discusses future research possibilities and extensions of the models in previous chapters.

4.A Appendix

4.A.1 Output
Table A9: Sensitivity: estimation of all substitution elasticities in $M_{flex}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Post. mean</th>
<th>90% HPDI</th>
<th>Post. mean</th>
<th>90% HPDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho_a$</td>
<td>0.76</td>
<td>[0.69, 0.84]</td>
<td>$\sigma_a$</td>
<td>0.041</td>
</tr>
<tr>
<td>$\rho_z$</td>
<td>0.40</td>
<td>[0.30, 0.50]</td>
<td>$\sigma_z$</td>
<td>2.42</td>
</tr>
<tr>
<td>$\rho_\xi$</td>
<td>0.48</td>
<td>[0.35, 0.61]</td>
<td>$\sigma_\xi$</td>
<td>0.30</td>
</tr>
<tr>
<td>$\rho_\varphi$</td>
<td>0.52</td>
<td>[0.41, 0.62]</td>
<td>$\sigma_\varphi$</td>
<td>1.10</td>
</tr>
<tr>
<td>$\rho_{rpf}$</td>
<td>0.60</td>
<td>[0.53, 0.68]</td>
<td>$\sigma_{rpf}$</td>
<td>0.17</td>
</tr>
<tr>
<td>$\rho_{mc}$</td>
<td>0.61</td>
<td>[0.45, 0.77]</td>
<td>$\sigma_{mc}$</td>
<td>0.23</td>
</tr>
<tr>
<td>$\rho_{mi}$</td>
<td>0.54</td>
<td>[0.40, 0.68]</td>
<td>$\sigma_{mi}$</td>
<td>5.60</td>
</tr>
<tr>
<td>$\rho_X$</td>
<td>0.60</td>
<td>[0.45, 0.75]</td>
<td>$\sigma_X$</td>
<td>0.38</td>
</tr>
<tr>
<td>$\phi_p$</td>
<td>0.76</td>
<td>[0.71, 0.81]</td>
<td>$\varsigma_p$</td>
<td>0.34</td>
</tr>
<tr>
<td>$\phi_w$</td>
<td>0.70</td>
<td>[0.64, 0.76]</td>
<td>$\varsigma_w$</td>
<td>0.54</td>
</tr>
<tr>
<td>$\phi_{mc}$</td>
<td>0.74</td>
<td>[0.60, 0.89]</td>
<td>$\varsigma_{mc}$</td>
<td>0.32</td>
</tr>
<tr>
<td>$\phi_{mi}$</td>
<td>0.47</td>
<td>[0.34, 0.60]</td>
<td>$\varsigma_{mi}$</td>
<td>0.50</td>
</tr>
<tr>
<td>$\phi_X$</td>
<td>0.53</td>
<td>[0.39, 0.68]</td>
<td>$\varsigma_X$</td>
<td>0.48</td>
</tr>
<tr>
<td>$\eta_c$</td>
<td>0.75</td>
<td>[0.35, 1.14]</td>
<td>$\rho_i$</td>
<td>0.60</td>
</tr>
<tr>
<td>$\eta_i$</td>
<td>1.17</td>
<td>[0.37, 1.92]</td>
<td>$\phi_\pi$</td>
<td>1.20</td>
</tr>
<tr>
<td>$\eta_f$</td>
<td>0.81</td>
<td>[0.53, 1.08]</td>
<td>$\phi_y$</td>
<td>0.05</td>
</tr>
<tr>
<td>$b$</td>
<td>0.65</td>
<td>[0.56, 0.74]</td>
<td>$\phi_{dy}$</td>
<td>0.04</td>
</tr>
<tr>
<td>$\phi_a$</td>
<td>0.01</td>
<td>[0.01, 0.012]</td>
<td>$\phi_{rS}$</td>
<td>-0.012</td>
</tr>
<tr>
<td>$\tau$</td>
<td>2.35</td>
<td>[1.72, 2.95]</td>
<td>$\sigma_i$</td>
<td>0.04</td>
</tr>
<tr>
<td>$\delta$</td>
<td>3.90</td>
<td>[2.60, 5.16]</td>
<td>$\sigma_\delta$</td>
<td>0.07</td>
</tr>
</tbody>
</table>

MDD: -971.17

Figure A10: Brooks and Gelman’s multivariate convergence diagnostics for $M_{flex}$. 
Figure A11: Export mark up shock in model $M_{flex}$. 
Figure A12: Bank value and preference shocks in $M_{flex}$.

Figure A13: Government exp. and risk premium shocks in $M_{flex}$.

Note: For every row in Fig.A12 and Fig.A13, the first variable contains the name of the shock for that row.
4.A.2 Model equations

Households

Household’s aggregate consumption, similar to Adolfson et al. (2007) is, 

\[ C_t = \left(1 - \omega_c\right)^{1/\eta_c} C_{d,t}^{\omega_c} + \omega_c^{1/\eta_c} C_{m,t}^{\omega_c} \] \quad (A52)

Households maximise Eq.(A52) subject to \( P_t C_{d,t} + P_{mc,t} C_{m,t} = P_{c,t} C_t \). This implies the optimal demand for domestic consumption and imported consumption. Household’s lifetime utility maximization implies the following optimal conditions:

\[
\begin{align*}
\frac{\delta L}{\delta C_t} &= \frac{\theta_t}{P_t} - \frac{\beta b}{C_t - b C_{t-1}} - \beta b C_{t+1} - b C_t = 0; \quad \Rightarrow \gamma_{cd,t} \lambda_t = \frac{\theta_t}{C_t - b C_{t-1}} - \beta b C_{t+1} - b C_t.
\end{align*}
\]

\[
\begin{align*}
\frac{\delta L}{\delta B_{t+1}} &= \frac{\lambda_t}{P_t} - \beta \lambda_{t+1}^{-1} \left(1 + \iota_t\right) = 0 \Rightarrow \beta \Lambda_{t+1}^{-1} \left(1 + \iota_t\right) \Rightarrow 1 = \beta \Lambda_{t+1} R_{t+1}.
\end{align*}
\]

\[
\begin{align*}
\frac{\delta L}{\delta B_{t+1}^s} &= \lambda_t S_t \frac{\beta \lambda_{t+1}^{-1} \left(1 + \iota_t\right) \Phi^{-1} \left(f_{at}^{\delta t} \hat{\phi}_t\right) - \beta \lambda_{t+1}^{-1} \left(S_{t+1} - S_t\right)}{S_t} = 0 \\
&\Rightarrow 1 = \frac{S_{t+1} - S_t}{S_t} \Phi^{-1} \left(f_{at}^{\delta t} \hat{\phi}_t\right) + \frac{1}{\left(1 + \iota_t\right)} \left(S_{t+1} - S_t - 1\right).
\end{align*}
\]

\[
\begin{align*}
\frac{\delta L}{\delta x_{t+1}} &= \beta \lambda_{t+1} \left(d_{t+1} + \nu_{t+1}\right) N_{B,t+1} - \lambda_t \nu_t R_{t+1} = 0 \Rightarrow \lambda_t \nu_t = \beta \lambda_{t+1}^{-1} \frac{1}{\left(d_{t+1} + \nu_{t+1}\right)}.
\end{align*}
\]

CPI is a CES aggregate of domestic price \( P_t \) and imported consumption price \( P_{mc,t} \):

\[
P_{c,t} = \left(1 - \omega_c\right) P_t^{1-\eta_c} + \omega_c P_{mc,t}^{1-\eta_c} \] \quad (A57)

In wage setting, if households cannot re-optimize a new wage level, it simply indexes to previous periods CPI inflation as follows:

\[
\frac{W_{t+s}(l)}{P_{t+s}} = \frac{W_t(l)}{P_t} \Pi_{c,t-l,s-1} \Rightarrow w_{t+s}(l) = w_t(l) \Pi_{t,t+s}^{-1} \Pi_{c,t-l,s-1}^{-1}.
\]

Therefore the first order condition becomes:

\[
\begin{align*}
\frac{\delta L}{\delta w_t(l)} &= 0 \Rightarrow \epsilon_l w_t(l)^{-\epsilon_l(1+\eta)} \sum_{s=0}^{\infty} \left(\beta \phi_w\right)^s \psi w_t(l)^{\epsilon_l(1+\eta)} \Pi_{t,t+s}^{\epsilon_l(1+\eta)} \Pi_{c,t-l,t+s}^{\epsilon_l(1+\eta)} l^{1+\eta} \\
&\quad + \epsilon_c w_t(l)^{-\epsilon_c} \sum_{s=0}^{\infty} \left(\beta \phi_w\right)^s \lambda_{t+s} \Pi_{t,t+s}^{-1} \Pi_{c,t-l,t+s-1}^{\epsilon_c(1-\epsilon_c)} w_t(l)^{\epsilon_c} N_{t+s} = 0.
\end{align*}
\]

From first order condition of \( w(l) \) we can write the common reset wage \( \left(w_t^\#\right) \) as

\[
\begin{align*}
w_t^\#,1+\epsilon_c &= \frac{\epsilon_l}{\epsilon_c - 1} \frac{E_t \sum_{s=0}^{\infty} \left(\beta \phi_w\right)^s \psi w_t(l)^{\epsilon_l(1+\eta)} \Pi_{t,t+s}^{\epsilon_l(1+\eta)} \Pi_{c,t-l,t+s}^{-\epsilon_c(1-\epsilon_c)} N_{t+s}^{1+\eta}}{E_t \sum_{s=0}^{\infty} \left(\beta \phi_w\right)^s \lambda_{t+s} \Pi_{t,t+s}^{-1} \Pi_{c,t-l,t+s-1}^{\epsilon_c(1-\epsilon_c)} w_t(l)^{\epsilon_c} N_{t+s}}.
\end{align*}
\]
The first order condition is,

\[ w_t^{#1+\epsilon \omega \eta} = M_{w,t} \frac{f_{1,t}}{f_{2,t}}, \quad (A61) \]

\[ M_{w,t} = \frac{\epsilon \omega}{\epsilon \omega - 1} \mu_t^w. \quad (A62) \]

\[ f_{1,t} = \varrho_t \psi w_t^{\epsilon \omega(1+\eta)} N_t^{1+\eta} + \beta \phi_w \Pi_{t+1}^{\epsilon \omega(1+\eta)} \Pi_{c,t}^{1-\epsilon \omega(1+\eta)} f_{1,t+1}, \quad (A63) \]

\[ f_{2,t} = \lambda_t w_t^{\epsilon \omega} N_t + \beta \phi_w \Pi_{t+1}^{\epsilon \omega-1} \Pi_{c,t}^{(1-\epsilon \omega)} f_{2,t+1}. \quad (A64) \]

Applying the properties of Calvo pricing to the aggregate nominal wage index and dividing both sides by \( P_t^{1-\epsilon \omega} \) gives the real wage as

\[ (w_t)^{1-\epsilon \omega} = (1 - \phi_w) w_t^{#1-\epsilon \omega} + (\Pi_{c,t-1})^{\epsilon \omega(1-\epsilon \omega)} (\Pi_t)^{\epsilon \omega-1} \phi_w w_t^{1-\epsilon \omega}. \quad (A65) \]

**Domestic intermediate production**

Optimal conditions of intermediate goods producers:

\[ P_{m,t}(1 - \alpha) \frac{Y_{m,t}}{N_t} = w_t, \quad (A66) \]

\[ P_{m,t} \alpha Y_{m,t} = b_1 u_t^c \xi_t K_t, \quad (A67) \]

\[ R_{k,t+1} = \frac{P_{m,t+1} \alpha Y_{m,t+1}}{K_{t+1}} + (Q_{t+1} - \delta (u_{t+1})) \xi_{t+1}. \quad (A68) \]

**Retailers in domestic production**

Final output is a CES aggregate of all retailers output: \( Y_t = \left[ \int_0^1 Y_{ft} \right]^{1-\epsilon_p} \) and aggregate price \( P_t = \left[ \int_0^1 P_{ft}^{1-\epsilon_p} df \right]^{1-\epsilon_p} \). The retailers objective:

\[ \text{Max} \quad E_t \sum_{s=0}^{\infty} (\beta \phi_p)^s A_{t+s} \left( \Pi_{t-1,t+s-1}^{\epsilon \beta_p(1-\epsilon_p)} P_{ft}^{1-\epsilon_p} Y_{t+s} - P_{mt} \Pi_{t-1,t+s-1}^{\epsilon \beta_p} P_{ft}^{1-\epsilon_p} P_{t+s}^{1-\epsilon_p} Y_{t+s} \right). \quad (A69) \]

The first order condition is,

\[ (1 - \epsilon_p) P_{ft}^{1-\epsilon_p} E_t \sum_{s=0}^{\infty} (\beta \phi_p)^s A_{t+s} \Pi_{t-1,t+s-1}^{\epsilon \beta_p(1-\epsilon_p)} P_{t+s}^{1-\epsilon_p} Y_{t+s} \]

\[ + \epsilon_p P_{ft}^{1-\epsilon_p} E_t \sum_{s=0}^{\infty} (\beta \phi_p)^s A_{t+s} \Pi_{t-1,t+s-1}^{\epsilon \beta_p} P_{mt} P_{t+s}^{1-\epsilon_p} Y_{t+s} = 0, \quad (A70) \]

\[ P_{ft} = \frac{\epsilon_p}{\epsilon_p - 1} \frac{E_t \sum_{s=0}^{\infty} (\beta \phi_p)^s A_{t+s} \Pi_{t-1,t+s-1}^{\epsilon \beta_p} P_{mt} P_{t+s}^{1-\epsilon_p} Y_{t+s}}{E_t \sum_{s=0}^{\infty} (\beta \phi_p)^s A_{t+s} \Pi_{t-1,t+s-1}^{\epsilon \beta_p(1-\epsilon_p)} P_{t+s}^{1-\epsilon_p} Y_{t+s}}. \quad (A71) \]
After recursively writing, we get the optimal reset price as,

$$P_t^# = M_{p,t} \frac{X_{1,t}}{X_{2,t}},$$  \hspace{1cm} (A72)

$$M_{p,t} = \frac{\epsilon_p}{\epsilon_p - 1} \mu_t,$$  \hspace{1cm} (A73)

$$X_{1,t} = P_m(t) X_{1,t+1},$$  \hspace{1cm} (A74)

$$X_{2,t} = P_{t+1} X_{2,t+1}.$$

After dividing Eq. (A74) by $P_t^p$ and Eq. (A75) by $P_t^p - 1$ and defining\[ \frac{X_{1,t+1}}{P_t^p} = x_{1,t}, \quad \frac{X_{2,t+1}}{P_t^p} = x_{2,t} \]

and $\Pi_t^#$ as the reset price inflation, we

$$x_{1,t} = P_m(t) X_{1,t} + \phi_p \beta \Lambda(t) X_{1,t+1},$$  \hspace{1cm} (A76)

$$x_{2,t} = Y_t + \phi_p \beta \Lambda(t) X_{2,t+1},$$  \hspace{1cm} (A77)

$$\Pi_t^# = M_{p,t} \frac{x_{1,t}}{x_{2,t}}.$$  \hspace{1cm} (A78)

**Capital Producers**

After defining $Q_t = \frac{\hat{Q}_t}{P_t^p}$, capital goods producer’s optimal condition is,

$$Q_t Z_t \left[ 1 - \frac{\tau}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 - \frac{I_t}{I_{t-1}} \right] + \beta Q_{t+1} \frac{\lambda_t + 1}{\lambda_t} Z_{t+1} \left( \frac{I_{t+1}}{I_t} - 1 \right) \left( \frac{I_{t+1}}{I_t} \right)^2 = 1.$$  \hspace{1cm} (A79)

**Importers**

Optimal condition of consumption goods importers:

$$(1 - \epsilon_{mc}) \Pi_{mc,t}^j \sum (\beta \phi_{mc}) \Lambda_{mc,t} \Pi_{mc,t} X_{mc,t} - \Pi_{mc,t} - \epsilon_{mc} C_{mc,t}$$

$$+ \epsilon_{mc} \Pi_{mc,t} - \epsilon_{mc} X_{mc,t} = 0.$$  \hspace{1cm} (A80)

$$\Rightarrow \Pi_{mc,t} = \frac{\epsilon_{mc}}{\epsilon_{mc} - 1} \frac{E_t \sum_{s=0}^\infty (\beta \phi_{mc}) \Lambda_{mc,t+s} \Pi_{mc,t+s} C_{mc,t+s}}{E_t \sum_{s=0}^\infty (\beta \phi_{mc}) \Lambda_{mc,t+s} \Pi_{mc,t+s}}.$$  \hspace{1cm} (A81)

Following steps similar to domestic retailers, we express the re-set price inflation ($\pi_{mc,t}^#)$ of consumption imports as,

$$\pi_{mc,t}^# = \frac{\epsilon_{mc}}{\epsilon_{mc} - 1} \frac{x_{1mc,t}}{x_{2mc,t}} \pi_{mc,t} = M_{mc,t} \frac{x_{1mc,t}}{x_{2mc,t}} \pi_{mc,t},$$  \hspace{1cm} (A82)

where $M_{mc,t} = \frac{\mu_{mc,t}}{\epsilon_{mc} - 1} \mu_{mc,t}$ is the time varying mark-up and $\mu_{mc,t}$ is an AR(1) process and

$$x_{1mc,t} = m_{mc,t} C_{mc,t} + \phi_{mc} \beta \Lambda_{mc,t} \pi_{mc,t}^# \pi_{mc,t+1} x_{1mc,t+1},$$  \hspace{1cm} (A83)

$$x_{2mc,t} = C_{mc,t} + \phi_{mc} \beta \Lambda_{mc,t} \pi_{mc,t}^# \pi_{mc,t+1} x_{2mc,t+1}.$$  \hspace{1cm} (A84)
Aggregate import consumption inflation:

\[
\pi_{mc,t}^{1-\epsilon_{mc}} = (1 - \phi_{mc}) \pi_{mc,t}^{#1-\epsilon_{mc}} + \phi_{mc} \pi_{mc,t-1}^{\zeta_{mc}(1-\epsilon_{mc})}.
\]  

(A85)

Similarly we can define the equations for imported investment goods where mc in the subscript for import consumption is to be read with mi for import investment. For brevity, I skip listing them. Evolution of net foreign assets:

\[
S_t B^*_t = S_t P_x,t (C_{x,t} + I_{x,t}) - S_t P^*_t (C_{m,t} + I_{m,t}) + (1 + i^*_t) \Phi \left( f_{a_t-1, \phi_{t-1}} \right) S_t B^*_t.
\]  

(A86)

Exporters

Export demand faced by individual exporter \( j \) is,

\[
\tilde{X}_{j,t} = \left( \frac{P_{jx,t}}{P_x,t} \right)^{-\epsilon_x} \tilde{X}_t \text{ where, } P_{jx,t} \text{ is the price in foreign currency term or, export market’s local currency faced by the individual exporter. The marginal cost of export is domestic production price, } P_t. \text{ Price is sticky in export (foreign) market. Thus, } \frac{P_{x,t}}{P_x,t} + s = \pi_x \zeta_x \frac{P_{x,t}}{P_x,t}. \text{ The export sector Phillips curve is same as in Adolfson et al. (2007), except there is no trend inflation in export price inflation.}
\]

Aggregation

The domestic price dispersion \( \nu_t^p \) is,

\[
\nu_t^p = \phi_p \nu_{t-1}^p (\Pi_{t-1})^{-\epsilon_{px}} \Pi_t^p + (1 - \phi_p) \left( \frac{1 - \phi_p \Pi_t^{#(1-\phi_p)} \Pi_t^{\phi_p-1}}{1 - \phi_p} \right)^{-\epsilon_{px}}.
\]  

(A87)

Evolution of aggregate domestic producer price:

\[
(P_t)^{1-\epsilon_{px}} = (1 - \phi_p) P_t^{#1-\epsilon_{px}} + \int_{1-\phi_p}^1 (\Pi_{t-1})^{#(1-\epsilon_{px})} P_{f,t-1}^{1-\epsilon_{px}} df,
\]  

(A88)

which can be written in terms of inflation rate:

\[
(\Pi_t)^{1-\epsilon_{px}} = (1 - \phi_p)(\Pi_t^{#1-\epsilon_{px}}) + \phi_p (\Pi_{t-1})^{#(1-\epsilon_{px})}.
\]  

(A89)

Fisher equation (the link between nominal and real interest rate) is \( 1 + i_t = (R_{t+1})(\Pi_{t+1}) \).

In addition, the model uses some important price ratios that are defined as follows:

\[
\gamma_{cd,t} \equiv \frac{P_{c,t}}{P_t}, \quad \gamma_{dt} \equiv \frac{P_{d,t}}{P_t}, \quad \gamma_{x,t} \equiv \frac{P_{x,t}}{P_t}, \quad \gamma_{mc,dt} \equiv \frac{P_{mc,t}}{P_t}, \quad \gamma_{mi,dt} \equiv \frac{P_{mi,t}}{P_t}, \quad \gamma_{j,t} \equiv \frac{P_t}{S_t}.
\]

Also define, \( \Pi_{mc,t} = \frac{P_{mc,t}}{P_{mc,t-1}} \), and \( \Pi_{X,t} = \frac{P_{X,t}}{P_{X,t-1}} \). Marginal cost of export is defined as,
\[ m_{c,t} = \frac{P_{c,t}}{S_t P_{x,t}} \text{. From Eq.}(A57), \]
\[ \gamma_{cd,t} = \frac{P_{c,t}}{P_t} = \left[ (1 - \omega_c) + \omega_c \left( \frac{P_{mc,t}}{P_t} \right)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}} = \left[ (1 - \omega_c) + \omega_c (\gamma_{mc,dt})^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}} ; \]  
\[ (A90) \]
\[ \gamma_{mc,dt} = 1 \quad \text{. From Eq.}\,(A57), \]
\[ \gamma_{mc,dt} = \Pi_{mc,dt} \gamma_{mc,dt-1} ; \]  
\[ (A93) \]
\[ \gamma_{mi,dt} = \Pi_{mi,dt} \gamma_{mi,dt-1} ; \]  
\[ (A94) \]
\[ \gamma_{x,t}^* = \Pi_{x,t} \gamma_{x,t-1}^* ; \]  
\[ (A95) \]
\[ m_{c,t} = \Pi_t m_{c,t-1} \frac{1}{\Pi_{x,t}} S_{t-1} ; \]  
\[ (A96) \]
\[ m_{mc,t} = \frac{1}{m_{c,t} \gamma_{x,t}^* \gamma_{mc,dt}} ; \]  
\[ (A97) \]
\[ m_{mi,t} = \frac{1}{m_{c,t} \gamma_{x,t}^* \gamma_{mi,dt}} . \]  
\[ (A98) \]

Marginal costs in both consumption and investment imports if \( j = c, i \):
\[ m_{c,j,t} = \frac{P_j S_t}{P_{mj,t}} = \left( \frac{S_t P_{x,t}^*}{P_t} \right) \left( \frac{P_t}{P_{mj,t}} \right) = \frac{1}{\gamma_{f,t}} \frac{1}{\gamma_{mjd,t}} = \frac{1}{m_{c,t} \gamma_{x,t}^* \gamma_{mc,dt}} . \]  
\[ (A99) \]

### 4.A.3 Log-linearised equations

#### Household sector and labour market

\[ \lambda_t = \frac{-1}{(1 - b) (1 - \beta_b)} \left[ C_t - bC_{t-1} - \beta_b (C_{t+1} - bC_t) - (1 - b) (q_t - \beta_b q_{t+1}) \right] - \gamma_{cd,t} ; \]  
\[ (A100) \]
\[ \lambda_{t+1} + R_{t+1} = 0 ; \]  
\[ (A101) \]
\[ \lambda_{t+1} = \lambda_{t+1} - \lambda_t ; \]  
\[ (A102) \]
\[ (1 + \epsilon \omega \eta) \varepsilon_{f} = f_{1,t} - f_{2,t} + \mu_t^w ; \]  
\[ (A103) \]
\[ f_1 f_1,t = \psi w^u (1 + \eta) N^{1+\eta} \left[ \epsilon_{u} (1 + \eta) w_t + (1 + \eta) N_t + \varphi_t \right] \]
\[ + \phi_w \beta f_1 \left[ -\zeta_{w} e_{w} (1 + \eta) \Pi_{ct} + e_{w} (1 + \eta) \Pi_{t+1} + f_{1,t+1} \right] ; \]  
\[ (A104) \]
\[ f_2 f_2,t = w^u N . \lambda \left[ \lambda_t + \epsilon_{w} \omega_t + N_t \right] \phi_w \beta f_2 \left[ \zeta_{w} (1 - \epsilon_{w}) \Pi_{ct} + (\epsilon_{w} - 1) \Pi_{t+1} + f_{2,t+1} \right] ; \]  
\[ (A105) \]
\[ w_t = (1 - \phi_w) w_t^\# + \phi_w (\zeta_{w} \Pi_{ct} - 1 - \Pi_t + w_{t-1}) . \]  
\[ (A106) \]
Financial sector

\[ \nu_t = -A_t + \frac{1}{\epsilon_b - 1} N_{B,t} - \mu_t; \]  
\[ \nu_t = \Lambda_{t+1} + \frac{1}{d + \nu} (dd_{t+1} + \nu \nu_{t+1}) + \epsilon_b; \]  
\[ d_t = \frac{1}{r_K - R} (r_k r_{k,t} - R \hat{u}) + \frac{\epsilon_b}{1 - \epsilon_b} N_{B,t} + O_t; \]  
\[ O_t = Q_{t-1} + K_t; \]  
\[ D_t = N_{B,t} + d_t; \]  
\[ r_{k,t} = \mu_t + \bar{i}; \text{ or}; \]  
\[ r_k r_{k,t} = \mu R (i_t + \mu_t) - \frac{\kappa_b N_B}{(N_B - 1) \epsilon_b - N_B} \theta_t; \]  
\[ \mu_t = \frac{N_B}{(N_B - 1) N_{B,t} - \frac{N_B (\epsilon_b - 1)}{(N_B - 1) \epsilon_b - N_B} N_{B,t}; \]  
\[ N_{B,t} = \frac{1}{N_B + N_{BE}} (N_B N_{B,t-1} + N_{BE} N_{B,t-1}); \]  
\[ R_{k,t} = \frac{1}{1 - \epsilon_b} N_{B,t} + r_{k,t}. \]

Intermediate goods sector

\[ w_t = P_{m,t} + Y_{m,t} - N_t; \]  
\[ R_k K (R_{k,t+1} + Q_t + K_{t+1}) = \alpha Y_m P_m (P_{m,t+1} + Y_{m,t+1}); \]  
\[ + K (Q_{t+1} + \xi_{t+1} + K_{t+1}) - \delta K (\hat{t}_{t+1} + \hat{\xi}_{t+1} + K_{t+1}); \]  
\[ Y_{m,t} = A_t + \epsilon u_t + \alpha \xi_t + \alpha K_t + (1 - \alpha) N_t; \]  
\[ \delta_0 \delta (u_t) = \delta_1 u_t; \]  
\[ P_{m,t} + Y_{m,t} - u_t = \frac{\delta_2}{\delta_1} u_t + \xi_t + K_t. \]

Capital producer

\[ Q_t = \tau (I_t - I_{t-1}) - \beta \tau (I_{t+1} - I_t) - z_t; \]  
\[ K_{K,t+1} = I (z_t + I_t) + K (\xi_t + K_t) - \delta K (\hat{U}_t + \xi_t + K_t). \]

Retail sector

\[ Y_t = Y_{m,t} + \nu_t^p; \]  
\[ \nu_t^p = \phi_p (\nu_{t-1}^p - \epsilon_p \xi_t + \gamma_t \Pi_t); \]  
\[ Y_{1x,1,t} = Y P_m (Y_t + P_{m,t}) + \beta \phi_p x_1 \left[ \xi_t + x_{1,t+1} - \epsilon_p \xi_t + \epsilon_p \Pi_{t+1} \right]; \]  
\[ Y_{2x,2,t} = Y Y_t + \beta \phi_p x_2 \left\{ \xi_p (1 - \epsilon_p) \Pi_t + \Lambda_{t+1} + x_{2,t+1} + (\epsilon_p - 1) \Pi_{t+1} \right\}; \]  
\[ \Pi_t = x_{1,t} - x_{2,t} + \beta \mu_t^p; \]  
\[ \Pi^2_t = \phi_p \xi_p \Pi_{t-1} + (1 - \phi_p) \Pi^2_t. \]

Imports and export sectors

\[ x_{1mc,x_{1mc},t} = C_m m_{mc} (C_m,t + m_{mc,t}) + \beta m_{mc,x_{1mc}} \]  
\[ [\Lambda_{t+1} + x_{1mc,t+1} - \epsilon_{mc,m} \Pi_{mc,t} + \epsilon_m \Pi_{mc,t+1}]; \]  
\[ x_{2mc,x_{2mc},t} = C_m (C_m,t) + \beta m_{mc,x_{2mc}} \]  
\[ [\Lambda_{t+1} + x_{2mc,t+1} + \epsilon_{mc} (1 - \epsilon_{mc}) \Pi_{mc,t} - (1 - \epsilon_{mc}) \Pi_{mc,t+1}]; \]  
\[ \Pi^2_{mc,t} = x_{1mc,t} - x_{2mc,t} + \beta \mu_{mc,t}; \]  
\[ \Pi_{mc,t} = \phi_{mc} \xi_{mc} \Pi_{mc,t-1} + (1 - \phi_{mc}) \Pi^2_{mc,t}; \]  
\[ x_{1mi,x_{1mi},t} = I_m m_{mi} (I_{m,t} + m_{mi,t}) + \beta m_{mi,x_{1mi}} \]
\[ \Pi_{t+1} + x_{1mi,t+1} - \zeta_{mi} \epsilon_{mi} \Pi_{mi,t} + \epsilon_{mi} \Pi_{mi,t+1} \];
\[ x_{2mi,t} \Pi_{2mi,t} = I_m (I_{m,t}) + \beta \phi_{mi} x_{2mi} \]
\[ \Pi_{t+1} + x_{2mi,t+1} + \zeta_{mi} (1 - \epsilon_{mi}) \Pi_{mi,t} - (1 - \epsilon_{mi}) \Pi_{mi,t+1} \];
\[ \Pi_{mi,t} = x_{1mi,t} - x_{2mi,t} + \Pi_{mi,t} + \mu_{mi,t} \];
\[ \Pi_{mi,t} = \phi_{mi} \zeta_{mi} \Pi_{mi,t-1} + (1 - \phi_{mi}) \Pi_{mi,t} \];
\[ \Pi_{\epsilon,t} = \frac{\beta}{1 + \zeta_{\epsilon} \beta} \Pi_{\epsilon,t+1} + \frac{\zeta_{\epsilon}}{1 + \zeta_{\epsilon} \beta} \Pi_{\epsilon,t-1} + \frac{(1 - \phi_{\epsilon}) (1 - \phi_{\epsilon} \beta)}{\phi_{\epsilon} (1 + \zeta_{\epsilon} \beta)} m_{c,t} + M_{\epsilon,t} \];
\[ C_{m,t} = -\eta_c (1 - \omega_c) \gamma_{cd}^{-1} \Pi + \omega_{c,mc} \gamma^{-1} \Pi_{mc,t} \];
\[ X_t = -\eta_f \gamma_{x,t} + Y_t^* \];
\[ rS_t = -mc_{x,t} - \gamma_{x,t} - \omega_{c,mc} \gamma^{-1} \gamma_{cd,t} \];
\[ Y = (1 - \omega_c) \gamma_{cd} \frac{C}{Y} (C_t + \eta_{cd,t}) + (1 - \omega) \gamma_{id} \frac{I}{Y} (I_t + \eta_{id,t}) + \frac{G_t}{Y} \frac{Y^*}{Y} \eta_{f,y,t} - Y_t^* \];
\[ Y_t = \nu N_{BE} (v_t + N_{BE,t}) = wN (w_t + N_t) + N_B d (N_{B,t} + d_t) + KRQ (K_t + Q_{t-1} + R_{t+1} + u_t) \];
\[ \gamma_{mod,t} = \gamma_{mod,t-1} - \pi_t \];
\[ \gamma_{mid,t} = \gamma_{mid,t-1} - \pi_t \];
\[ \gamma_{x,t} = \gamma_{x,t-1} - \pi_t \];
\[ mc_{x,t} = \pi_t + mc_{x,t-1} - \pi X_t - dS_t \];
\[ \gamma_f = mc_{x,t} + \gamma_{x,t} \];
\[ \gamma_{cd,t} = \omega_c (\gamma_{c,mc})^{-1} \gamma_{cd,t} \];
\[ \gamma_{id,t} = \omega_c (\gamma_{id})^{-1} \gamma_{id,t} \];
\[ mc_{mc,t} = -mc_{x,t} - \gamma_{x,t} \gamma_{mc,t} \];
\[ mc_{mi,t} = -mc_{x,t} - \gamma_{x,t} \gamma_{mi,t} \];
\[ \hat{\pi}_t = \beta \hat{\pi}_{t+1} + \frac{K}{100} \hat{Y}_{t+1} + \epsilon_{\pi_t} \];
\[ Y_t^* = Y_t + R_t^* - \pi_{t+1} + \epsilon_{y,t} \];
\[ \hat{R}_t^* = \rho R^* \hat{R}_{t-1}^* + (1 - \rho R^*) \left( \phi_{\pi} \hat{\pi}_t + \phi_{\gamma} \hat{Y}_t + \phi_{\gamma^*} \left( \hat{Y}_t^* - \hat{Y}_{t-1}^* \right) \right) + \epsilon_{R^*,t} \];
\[ \epsilon_{\pi^*,t} = \rho_{\pi^*} \epsilon_{\pi^*,t-1} + \epsilon_{\pi^*,t} \];
\[ \epsilon_{\gamma^*,t} = \rho_{\gamma^*} \epsilon_{\gamma^*,t-1} + \epsilon_{\gamma^*,t} \];
\[ \hat{A}_t = \rho A_{t-1} + \epsilon_{a,t} \];
\[ \hat{\varrho}_t = \rho \varrho_{t-1} + \epsilon_{\varrho,t} \];
\[ \hat{\varphi}_t = \rho \varphi_{t-1} + \epsilon_{\varphi,t} \].
\[
\mu^w_t = \rho \mu^w_{t-1} + e_{w,t}; \\
\mu^p_t = \rho \mu^p_{t-1} + e_{p,t}; \\
z_t = \rho z_{t-1} + e_{z,t}; \\
\xi_t = \rho \xi_{t-1} + e_{\xi,t}; \\
G_t = \rho G_{t-1} + e_{g,t}; \\
M_{x,t} = \rho M_{t-1} + e_{x,t}; \\
\mu_{mc,t} = \rho \mu_{mc,t-1} + e_{mc,t}; \\
\mu_{mi,t} = \rho \mu_{mi,t-1} + e_{mi,t}.
\]

\[ (A165) \]

\[ (A166) \]

\[ (A167) \]

\[ (A168) \]

\[ (A169) \]

\[ (A170) \]

\[ (A171) \]

\[ (A172) \]

4.A.4 Data construction

Unless otherwise stated all data are collected from Australian Bureau of Statistics in quarterly frequency from 1993Q1 to 2015Q4.

Population: Estimated resident population (ERP) for age group 16 to 65 and over is used to make relevant data in AUD per capita term.

Output: Non-farm gross domestic product, chain volume measures, seasonally adjusted, (Series ID: A2302589X ).

Consumption: Households final consumption expenditure, seasonally adjusted, (Series ID: A2304081W).

Investment: Private gross fixed capital formation, seasonally adjusted, (Series ID: A2304100T ).

Exports: Exports of goods and services, seasonally adjusted, (Series ID: A2304114F ).

Imports: Imports of goods and services, seasonally adjusted, (Series ID: A2304115J ).

Hours worked: Quarterly hours worked in all jobs, seasonally adjusted, (Series ID: A84426298K ).

CPI inflation: Consumer price index: all groups, Index 2011/12=100, quarterly, Reserve Bank of Australia (RBA), Statistical table G1, (Series ID: GCPIAG ).

Real exchange rate: AUD trade-weighted exchange rate index, adjusted for relative consumer price levels, Index, March 1995 = 100, quarterly, RBA, (Series ID: FRERTWI ).
Nominal interest rate: Cash rate target in percent, Statistical table A2, RBA, (Series ID: ARBAMPCNCRT).

Lending rate: Average of the two lending rates: Large business loan; weighted-average rate on credit outstanding; variable, (Series ID: FILRLBWAV) and lending rates in housing loans, variable, owner occupied, standard (Series ID: FILRHLBVS) from RBA statistical table F5. Average of the end of quarter rates have been considered.

Total mass of banks: Quarterly ADI performance of banks statistics, Australian Prudential Regulatory Authority (APRA). The back series are from RBA statistical table J1-number of banks that reported their asset-liability positions.

Foreign GDP: Export weighted real GDP index of Australia’s major trading partners, Base March 2005 = 100, Quarterly, RBA’s own calculation by aggregating 17 economies plus the Euro area (36), starting from 1997Q1.

Foreign inflation: Weighted average Consumer Price Index (CPI) of 14 countries: Hong Kong, China, France, Germany, Indonesia, Italy, Japan, Republic of Korea, Malaysia, New Zealand, Singapore, Thailand, UK and US. Quarterly CPI indices are collected from International Financial Statistics (IFS) database. Trade weights are calculated from annual goods and service trade data of Australia with these 14 countries from Trade and Investment statistics of Department of Foreign Affairs and Trade. Weights are annual, hence, the four quarters a year have same weights.

Foreign interest rate: Effective Federal Funds Rate, St. Louis FED- FRED Database, (Series ID: FEDFUNDS).
Chapter 5

Conclusion

5.1 Summary and implications

The orientation of the thesis is towards investigating monetary policy and various other shock transmissions in presence of financial frictions. To do this I construct appropriate models based on the gaps in the literature and analyse implications of various estimated models in terms of shock impacts and the roles of various nominal and real frictions in their transmission processes. The research questions addressed in Chapters 2-4 of the thesis contribute to the literature in empirically and theoretically important ways for both developing and developed country issues.

In Chapter 2 the thesis has investigated monetary policy transmission channels with especial emphasis on the lending channel, in addition to analysing credit boom and external shock impacts, during the period of market based monetary policy instruments and floating exchange rates. An economy wide SVAR model for Bangladesh was constructed and the identification scheme of the SVAR model incorporated the Exchange Rate Pass Through (ERPT) literature along with the monetary policy literature. This is to reflect the practice of pursuing a separate foreign exchange policy apart from monetary policy by the central bank. In addition, the block exogeneity restriction ensures that the domestic economy is affected by the developments in the rest of the world but not the other way around. The estimated model finds that the responses of macro aggregates to monetary policy shock are similar to empirical regularities. The current monetary aggregates targeting
policy regime is able to affect the price level of the country significantly. The fact that targeting a monetary aggregate is able to influence price is consistent with the observation that financial sector advancement is an ongoing process and the variation of money is less complicated in Bangladesh. Exchange rate channel of monetary policy appears less effective, as expected, due to frequent interventions of Bangladesh Bank in foreign exchange market. Credit booms are inflationary and external shocks are found to be important.

The findings of Chapter 2 suggest a non-trivial but moderate existence of bank lending channel and indicate a greater attention from prudential regulations are needed to remove existing impediments in the channel to make it even more functional. Particular attention needs to be paid to remove the factors, discussed in Chapter 2, that create stickiness in rates in the loan market and deter monetary policy rates to be translated to commercial lending rates effectively. Second, frequent interventions in foreign exchange market reduce monetary policy effectiveness by weakening the exchange rate channel. Continuation of the tendency of exchange rate undervaluation for long time to promote exports can have negative impacts on the economy by creating inefficiencies in domestic production. In order for monetary policy to be effective, the central bank should cut its level and frequency of intervention in the foreign exchange market and allow market forces to determine exchange rates. Third, to bring greater amount of financial transactions under the formal financial system, financial services should be made cheaper and easily available particularly in the rural areas. If larger number of economic activities are accounted for by the banking system, then scope of the monetary policy will increase and transmission mechanism will be clearer and more effective.

In Chapter 3 the thesis extended the financial friction DSGE model of Gertler & Karadi (2011) to incorporate various nominal and real frictions to analyse the the role of marginal efficiency of investment shock in business cycles. In addition, the chapter conducted experiments with financial shocks such as those originating in the finance sector (bank net worth
shock) and in the real sector (capital quality shock) and discussed the issues of separate
identification of them. The main findings are that although price and wage rigidities in the
model enhances the effects of marginal efficiency of investment shock, financial frictions
largely replace the shock impacts. Under the assumption of perfectly competitive banking
sector, while determining the lending rates, financial frictions work through the balance
sheet effects of changes in collateral valuations, caused by changes in stock market price of
capital. In addition, the chapter emphasises that financial shocks are important in business
cycles in their own capacity, not just because financial sector amplifies shocks of the real
sector.

The findings of Chapter 3 have important modelling and policy implications. Consid-
ering a bank net worth shock rather than capital quality shock as finance based shock can
improve the fit of the model. Since capital quality shock cannot rule out the possibility
of physical destruction of capital, the shock may not be a good representation of financial
shock. In case of physical destruction of capital, there can be greater need for investment,
and banks can make additional profits from making new investment. So, in the case of this
liability side financial friction, including a purely finance based shock such as the bank net
worth shock is useful to improve fit of the model and to draw accurate inferences about
financial shocks. The results also highlight the importance of incorporating nominal wage
and price stickiness for the US economy, supporting micro founded evidence on the US.

In a highly competitive financial environment, as assumed in Chapter 3, the bank net
worth shock plays an important role and has huge repercussions not just for the financial
sector but also for the real sector through credit market. Bank capital response is much
higher and prolonged to a net worth shock than to capital quality (asset side) shocks. This
indicates the way policy makers should respond to different financial shocks. In response
to exogenous events creating variations in bank net worth, policymakers should focus
on the ways to replenish bank net worth which will automatically be reflected in easing
credit conditions. This highlights the importance of stress testing and increased prudential supervisions and regulations to check the health of the financial intermediaries on a regular basis in addition to having sufficient regulatory capital. In contrary, if the financial shocks belong to the asset side, then instant measures should be taken to reduce the interest spread in the loan market. Overall, financial sector amplifies impacts of negative real sector shocks by raising interest spread which is observed in both Chapter 3 and Chapter 4. So, any policy stance that can mitigate the upward trend in spread can be an effective way to deal with a crisis.

Considering the highly concentrated financial sector in some countries and limited studies deal with the issue in estimated general equilibrium models, Chapter 4 has analysed the role of an oligopolistic financial sector in the context of a small open economy. The chapter is an application of oligopolistic competition and endogenous firm entry model in case of financial sector where imperfect competition is measured through mark up. Taking Australia as an example of such a country, the DSGE model of Chapter 3 was augmented with standard trade features and estimated with Australian data following the Bayesian estimation technique. One of the main results from the model is the counter cyclical movements in the interest mark up or spread in the credit market, similar to Chapter 3. For example, a negative technology shock increases the interest mark up through the bank entry channel and thereby amplifies the shock impacts.

The results of Chapter 4 imply that oligopolistic competition in financial market affects the dynamics of output and investment in important ways. Ignoring this feature of financial market in the model may lead monetary policy and other shocks to have their impacts on the real economy overestimated or under estimated. For example monetary policy in Chapter 4 is found to be less effective, similar to some other studies. And the chapter also demonstrates the way an oligopolistic banking sector interact with stock market price which makes monetary policy less effective. Although bank entry channel tends to amplify
the effect of a contractionary monetary policy, a strong stock market effect of exchange rate works in the opposite direction to reduce the amplifying effect. For various technology shocks and foreign shocks, the oligopolistic banks work as amplifiers in the model in most of the cases.

Second, since the friction in the finance market in Chapter 4 arises due to the strategic behaviour among banks, the results provide important insights for policymakers to shape the competition structure in financial sector. Further merger and acquisition in the financial sector can be detrimental to the economy, validating the current policy of prohibiting further merger and acquisition among the big four banks in Australia.

Third, the bank entry condition implies that relevant authority should facilitate reducing the entry costs to attract new domestic and foreign banks in the market. Increased competition can decrease loan mark ups and make banking products less costly.

However, oligopolistic banks can be too strong to fail due to huge capital base, out of their high profit margins (e.g Australian banks), compared to the competitive banks. So, greater stability within the financial sector is expected in an oligopolistic set-up, although high market power may enhance fluctuations in the real economy by charging higher costs on financial services in the events of negative domestic and foreign shocks.

The thesis conducted a wide arrays of sensitivity analysis and other forms of estimations in each of the three self contained chapters to check whether results in the baseline models are robust. Overall, these additional estimations usually validated the claims or findings of the main models.

5.2 Outlook

As in most economics research the chapters of this thesis have revealed some further questions to be addressed in subsequent research. The model for Bangladesh economy in Chapter 2 is estimated with monthly data due to unavailability of quarterly national
income account data, particularly GDP data which is available only with annual frequency for the entire period of study. This leaded the study to use industrial production instead of GDP. When sufficient data in quarterly frequency\footnote{Bangladesh Bureau of Statistics recently calculates quarterly GDP.} becomes available the model can be re-estimated with GDP data instead of industrial production index to get better insights of the output dynamics and adjustment timing towards steady state after a shock. Data limitations such as import and export price indices in required frequency also constrained the study to focus more on trade issue, although this is an important feature to be included in the SVAR model of Bangladesh. Monetary policy response to fiscal risks can be another important dimension in the model which is particularly important for countries with fiscal sector dominance.

The benefits of separating asset and liability side financial shocks in Chapter 3 arise because of the construction of capital quality shock. In order to assess a deterioration of asset market, a shock can be designed in a way that represents only exogenous change in capital price so that the shock represents only change in valuation rather than any physical destruction of capital. Another interesting question that arise out of Chapter 3 is: how strong does the endogenous balance sheet constraint remain when banks are open to collect deposits from households in rest of the world, rather than from the domestic economy only. Similarly, households can have the opportunity to invest money in the rest of the world. In this connection, the elaborate open economy features in Chapter 4 can be incorporated into Chapter 3 and estimated to see what changes they bring compared to the findings of Chapter 3.

For simplicity the financial sector in Chapter 4 assumes no information asymmetry between borrowers and bankers. The mark up charged on loan rate is entirely due to strategic behaviour among banks. Unlike goods production sector, information asymmetry is very common and important phenomenon in financial sector and banks charge mark ups
to cover borrower default risks. Thus, an explicit modelling of default risks based on borrowers net worth in spirit of Bernanke et al. (1999b) is a natural extension of Chapter 4. Another interesting avenue of future research of this chapter is allowing foreign deposits and lending into bank balance sheet. This is particularly important for countries that have high exposures in international financial markets. For commodity exporting countries like Australia, a separate commodity exporting sector can be introduced due to the special nature of commodity exporting sectors, as in Jasskela & Nimark (2011) for example.

The findings of the thesis in Chapter 3 and Chapter 4 together indicate very interesting avenues for future research. Is the financial frictions proposed by Gertler & Karadi (2011) valid or effective in countries where financial sector is not as much competitive as in the US? Alternatively, which type of the friction will provide better fit and hence should be included in the model? Chapter 4 implicitly assumes that in an imperfectly competitive markets the moral hazard problem described in Gertler & Karadi (2011) is less likely to occur. Hence, the balance sheet constraint on the bank’s leverage is less likely to be effective because households have only few banks to deposit savings and receive banking services from. This assumption can be tested by estimating both models with the same data for countries with highly concentrated banking sectors.
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