A small open economy modelling: A Bayesian DSGE approach

Gan-Ochir Doojav

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Declaration

I declare that this thesis is my own work, except where due reference is made and has not been previously included in a thesis or report submitted to this university or to any institution for a degree, diploma or other qualifications.

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Gan-Ochir Doojav

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Abstract

Examining the business cycle and the monetary transmission mechanism in a small open economy based on the macroeconomic models is vital for successfully implementing forward-looking and counter-cyclical macroeconomic policies. In the context, this thesis focuses on the importance of various modelling implications (i.e., frictions and shocks) in developing empirically viable small open economy dynamic stochastic general equilibrium (DSGE) models. The thesis comprises three self-contained chapters on formulating, estimating and evaluating the DSGE models using Bayesian methods and data for Australia and the United States (US) (or G7 for Chapter 2), as well as a general thesis introduction and conclusion.

Chapter 2 investigates the quantitative role of a cost channel of monetary policy and an uncovered interest rate parity (UIP) modification in an estimated small open economy DSGE model. For this purpose, a small open economy New Keynesian DSGE model developed by Justiniano and Preston (2010a) (i.e., benchmark model for the thesis) is augmented to incorporate the cost channel and the UIP modification based on a forward premium puzzle. The empirical analysis shows that introducing the cost channel and the UIP modification into the estimated model improves its ability to fit business cycle properties of key macroeconomic variables and to account for the empirical evidence on the monetary transmission mechanism.

Chapter 3 assesses the importance of news shocks in a small open economy DSGE model for analysing business cycle properties of macroeconomic aggregates, including labour market variables. To this end, the model in Chapter 2 is enlarged in Chapter 3 to include (i) the theory of invoulntary unemployment proposed by Galí (2011), (ii) an endogenous preference shifter, similar to that used by Galí et al. (2011), and (iii) both news (anticipated) and unanticipated components in each structural shock. The results show that the estimated model is able to qualitatively replicate the existing VAR-based results (e.g., Kosaka 2013, Kamber et al. 2014 and Theodoridis and Zanetti 2014) on news driven business cycles, and the presence of news shocks has the potential to improve the model fit. Another important finding is that news shocks have been the main drivers of the Australian business cycle in the inflation-targeting period.

Chapter 4 examines the significance of financial frictions and shocks in a small open economy DSGE model for explaining macroeconomic fluctuations. In doing so, Chapter

4 has further extended the model in Chapter 3 to a rich DSGE model in the two-country setting with involuntary unemployment, financial frictions and shocks. The main results include (i) the presence of financial accelerator improves the model fit, (ii) the financial accelerator amplifies and propagates the effects of monetary policy shocks on output, but dampens the effects of technology and labour supply shocks in Australia and the US, and (iii) financial shocks (i.e., shocks to the credit spread) are important for explaining investment and output fluctuations in both countries.

Finally, this thesis provides implications for designing macroeconomic policies and building empirically viable open economy DSGE models to analyse the transmission mechanism of monetary policy and the business cycle.

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Chapter 1

Introduction

1.1 The context

It is acknowledged in the literature that macroeconomic models are powerful tools providing a coherent framework for decision-making and policy analysis. Since an economy is an evolving complex system with interconnected components, the models that incorporate such structural linkages are useful for several aspects of policy analysis, including communication and simulation of policy actions, testing of competing theories, forecasting of future developments and stress testing (Bårdson and Nymoen 2009). Therefore, model-based policy analysis is essential to successfully implementing forward-looking as well as counter-cyclical macroeconomic policies. To satisfy the different objectives of policy-making, a number of models[1] has been used in policy analysis. Such models include calibrated theoretical models, Simultaneous Equation Models (SEM, also referred as macro-econometric models), Structural and Bayesian Vector Autoregression (VAR), and Dynamics Stochastic General Equilibrium (DSGE) models (see Pagan 2003 for an overview).

There has been enormous progress in the development of macroeconomic models. The literature (e.g., Galí and Gertler 2007, Blanchard 2009, Fukac and Pagan 2009) has agreed that evolution rather than revolution is a better description of the development process. Leading macroeconomists (e.g., Lucas 1976 and Sargent 1981)[2] have argued that structural macro-econometric models, which fit largely on statistical relationships, cannot be used to predict the outcome of policy changes. In responding to the Lucas critique and the downfall of the traditional macro-econometric models in the 1970s, two alternative modelling approaches started to develop in the 1980s: (i) the VAR models contributed by

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[1] As stated by Bårdson and Nymoen (2009), the models vary with theoretical foundations (micro-foundations/aggregation/general/partial), model properties (size/robustness/non-linearities/dynamics) and econometric methods (classical/Bayesian).

[2] They argued that estimated coefficients of structural models, not developed from an optimization based approach, are likely not invariant to shifts in policy regimes or other structural changes.

Sims (1980) and Litterman (1980, 1986), and (ii) the micro-founded macroeconomic models based on rational expectation (e.g., real business cycle (RBC)) contributed by Kydland and Prescott (1982). These RBC models, derived from microeconomic principles, are also known as DSGE models[3]. Moreover, two independent literatures based on RBC theory and New Keynesian theory have emerged to develop the New Keynesian DSGE modelling[4] that corresponds to a RBC theory, on which key elements of the Keynesian approach (e.g., imperfect competition and nominal rigidities) are superimposed.

Of the macroeconomic models, the New Keynesian DSGE models represent a key development in the field of macroeconomic modelling for policy analysis. As the models are based on a sound, micro-founded structure, they are useful in explaining aggregate economic phenomena, such as economic growth, business cycles, and the effects of monetary and fiscal policies on the real economy. The models are suitable for conducting policy analysis and forecasting as they overcome Lucas' (1976) critique and provide a good empirical fit. Therefore, policy makers are currently focusing on the estimated New Keynesian DSGE models with both nominal and real rigidities to tell stories about how an economy responds to structural shocks and to forecast future developments of an economy. However, progress has been slower in developing empirically viable DSGE models in the new open economy macroeconomics (NOEM)[5] paradigm, compared to the models in the closed-economy setting.

This thesis, therefore, aims to contribute to the literature on empirical NOEM modelling by examining the importance of various modelling implications (i.e., frictions and shocks) in building estimated small open economy New Keynesian DSGE models[6]. In this thesis, the assumption of a small open economy[7] is used to model a price-taking economy,

[3] A related methodology that pre-dates DSGE model is computable general equilibrium (CGE) model. Though the CGE models are also based on micro-foundation, they focus mostly on long-run relationships.
[4] This modelling framework has been introduced by Rotemberg and Woodford (1997) and Goodfriend and King (1997), and the synthesis is also referred as the New Neoclassical Synthesis.
[5] NOEM is set forth by Obstfeld and Rogoff (1995) who consider a two-country general equilibrium model with imperfect competition and price rigidities. The earlier development of the theoretical and empirical NOEM models have been reviewed by Lane (2001) and Lubik and Schorfheide (2006). The recent development of open economy DSGE models can be seen from Christiano et al. (2011b) and Adolfson et al. (2007, 2013).
[6] The models consist of a small open economy and the rest of the world. The rest of the world is modelled as a closed version of the open economy model. However, the model is asymmetric in structure, implying that there is one-way effect from the large economy to the small economy.
[7] A small open economy is an economy that participates in international trade, but is small enough compared to its trading partners that its policies do not alter world prices, interest rates, or incomes. This economy is unlike a large open economy, the actions of which do affect world prices and income.

allowing exogenous assumptions of the conditions in the rest of the world. Several econometric procedures have been proposed to parameterize and evaluate DSGE models[8]. However, compared to its alternatives, the Bayesian approach is rich enough to deal with both misspecification and identification problems raised in structural empirical models. Therefore, the DSGE models in the thesis are estimated and evaluated using Bayesian methods. The estimated DSGE models are particularly useful for monetary authorities to design and implement robust monetary and financial policies in both small open developed and developing economies.

The contribution of this thesis to the literature is a comprehensive analysis of theoretical development, estimation and evaluation of a range of modelling assumptions in explaining the properties of macroeconomic and financial market data. Specifically, this thesis builds small open economy DSGE models, ranging from a standard small-scale model to a richer DSGE model, featuring both labour market imperfection and financial frictions. In doing so, it aims at integrating a number of extensions in DSGE modelling, proven to be crucial in explaining the macroeconomic fluctuations. Moreover, the thesis offers assessments on the importance of various frictions and shocks for analysing the macroeconomic dynamics of both small (Australia) and large (the US and G7) economies.

1.2 Structure and preview

This thesis contains three self-contained chapters on formulating and evaluating the small open economy New Keynesian DSGE models using Bayesian methods.

From the modelling contribution point of view, the thesis develops New Keynesian DSGE models for a small open economy, linked to each other as shown in Figure 1.1. Chapter 2 sets out a simple small open economy New Keynesian DSGE model developed by Justiniano and Preston (2010) as the benchmark model for the thesis. However, this kind of open economy DSGE models considers the standard uncovered interest rate parity (UIP) and the demand side effect of monetary policy. Therefore, such models do not

[8] The procedures range from calibration (Kydland and Prescott 1982), over GMM estimation of equilibrium relationship (Christiano and Eichenbaum 1992), minimum distance estimation based on the discrepancy among VAR and DSGE model impulse response functions (Rotemberg and Woodford 1997, Christiano et al. 2005), full-information likelihood based estimation (Leeper and Sims 1994, Kim 2000), to Bayesian estimation (Smets and Wouters 2003, An and Schorfheide 2007).

account for the empirical facts on the monetary transmission mechanism (i.e., price puzzle and delayed overshooting puzzle), obtained from the VAR-based studies.

Figure 1.1 DSGE models developed through the thesis

Benchmark model

A small open economy DSGE model developed by Justiniano and Presen (2010)

↓

The model developed in Chapter 2

The benchmark model is augmented by

- Incorporating cost channel of monetary policy
- Modifying UIP condition to allow a negative relationship between the country risk premium and the expected change in the nominal exchange rate

↓

The model developed in Chapter 3

The model built in Chapter 2 is extended by

- Incorporating labour market imperfection (wage dynamics and unemployment) based on Galí (2011)
- Introducing an endogenous preference shifter following Galí et al. (2011)
- Including both news and unanticipated components in each of the structural shocks

↓

The model developed in Chapter 4

The model developed in Chapter 3 is further extended by

- Incorporating the capital
- Including financial frictions based on financial accelerator framework developed by Bernanke et al. (1999)
- Introducing two financial shocks (i.e., credit supply shock and financial wealth shock)

However, each of the structural shocks features only the unanticipated component.

The literature on monetary DSGE models has shown that augmenting (or relaxing) standard assumptions in the models may help to account for the empirical evidence on the monetary transmission mechanism.

Therefore, in Chapter 2, the benchmark model is augmented in the following two dimensions to investigate the relevance of the additional assumptions (i.e., cost channel of monetary policy and the forward premium puzzle) in accounting for the existing VAR results. First, following Christiano et al. (2005), Rabanal (2007) and Christiano et al. (2011a), the cost channel (i.e., supply side effect) of monetary policy is included in the model by assuming that a fraction of firms' working capital must be financed by short-term loans since firms have to pay some costs of their variable inputs in advance of selling their product. Second, as suggested by Adolfson et al. (2008) and Adolfson et al. (2013), the UIP condition is modified by allowing for the country risk premium to be negatively correlated with the expected depreciation in the nominal exchange rate.

The model built in Chapter 2 assumes (i) a perfectly competitive market, in which households and firms take the wage as given, (ii) a standard household utility function, a preference of the class discussed in King et al. (1988), and (iii) shocks are unanticipated by agents until they are realized, and hence observed. However, the recent literature on DSGE modelling has highlighted the importance of labour market characteristics (i.e., unemployment, wage setting process and shocks in the market) in understanding the link between labour market and macroeconomic fluctuations. Recently, the view that business cycles can be driven purely by anticipated developments in the economy – so-called news shocks – has been revived. Furthermore, the news-driven business cycle literature addresses the fact that a DSGE model is able to reproduce the business cycle co-movements in response to news shocks when the wealth effect of the shocks on the labour supply in the model is weak. Therefore, the model in Chapter 2 is further extended in Chapter 3 to include (i) labour market imperfection by incorporating the theory of involuntary unemployment proposed by Galí (2011), a variant of the staggered wage setting developed by Erceg et al. (2000) and labour market shocks, (ii) a utility function with an endogenous preference shifter, similar to that used by Galí et al. (2011), to mitigate the wealth effect, and (iii) both news (anticipated) and unanticipated components in each structural shock. Those extensions do not change the main features of the model, and they allow us to study labour market dynamics and macroeconomic effects of news shocks in a small open economy.

Recently, the global financial crisis (GFC) has spotlighted the importance of real-financial linkage in explaining macroeconomic fluctuations and macroeconomic models for designing appropriate stabilization policy. In addition, the model built in Chapter 3 is abstracted from capital accumulation and real-financial linkages. Therefore, Chapter 4 further develops the model to incorporate (i) capital accumulation, (ii) financial frictions based on the financial accelerator framework developed by Bernanke et al. (1999), and (iii) two financial shocks directly affecting the financial sector (i.e., credit supply shock and financial wealth shock) building on the recent literature (e.g., Dib et al. 2008, Gilchrist et al. 2009 and Christiano et al. 2010). The resulting model in an open economy setting is the rich in the sense that it has similar features of the medium-scale New Keynesian economy DSGE models (e.g., Smets and Wouters 2003, 2007, Christiano et al. 2005, Adolfson et al. 2007, 2008, Galí et al. 2011), but with an addition of involuntary unemployment, financial frictions and financial shocks. In particular, the model is closer to the small open economy DSGE models developed by Chiristiano et al. (2011) and Adolfson et al. (2013), reflecting both financial frictions and labour market imperfections. The estimated model with many frictions and shocks is suitable for assessing the prominence of structural shocks (e.g., financial, investment and labour market shocks) in explaining business cycles.

From the methodological point of view, this thesis uses Bayesian methods for both estimation and empirical assessment of the developed DSGE models. As explained earlier, the Bayesian approach has its advantage over alternative approaches. In the Bayesian approach, a prior distribution on parameter is updated by sample information contained in the likelihood function to form a posterior distribution. Since the prior is based on 'non-sample' information (either from microeconomic studies or from previous macroeconomic exercises), the Bayesian method provides an ideal framework for combining different sources of information (Del Negro and Schorfheide 2011). The resulting posterior distributions of parameters provide a coherent measure of uncertainty about the parameters and the model specification. There is also a further advantage when it comes to formal comparison of models that are not nested using the model's marginal likelihood.

From the empirical point of view, this thesis examines important issues of a small open economy concerning the monetary policy transmission and the business cycle. Chapter 2 investigates the quantitative role of the cost channel and the uncovered interest rate parity

(UIP) modification in an estimated small open economy New Keynesian model. This study contributes to the literature on the effect of monetary policy in a small open economy. First, it is one of the first attempts to assess the empirical relevance of the supply-side effects of monetary policy in a small open economy New Keynesian DSGE model estimated by Bayesian methods. Second, it attempts to assess a structural interpretation for violation of the standard UIP and the delayed overshooting puzzle using the Bayesian DSGE approach. Four variants of the model developed in Chapter 2 are separately estimated by Bayesian methods using data for Australia and the G7 economies[9]. To evaluate the empirical relevance of the cost channel and the UIP modification, several assessment techniques are used. The empirical analysis suggests that (i) the presence of the cost channel and the UIP modification improves the model fit, (ii) though there is evidence of the cost channel, its strength is not sufficient to reproduce the price puzzle, and (iii) the standard UIP condition is violated in Australia and the presented UIP modification potentially resolves the delayed overshooting puzzle.

Chapter 3 examines the importance of news shocks in an estimated small open economy model for analysing business cycle properties of macroeconomic aggregates, including labour market variables. The chapter contributes to the existing literature on the news-driven business cycle in several ways. In particular, the chapter provides one of the first attempts to empirically assess (i) the international transmission mechanism of news shocks and (ii) the relevance of news shocks in generating exchange rate and labour market fluctuations using Bayesian open economy New Keynesian DSGE model in an international setting. Moreover, as a novelty in the literature, the chapter allows that news horizon(s) for each structural shock can be different depending on best-fitting searching results based on the approach originally proposed by Fujiwara et al. (2011). In Chapter 3, the model in Chapter 2 is further extended to include labour market imperfection, and both unanticipated and news shocks drive the extended model. The model is fitted to data for Australia and the US. Bayesian methods are employed to estimate the role of the news shocks and evaluate the model's empirical properties. The main results show that the estimated model is able to qualitatively replicate the existing results of the VAR analyses on news-driven business cycles (e.g., Kosaka 2013 and Kamber et al. 2014), and news

[9] However, in Chapter 3 and Chapter 4, the rest of the world is proxied by the US data instead of the G7 data as to identify a country specific news and financial shocks and to study their impacts on the Australian economy.

shocks are the main drivers of Australian business cycle fluctuations in the inflation-targeting period.

Chapter 4 focuses on the importance of financial frictions and shocks in an estimated small open economy DSGE model for explaining business cycle fluctuations. Financial frictions are introduced only in Chapter 4 based on an open economy version of the financial accelerator framework, and only the accumulation and management of capital involves the frictions. To this end, Chapter 4 extends the model in Chapter 3 to incorporate financial frictions and shocks as described in Figure 1.1. This study introduces some novelties and contributes to the literature in distinct ways. First, it assesses the empirical relevance of foreign-currency denominated debt assumption in the model using Bayesian methods. Second, it is one of the first attempts to examine the significance of financial frictions and shocks in an estimated open economy DSGE model in a two-country setting. Third, this paper investigates empirically the international transmission mechanism of financial shocks (i.e., credit supply shock and financial weal shock). Three versions of the model are estimated using Bayesian methods on Australian and the US data over the period 1993:Q1 -2013:Q4, covering the inflation-targeting period in Australia and the GFC of 2008-2009. The empirical analysis shows that the financial accelerator is operative in both Australia and the US, and that financial shocks (i.e., two shocks that directly affect the credit spread) play a pivotal role in explaining investment and output fluctuations.

Chapter 5 provides a summary of key findings and presents implications for designing macroeconomic policies. Furthermore, the chapter offers some important policy implications for developing empirically viable small open economy DSGE models.

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Chapter 2

The cost channel of monetary policy and the UIP modification in an estimated small open economy DSGE model

Abstract

This chapter examines the quantitative role of the cost channel and the uncovered interest rate parity (UIP) modification in an estimated small open economy DSGE model. For this purpose, a standard model (i.e., Justiniano and Preston 2010a) is augmented to incorporate (i) the cost channel of monetary policy and (ii) the UIP modification allowing for the country risk premium to be negatively correlated with the expected exchange rate depreciation. Four variants of the augmented model are estimated using Bayesian methods with data from Australia and the G7 economies. The empirical analysis shows that introducing the cost channel and the UIP modification into the standard model improves its ability to fit the business cycle features of key macroeconomic variables and to account for the empirical evidence on the monetary transmission mechanism.

Keywords: Cost channel, UIP condition, Monetary transmission, Open economy macroeconomics, New Keynesian DSGE model, Bayesian estimation.

JEL classification: C11, E30, E40, E52

2.1 Introduction

The vector autoregression (VAR) analyses of the monetary transmission have highlighted various puzzles. These puzzles include the 'price puzzle', first used by Eichenbaum (1992), which refers to a phenomenon, in which an unexpected tightening in monetary policy leads to a rise in inflation at least temporarily (see, Dungey and Fry 2003, Jacob and Rayner 2012 for Australia); and the 'delayed overshooting puzzle', which refers to a circumstance in which the response of real exchange rate to a monetary policy shock is hump-shaped with a peak effect after a period of time (see, Eichenbaum and Evans 1995, Faust and Rogers 2003 for G7 countries, and Dungey and Pagan 2000, 2009, Liu 2010 for Australia). However, the standard small open economy DSGE models in the New Keynesian tradition have challenges to account for the results shown by the VAR-based studies. The New Keynesian DSGE models, embedding only the traditional aggregate demand channel and the standard UIP condition, suggest that an unexpected tightening in monetary policy declines prices immediately and leads to an immediate appreciation of the exchange rate followed by depreciation in line with Dornbusch's (1976) immediate overshooting prediction (e.g., Bergin 2006 for the US, and Nimark 2009, Jääskelä and Nimark 2011 for Australia).

The existing literature suggests a couple of modifications for resolving those empirical puzzles. For instance, introducing a cost channel of monetary policy into the standard New Keynesian DSGE model has been known as a potential way to resolve the price puzzle (e.g., Chowdharry et al. 2006, Tillman 2008 and Henzel et al. 2009)[10]. Moreover, recent studies (e.g., Adolfson et al. 2008, Christiano et al. 2011b and Adolfson et al. 2013) have argued that modifying the UIP condition is a possible way to reproduce the delayed overshooting puzzle.

This chapter is therefore motivated by some important questions: (i) is there a structural interpretation (i.e., cost channel interpretation) of the price puzzle in the case of a small open economy like Australia?, (ii) is there a structural model-based evidence for violation of the standard UIP and the delayed overshooting puzzle?, and (iii) does the presence of the cost channel and the UIP modification improve the model's ability to fit

[10] As stated by Sims (1992), the price puzzle was initially thought of as a consequence of the misidentification of monetary policy shocks in VARs. However, scholars have paid attention to the cost channel interpretation of the price puzzle after the VAR study on the supply side of monetary policy, conducted by Barth and Ramey (2001).

macroeconomic data? In order to address these questions, it is necessary to carry out empirical research with appropriate modifications to the empirical model. Given this context, the chapter contributes to the literature on macroeconomic modelling for monetary policy in the open economy.

In particular, the chapter examines the quantitative role of the cost channel and the UIP modification in an estimated small open economy DSGE model. To this end, the standard model of Justiniano and Preston (2010a, henceforth J-P model)[11] is augmented in two dimensions. First, following Christiano et al. (2005), Rabanal (2007) and Christiano et al. (2011a), the cost channel of monetary policy is included in the model by assuming that a fraction of firms' working capital (e,g., wage bills) must be financed by short-term loans since firms have to pay some costs of their variable inputs in advance of selling their product. Second, based on Adolfson et al. (2008) and Adolfson et al. (2013), the UIP condition is modified by allowing for the country risk premium to be negatively correlated with the expected depreciation in the nominal exchange rate.

The cost channel describes the supply side effect of interest rates on firms' cost: a monetary policy tightening increases the marginal cost of production, and hence drives inflation[12]. If there is a cost channel, then a monetary policy shock will shift both the aggregate supply and aggregate demand curves in the same direction, leading to a large change in output complemented by ambiguous changes in prices. Using the New Keynesian DSGE models, several papers (e.g., Ravenna and Walsh 2006, Chowdhury et al. 2006, Tillmann 2008, 2009, Hülsewig et al. 2009, Henzel et al. 2009 and Christiano et al. 2011a) have found the empirical evidence for the cost channel in the closed economy context, calling for a serious rethinking of designing optimal monetary policy. In the context of a small open economy, Chang and Jansen (2014) show evidence for the cost channel in Canada and Australia based on the present value model of the forward-looking Phillips curve. According to the cost channel interpretation, the price puzzle emerges when the inflationary impact induced by monetary policy tightening through the cost

[11] The J-P model is technically a semi-small open economy model, where domestic producers have some market power. The specification of the model allows for incomplete asset markets, habit formation and indexation of prices to past inflation in a small open economy model proposed by Monacelli (2005) and Galí and Monacelli (2005).

[12] Motivation of the cost channel is that firms must pay factors of production before receiving their revenues, and hence firms' variable inputs must be financed by short-term loans. Therefore, monetary policy has an impact on firms' costs of production, thereby on the supply side of the economy (Christiano et al. 2011a).

channel is stronger than the one operating through the standard demand channel[13]. However, empirical results for the cost channel interpretation of the price puzzle have been varied. Some papers (e.g., Chowdhury et.al 2006, Tillman 2008, Henzel et al. 2009 and Christiano et al. 2011a) support the structural interpretation of the price puzzle. On the other hand, many others (e.g., Rabanal 2007, Kaufmann and Scharler 2009, Gabriel and Martins 2010, Castcluovo 2012, and Malikane 2012) find that the cost channel does not provide the structural interpretation of the prize puzzle. Moreover, as suggested by Barth and Ramey (2001) and Christiano et al. (2005), the presence of the cost channel may allow the model to reproduce the delayed and gradual response of inflation, and the large and persistent response of output to a monetary policy shock.

Recent papers based on DSGE models have shown that the delayed overshooting puzzle can be solved when new features such as (i) incomplete information about the monetary policy (Hoffman et al. 2011, only for inflation target shock), (ii) learning process (Gouranchas and Tornel 2004, Jääskelä and McKibbin 2010) and (iii) modelling the country risk premium in the UIP condition (Adolfson et al. 2008, Christiano et al. 2011b) are incorporated into a standard small open economy DSGE model. The first two methods based on the alternative modelling of expectations possibly match the real exchange rate persistence, while satisfying the standard UIP condition (e.g., Milani 2012). However, in the latter way, the UIP condition is modified by considering the following empirical evidence. According to the hypothesis of standard UIP condition, the slope coefficient from the regression of expected changes in the nominal exchange rate on interest rate differential across countries should be 1. However, the empirical evidence suggests that the slope coefficient is significantly negative, implying that the standard UIP is violated in the data. This empirical finding is referred to as the ‘forward premium puzzle’ (e.g., Hodrick 1987, Lewis 1995 and Engle 1996)[14]. According to the risk premium explanation (e.g., Fama 1984), this failure of the UIP hypothesis can be interpreted as an outcome of time-variation in the risk premium, and implies that (i) the covariance between the risk premium and the expected depreciation must be negative, and (ii) absolute size of the covariance must be less than the variance of the risk premium and greater than the variance of the expected depreciation (Bansal and Dahliquist 2000). Based on the long-standing empirical finding, recent studies (Adolfson 2008, Christiano et al. 2011b and

[13] The positive response of inflation to monetary policy tightening has been called ‘Wright Patman effect’ since the US congressman Wright Patman said the following statement in 1970: raising interest rate to fight inflation is like ‘throwing gasoline on fire’.

[14] Inability of asset pricing models to reproduce this result is also referred to as the UIP puzzle (Backus et al. 2010).

Adolfson et al. 2013) have modified the UIP condition in their DSGE models by allowing a negative relationship between the risk premium and the expected depreciation[15].

The models with/without the cost channel and/or the UIP modification are estimated by Bayesian methods using the data for Australia and the G7 economies over the period 1993:Q1-2013:Q4, covering the inflation-targeting period in Australia. Empirical results show that the presence of the cost channel and the presented UIP modification in the model is supported by the data and improves the model's ability to fit the business cycle features of main macroeconomic variables. The primary role played by the cost channel in the model is to generate inflation inertia without obtaining a high estimated degree of domestic price stickiness as highlighted by Christiano et al. (2005). The presented UIP modification in the estimated model plays an important role in generating the persistence of exchange rate. Monetary transmission analysis suggests (i) no evidence of the cost channel interpretation of the price puzzle, and (ii) evidence for the delayed overshooting of exchange rate in response to a monetary policy shock in Australia over the inflation-targeting period. The estimated model with such modifications generates both persistence and volatility in real exchange rate dynamics, as well as hump-shaped responses of real exchange rate and output to exogenous shocks, which have been difficult to see in standard small open economy DSGE models.

The remainder of the chapter is structured as follows. Section 2.2 describes the modified J-P model with the cost channel and the UIP modification. Section 2.3 presents the model solution and estimation strategy, consisting of the data and the priors for parameters. Section 2.4 shows empirical results on exploring the importance of the cost channel and the UIP modification in the model. Finally, section 2.5 concludes the paper with some policy implications and directions for future research.

[15] The suggested UIP modification provides a 'mechanical' source of persistence matching the observed exchange rate dynamics, and thereby helps the model to account for the delayed overshooting of exchange rate in response to a monetary policy shock. In addition, the models with the modified UIP potentially generate a persistent response of output to an unexpected monetary policy tightening since the response of demands for domestic goods depends on how much the exchange rate appreciates (e.g., Christiano et al. 2011b).

2.2 The Model

The J-P model is augmented to incorporate the cost channel of monetary policy and the UIP modification. The cost channel is introduced based on work conducted by Christiano et al. (2005), Rabanal (2007) and Christiano et al. (2011a). The UIP condition is modified as suggested by Adolfson et al. (2008) and Adolfson et al. (2013). The model consists of a small open economy and the rest of the world[16] and contains households, firms, a monetary authority and a passive fiscal authority. As modelled by Monacelli (2005) and Justiniano and Preston (2010b), the rest of the world is specified as the closed economy variant of the open economy model. The household consumes domestically produced and imported goods, supplies labour, and invests in either domestic or foreign one-period bonds. Firms are divided into domestic producers, retailers and final good producers. Domestic firms produce a variety of domestic goods by using only labour input and sell them both domestically and overseas. Retail firms import differentiated products from the rest of the world and sell them in the domestic market. In principle, there is also a perfectly competitive final goods sector that buys domestic and imports varieties and produces a final consumption good. However, the final goods sector is not modelled explicitly since perfectly competitive firms make zero profit. Under monopolistic competition, output would be below its Pareto-optimal levels in the absence of government intervention, even with perfectly flexible prices. Therefore, in the model, fiscal policy is responsible for a zero debt policy, with taxes equal to the subsidy required to eliminate the distortion associated with imperfect competition in the domestic and imported goods market. The rest of the world is large compared to the small open economy. As a result, all foreign economy variables are taken exogenously by the domestic economy. In what follows, the problems of each sector in the model are detailed. Derivations of the optimization problem and log-linear approximations are shown in Appendix 2.C.

2.2.1 Households

The representative agent maximizes lifetime utility, subject to a budget constraint. The household consumes, invests, and supplies labour to the domestic firms. The lifetime expected utility function, U, is given by

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \,\tilde{\varepsilon}_{g,t} \left[\frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right]$$

[16] The model is asymmetric in structure, with a small open economy responding to a large economy.

where E_0 denotes the expectation formed in period 0, β is the discount factor, N_t is the labour input, $H_t \equiv hC_{t-1}$ is external habit formation term that is taken as exogenously by the household and $0 < h < 1$, $\sigma, \varphi > 0$ are the elasticities of intertemporal substitution and labour supply, respectively, $\tilde{\varepsilon}_{g,t}$ is a preference shock that account for changes in consumption not explained by other economic features of the model, C_t is a composite consumption index defined by

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}}(C_{H,t})^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}}(C_{F,t})^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \qquad (2.1)$$

where $\alpha\epsilon[0,1]$ is the share of foreign goods in the aggregate consumption bundle; $\eta > 0$ is the elasticity of substitution between domestic and foreign goods, $C_{H,t}$ and $C_{F,t}$ are Dixit-Stiglitz aggregates of the available domestic and foreign produced goods given by

$$C_{H,t} = \left[\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right]^{\frac{\varepsilon}{\varepsilon-1}} \text{ and } C_{F,t} = \left[\int_0^1 C_{F,t}(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right]^{\frac{\varepsilon}{\varepsilon-1}}$$

where $i \in [0,1]$ is the index of differentiated goods, and $\varepsilon > 1$ is the elasticity of substitution between types of differentiated domestic or foreign goods.

It is assumed that all households have identical initial wealth and receive an equal fraction of both domestic and retail firm profits, so that each household faces the same budget constraint and makes identical consumption and portfolio decisions[17]. Assuming the only available assets are one-period domestic and foreign bonds, the flow budget constraint for all $t > 0$ is given by

$$P_tC_t + D_t + \tilde{e}_tB_t = D_{t-1}(1+\tilde{\imath}_{t-1}) + \tilde{e}_tB_{t-1}(1+\tilde{\imath}^*_{t-1})\phi_t$$
$$+W_tN_t + \Pi_{H,t} + \Pi_{F,t} + \mathrm{T}_t \qquad (2.2)$$

where P_t is the domestic consumer price index (CPI), D_t is the household's holding of one-period domestic bonds with interest rate, $\tilde{\imath}_t$, B_t is holdings of one-period foreign bonds with interest rate, $\tilde{\imath}^*_t$, $\tilde{e}_t$ is the nominal exchange rate (the domestic price of foreign currency); the households receive nominal wages, W_t, for labour supplied, $\Pi_{H,t}$ and $\Pi_{F,t}$ denote profits from equity holdings in domestic and retail firms, respectively, and T_t is lump-sum taxes and transfers. Since financial markets are imperfectly integrated, the term

[17] Without this assumption, which imposes complete markets within the domestic economy, the analysis would require modelling the distribution of wealth across agents.

ϕ_t represents a country risk premium (a relative risk adjustment of foreign asset return) as discussed by Benigno (2009).

A novel feature of the model is to allow possible violation of the standard UIP condition. In this chapter, the UIP condition is modified by assuming that the risk premium function has the following form

$$\phi_{t+1}(A_t, \tilde{e}_t, \tilde{\varepsilon}_{rp,t}) = exp\left(-\phi_a A_t - \phi_e\left(\frac{E_t\tilde{e}_{t+1}}{\tilde{e}_t}\frac{\tilde{e}_t}{\tilde{e}_{t-1}} - 1\right) + \tilde{\varepsilon}_{rp,t}\right) \qquad (2.3)$$

where $A_t \equiv \tilde{e}_t B_t / \bar{Y} P_t$ is the real quantity of outstanding net foreign debt expressed in terms of domestic currency as a fraction of steady-state output and $\tilde{\varepsilon}_{rp,t}$ is a country risk premium shock. As discussed by Schmitt-Grohé and Uribe (2003) and Bergin (2006), it is assumed that the risk premium depends on the net foreign debt of a country (A_t) to ensure a stationary steady-state in the model. This relationship also can be motivated from the fact that lenders demand a higher rate of return on a country with a large debt to compensate for perceived default risk. In addition, as suggested by Adolfson et al. (2008), the expected change in the exchange rate ($E_t\, \tilde{e}_{t+1}/\tilde{e}_{t-1} - 1$) is included into the risk premium function based on empirical findings that the risk premium is negatively correlated with the expected depreciation (e.g., Lewis 1995, Engle 1996 and Duarte and Stockman 2005). Finally, following McCallum and Nelson (2002), Jeanne and Rose (2002) and Kollmann (2002), a mean zero shock ($\tilde{\varepsilon}_{rp,t}$) is incorporated into the risk premium specification to capture time-varying exogenous deviations from the UIP condition. Another implication of the term is to introduce an economically interpretable shock that is helpful to avoid the model misspecification, in particular the singularity problem.

The household's optimization problem requires allocation of expenditures for all types of domestic and foreign goods both intratemporally and intertemporally. This yields the following demand functions for each category of consumption goods:

$$C_{H,t}(i) = (1-\alpha)\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} C_{H,t} \text{ and } C_{F,t}(i) = \alpha\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\varepsilon} C_{F,t}$$

for all i with associated aggregate price indexes for the domestic and foreign consumption bundles given by $P_{H,t}$ and $P_{F,t}$, respectively. Therefore, the optimal allocation of expenditure across domestic and foreign goods implies

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \qquad (2.4.1)$$

$$C_{F,t} = \alpha \left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t \tag{2.4.2}$$

Combining (2.1) with (2.4.1) and (2.4.2) yields the theoretically consistent CPI

$$P_t = [(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}]^{\frac{1}{1-\eta}} \tag{2.5}$$

The household maximizes its lifetime utility subject to the budget constraint (2.2) by choosing optimally how much to consume, work and invest. This gives the following set of optimality conditions:

$$(C_t - hC_{t-1})^{\sigma} N_t^{\varphi} = \frac{W_t}{P_t} \tag{2.6}$$

$$\Lambda_t = \beta E_t[\Lambda_{t+1}(1+\tilde{\imath}_t)] \tag{2.7}$$

$$E_t\left[\Lambda_{t+1}\left((1+\tilde{\imath}_t) - (1+\tilde{\imath}_t^*)\frac{\tilde{e}_{t+1}}{\tilde{e}_t}\phi_{t+1}\right)\right] = 0 \tag{2.8}$$

with Lagrange multiplier, $\Lambda_t = \tilde{\varepsilon}_{g,t}(C_t - hC_{t-1})^{-\sigma}P_t^{-1}$, implying the marginal utility of income. Equation (2.6) provides the optimal labour supply schedule, equation (2.7) presents the standard Euler equation, and equation (2.8) implies an arbitrage condition restricting the relative movements of domestic and foreign interest rates and changes in the nominal exchange rate.

2.2.2 Domestic firms and the cost channel

There is a continuum of monopolistically competitive domestic firms, indexed by $i \in [0,1]$. Each firm i produces differentiated goods using labour as a single input. The individual and aggregate production functions are given by

$$Y_{H,t}(i) = \tilde{\varepsilon}_{a,t}N_t(i) \quad \text{and} \quad Y_{H,t} = \left(\int_0^1 Y_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right)^{\frac{\varepsilon}{\varepsilon-1}} \text{[18]} \tag{2.9}$$

where $\tilde{\varepsilon}_{a,t}$ represents a neutral technology shock, $N_t(i)$ is homogenous labour, and ε is the elasticity of substitution between different varieties.

Another novel feature in the model is the presence of the cost channel. The supply side channel is introduced by assuming that a fraction (υ_H) of domestic firms' wage bills has to be paid before firms receive the proceeds from the sale of their products. Hence a firm

[18] It is useful for deriving an approximate aggregate production function. For instance, up to a first order log-linear approximation to $N_t \equiv \int_0^1 N_t(i)di = Y_{H,t}Z_t/\tilde{\varepsilon}_{a,t}$ where $Z_t \equiv \int_0^1 (Y_{H,t}(i)/Y_{H,t})di$ gives the aggregate relation, $y_t = \varepsilon_{a,t} + n_t$ where lower-case letters refer to $x_t = \log(X_t/X)$.

must borrow an amount, $\upsilon_H W_t N_t(i)$, of short-term loans at the nominal interest rate, $\tilde{\imath}_t$. Here, as employed by Ravenna and Walsh (2006) and Rabanal (2007), a complete interest rate pass-through (from the policy-controlled interest rate to the short-term loan rate) is assumed. This assumption is in line with the finding of Stewart et al. (2013) for Australia. The total cost of the domestic firm i in period t therefore is given by

$$TC_{H,t}(i) = W_t N_t(i) R_{H,t}$$

where $R_{H,t} \equiv 1 + \upsilon_H \tilde{\imath}_t$. The nominal marginal cost of the domestic firm i is then determined as

$$MC_{H,t}^{n}(i) = \left(\frac{\partial TC_{H,t}(i)}{\partial N_t(i)}\right)\left(\frac{\partial y_{H,t}(i)}{\partial N_t(i)}\right)^{-1} = \frac{W_t R_{H,t}}{\tilde{\varepsilon}_{a,t}} \tag{2.10}$$

By affecting firms' marginal cost, a nominal interest rate acts as a cost-push shock, so that the cost channel can be viewed as a supply side channel of monetary policy transmission.

Because the goods are imperfect substitutes, each firm has some degree of monopolistic power when setting prices. Calvo-style price setting is assumed, allowing for indexation to past domestic goods price inflation[19]. In any period t, a fraction, $1-\theta_H$, of firms (randomly selected) set prices optimally, while a fraction, $0 < \theta_H < 1$, of goods prices are adjusted according to the indexation rule[20]

$$P_{H,t}(i) = P_{H,t-1}(i)\left(\frac{P_{H,t-1}}{P_{H,t-2}}\right)^{\delta_H} \tag{2.11}$$

where $0 \leq \delta_H \leq 1$ indicates the degree of indexation to past inflation rate. Considering the symmetric equilibrium in which all firms behave identically, the index i is omitted in what follows. Since all firms having the opportunity to reset their prices in period t face the identical decision problem, they set a common price, $P'_{H,t}$. Therefore, the Dixit-Stiglitz aggregate price index for domestic goods evolves according to

$$P_{H,t} = \left[(1-\theta_H){P'_{H,t}}^{1-\varepsilon} + \theta_H\left(P_{H,t-1}\left(\frac{P_{H,t-1}}{P_{H,t-2}}\right)^{\delta_H}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{2.12}$$

[19] Collard and Dellas (2010) show that compared to the pricing decision under fixed duration scheme (Taylor 1980), the assumption of the pricing decision under random duration scheme, proposed by Calvo (1983) plays a critical role for empirical success of standard DSGE model with sticky price.

[20] θ_H denotes the probability that the firm cannot reset its price, so that prices are re-optimized every $1/(1-\theta_H)$ periods.

A firm choosing the optimal price in period t maximizes the present discounted value of profits, taking into account the probability of not being able to re-set prices in the future periods $t+\tau,\ \tau>0$. Firms sell their goods both domestically and abroad. When assuming that foreign demand ($C^*_{H,t}$) is of the same functional form as in domestic demand (2.4.1 and 2.4.2), the demand curve faced in period $t+\tau$ for a firm that last re-set prices optimally in period t and henceforth just adjusted prices according to the indexation rule (2.11) is given by

$$Y_{H,t+\tau|t} = \left(\frac{P'_{H,t}}{P_{H,t+\tau}}\left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}}\right)^{\delta_H}\right)^{-\varepsilon}\left(C_{H,t+\tau}+C^*_{H,t+\tau}\right) \tag{2.13}$$

The firm's price setting problem in period t is to maximize the following expected present discounted value of profits, subject to the demand curve (2.13):

$$E_t\sum_{\tau=0}^{\infty}\theta_H^{\tau}\,Q_{t,t+\tau}Y_{H,t+\tau|t}\left[P'_{H,t}\left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}}\right)^{\delta_H}-P_{H,t+\tau}MC_{H,t+\tau}\right]$$

where $MC_{H,t+\tau}=MC^n_{H,t+\tau}/P_{H,t+\tau}$ is the real marginal cost function, and $Q_{t,t+\tau}$ is a time-dependent stochastic discount factor. The factor θ_H^{τ} in the firm's objective function is the joint probability that the firm will not be able to adjust its price in the next τ periods. The firm's optimization problem implies the first-order condition

$$E_t\sum_{\tau=0}^{\infty}\theta_H^{\tau}\,Q_{t,t+\tau}Y_{H,t+\tau|t}\left[P'_{H,t}\left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}}\right)^{\delta_H}-\frac{\varepsilon}{\varepsilon-1}P_{H,t+\tau}MC_{H,t+\tau}\right]=0$$

The optimal price in period t resulting from the first-order condition is given by

$$P'_{H,t}=\frac{\varepsilon}{\varepsilon-1}\frac{\sum_{\tau=0}^{\infty}\theta_H^{\tau}E_t\left[Q_{t,t+\tau}Y_{H,t+\tau|t}\,P_{H,t+\tau}MC_{H,t+\tau}\right]}{\sum_{\tau=0}^{\infty}\theta_H^{\tau}E_t\left[Q_{t,t+\tau}Y_{H,t+\tau|t}\left(P_{H,t+\tau-1}/P_{H,t-1}\right)^{\delta_H}\right]} \tag{2.14}$$

Using lower-case letters to denote log-deviation from steady state values (i.e., $x_t\equiv\log(X_t/X)$), log-linear approximation to equations (2.12) and (2.14) yield the Phillips curve extended with the cost channel

$$\pi_{H,t}-\delta_H\pi_{H,t-1}=\beta E_t\left(\pi_{H,t+1}-\delta_H\pi_{H,t}\right)+k_H mc_t+\varepsilon_{cp^H,t} \tag{2.15}$$

where $k_H=\frac{(1-\theta_H)(1-\theta_H\beta)}{\theta_H}$ and $mc_t=\varphi y_t-(1+\varphi)\varepsilon_{a,t}+\alpha s_t+\sigma(1-h)^{-1}(c_t-hc_{t-1})+\upsilon_H i_t$ is the real marginal cost function[21]. The domestic inflation depends on the current marginal cost, expectation about inflation in the next period, the most recent

[21] The labour market is in equilibrium, so that wage, W_t, in equation (2.10) is substituted using equation (2.6).

observed inflation and a price markup shock, $\varepsilon_{cp^H,t}$, capturing inefficient variations in the domestic firm's price markup[22]. The domestically produced goods' inflation is also determined by the terms of trade, s_t, which will be discussed later in detail. In the presence of the cost channel of monetary policy, the nominal interest rate affects the supply side of the economy by changing firms' marginal cost, and hence the inflation.

2.2.3 Retail firms and the cost channel

Retail firms import foreign differentiated goods for which the law of one price holds at the docks. In determining the domestic currency price of imported goods, firms are assumed to be monopolistically competitive. The small degree of pricing power leads to deviation from the law of one price in the short-run. Retail firms face a Calvo-style price setting with indexation to past inflation. The sticky price parameter and the indexation parameter for retail sector are denoted by θ_F and δ_F, respectively. Hence, in any period, a fraction, $1-\theta_F$, of firms sets prices optimally, while a fraction, $0<\theta_F<1$, of goods prices are adjusted according to an indexation rule analogous to equation (2.10). The Dixit-Stiglitz aggregate price index for foreign goods consequently evolves according to

$$P_{F,t} = \left[(1-\theta_F){P'_{F,t}}^{1-\varepsilon} + \theta_F\left(P_{F,t-1}\left(\frac{P_{F,t-1}}{P_{F,t-1}}\right)^{\delta_F}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \qquad (2.16)$$

When focussing on the symmetric equilibrium in which all retail firms behave identically, the demand faced by a firm in period $t+\tau$ conditional on having last re-optimized its price in period t set by $P'_{F,t}$ is

$$C_{F,t+\tau|t} = \left(\frac{P'_{F,t}}{P_{F,t+\tau}}\left(\frac{P_{F,t+\tau-1}}{P_{F,t-1}}\right)^{\delta_F}\right)^{-\varepsilon} C_{F,t+\tau} \qquad (2.17)$$

For retail firms, the cost channel of monetary policy is also introduced by assuming that a fraction (υ_F) of firms' cost for buying imported goods from the foreign economy has to be paid before firms receive the proceeds from the sale of their imported goods. Thus retail firms must borrow an amount, $\upsilon_F \tilde{e}_t P^*_{F,t} C_{F,t}$, of domestic currency short-term loans at the nominal rate, $\tilde{\imath}_t$. The total cost of the retail firm in period t is given by

$$TC_{F,t} = \tilde{e}_t P^*_{F,t} C_{F,t} R_{F,t}$$

[22] Similar to Justiniano and Preston (2010a,b), the price markup shocks are just added in the Phillips curve equations. It is assumed that $\varepsilon_{cp^H,t} = k_H \mu^p_{H,t}$ and $\varepsilon_{cp^F,t} = k_F \mu^p_{F,t}$, where $\mu^p_{H,t}$and $\mu^p_{F,t}$ are price markup shocks in domestic and retail sectors as discussed in Smets and Wouters (2003, 2007).

where $R_{F,t} \equiv 1 + \upsilon_F \tilde{\imath}_t$, $P^*_{F,t}$ is the price of imported good in the foreign economy. The nominal marginal cost of the retail firm is then determined as

$$MC^n_{F,t} = \frac{\partial TC_{F,t}}{\partial C_{F,t}(i)} = \tilde{e}_t P^*_{F,t} R_{F,t}$$

A firm choosing the optimal price in period t maximizes the present discounted value of profits, taking into account the probability of not being able to re-set prices in the future periods $t + \tau$. The firm's price setting problem in period t is to maximize the following expected present discounted value of profits, subject to the demand curve (2.17):

$$E_t \sum_{\tau=0}^{\infty} \theta_F^{\tau} Q_{t,t+\tau} C_{F,t+\tau|t} \left[P'_{F,t} \left(\frac{P_{F,t+\tau-1}}{P_{F,t-1}} \right)^{\delta_F} - \tilde{e}_{t+\tau} P^*_{F,t+\tau} R_{F,t+\tau} \right]$$

where the factor θ_H^{τ} in the firm's objective function is the probability that the firm will not able to adjust its price in the next τ periods. The firm's optimization problem implies the first-order condition

$$E_t \sum_{\tau=0}^{\infty} \theta_F^{\tau} Q_{t,t+\tau} C_{F,t+\tau|t} \left[P'_{F,t} \left(\frac{P_{F,t+\tau-1}}{P_{F,t-1}} \right)^{\delta_F} - \frac{\varepsilon}{\varepsilon-1} \tilde{e}_{t+\tau} P^*_{F,t+\tau} R_{F,t+\tau} \right] = 0$$

The optimal price in period t resulting from the first-order condition is given by

$$P'_{F,t} = \frac{\varepsilon}{\varepsilon-1} \frac{\sum_{\tau=0}^{\infty} \theta_F^{\tau} E_t \left[Q_{t,t+\tau} C_{F,t+\tau|t} \tilde{e}_{t+\tau} P^*_{F,t+\tau} R_{F,t+\tau} \right]}{\sum_{\tau=0}^{\infty} \theta_H^{\tau} E_t \left[Q_{t,t+\tau} C_{F,t+\tau|t} \left(P_{F,t+\tau-1}/P_{F,t-1} \right)^{\delta_F} \right]} \qquad (2.18)$$

Log-linear approximations to (2.16) and (2.18) yield another Phillips curve extended with the cost channel

$$\pi_{F,t} - \delta_F \pi_{F,t-1} = \beta E_t (\pi_{F,t+1} - \delta_F \pi_{F,t}) + k_F (\psi_{F,t} + \upsilon_F i_t) + \varepsilon_{cp^F,t} \qquad (2.19)$$

where $k_F = \frac{(1-\theta_F)(1-\theta_F \beta)}{\theta_F}$. Inflation in the domestic currency price of imports is determined by current one price gap, $\psi_{F,t}$, nominal interest rate, expectations about next-period's inflation, the most recent observed inflation and a price markup shock, $\varepsilon_{cp^F,t}$, capturing inefficient variations in the retail firm's mark-up. By setting $\upsilon_H = 0$ and $\upsilon_F = 0$, the Phillips curves typically used in small open economy models are obtained. In the empirical analysis, we formally test which specification is supported by the data.

2.2.4 International risk sharing and the UIP modification

The real exchange rate is defined as $\tilde{q}_t = \tilde{e}_t P^*_t / P_t$, and the terms of trade is given by $S_t = P_{F,t}/P_{H,t}$. When the law of one price fails to hold, the law of one price gap is obtained as

$\Psi_{F,t} = \tilde{e}_t P_t^* / P_{F,t}$ (where $P^* = P_{F,t}^*$), originally defined by Monacelli (2005). Using lower-case letters to denote log-deviation from steady state values (i.e., $x_t \equiv \log(X_t/X)$), log-linear approximations to the country risk premium equation (2.3) and the arbitrage condition (2.8) provide the modified UIP condition as follows:

$$i_t - i_t^* = (1-\phi_e)E_t\Delta e_{t+1} - \phi_e \Delta e_t - \phi_a a_t + \varepsilon_{rp,t} \tag{2.20}$$

where $\Delta e_t = \pi_t - \pi_t^* + \Delta q_t$ is the change in the nominal exchange rate. By setting $\phi_e = 0$, equation (2.20) transfers to the standard UIP condition where a rise in i_t relative to i_t^* produces an anticipated depreciation of the currency[23]. However, there is evidence of the violation of the standard UIP condition. The existing results of the VAR analyses (e.g., Eichenbaum and Evans 1995 and Faust and Rogers 2003) on the response of exchange rate to a contractionary monetary policy shock suggest that $E_t e_{t+1} - e_t$ actually falls for a period of time, implying that the nominal exchange rate appreciates gradually. The modified UIP condition (2.20) helps the model to reproduce this empirical evidence since the modification allows 'mechanical' sources of persistence for the nominal exchange rate. A reason is that under the specification with the modified UIP, the current exchange rate in level depends on the combination of expected and lagged nominal exchange and the interest rate differential. Therefore, when the domestic interest rate increases, then the nominal exchange appreciates (a fall in e_t), and if there is high persistence, implied by the parameter ϕ_e, the nominal exchange rate will gradually appreciate for a substantial period of time. In the empirical analysis, we formally test which specification ($\phi_e = 0$ or $\phi_e > 0$) is supported by the data.

2.2.5 Monetary and fiscal policy

The short-term interest rate, $\tilde{\imath}_t$, linked to the gross interest rate by $R_t^M = 1 + \tilde{\imath}_t$. As discussed by An and Schorfheide (2007), the monetary policy is conducted according to a Taylor-type rule

$$R_t^M = (R_{t-1}^M)^{\rho_R}(R_t^*)^{1-\rho_R}\tilde{\varepsilon}_{R,t}, \text{with } R_t^* = R^M \left(\frac{P_t}{P_{t-1}}\right)^{\chi_\pi} \left(\frac{Y_t}{Y}\right)^{\chi_y} \left(\frac{Y_t}{Y_{t-1}}\right)^{\chi_{\Delta y}} \tag{2.21}$$

[23] This rise in $E_t e_{t+1} - e_t$ is accomplished in part by an instantaneous appreciation in e_t. The idea behind of the instantaneous appreciation is that asset holders respond to the unfavourable foreign rate of return by attempting to sell foreign assets and acquire domestic currency for the purpose of holding domestic assets. This process pulls e_t down until the anticipated depreciation precisely compensates domestic investor holding foreign assets.

where R_t^* is nominal target rate, R^M and Y are steady state values of gross nominal interest rate and output, respectively, and $\tilde{\varepsilon}_{R,t}$ is an exogenous monetary policy shock. Monetary policy responds to contemporaneous values of inflation, output and output growth[24]. Fiscal policy is specified as a zero debt policy, with taxes equal to the subsidy required to eliminate the distortion induced by imperfect competition in the domestic and imported goods market.

2.2.6 General equilibrium and the foreign economy

Goods market clearings in the domestic and foreign economies respectively require

$$Y_{H,t} = C_{H,t} + C_{H,t}^* \text{ and } Y_t^* = C_t^* \quad (2.22)$$

As discussed by Kollmann (2002), foreign demand for the domestically produced good is specified as

$$C_{H,t}^* = \varsigma \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\eta^*} Y_t^* \quad (2.23)$$

where ς represents the share of foreign imports to total foreign output, and $\eta^* > 0$ is the foreign elasticity of substitution[25]. It is assumed that there is no access to domestic debt markets for foreign households. Domestic debt market clearing therefore requires zero net supply, $D_t = 0$, for all t. A similar condition also holds for the foreign economy since domestic holdings of foreign debt, B_t, are negligible relative to the size of the foreign economy.

All foreign variables and parameters are denoted by superscript "*". Since the foreign economy is very large, trade flows to and from the domestic economy are negligible compared to total foreign economic activity. This implies that α^* tends to zero. As a result, the foreign consumption is given by $C_t^* = C_{F,t}^*$, which implies that the foreign CPI is entirely determined by foreign goods price ($P_t^* = P_{F,t}^*$). Foreign debt in the foreign economy is in zero net supply, using the property that the domestic economy engages in negligible financial asset trade. Foreign investors do not face a country risk premium, so the return on foreign bonds for them is simply $1 + i^*$. Because a negligible part of the

[24] The change in nominal exchange rate is eliminated from the Taylor rule based on the result of Lubik and Schorfheide (2007), showing that the RBA does not include the nominal exchange rate in its policy rule.

[25] The functional form of equation (2.23) is assumed to be the same as shown in equation (2.4.2). Because of the large open economy assumption, the parameter ς tends to zero. However, the parameter helps to get the well-defined steady state level of C_H^*. Constraining η^* to equal η gives similar results from the estimation, and hence the constraint is used in the estimation to reduce the number of estimated parameters.

foreign consumption bundle is imports from the small open economy, there is no foreign import sector. The remaining setting is same as for the domestic economy.

2.2.7 The log-linearized model

For the empirical analysis, a log-linear approximation of the model's optimality conditions around a non-stochastic steady state is derived. The log-linearized equations of the model are shown in Appendix 2.A. The domestic block is described by ten equations in the unknowns $\{c_{t,}y_t, i_t, q_t, s_t, \pi_t, \pi_{H,t}, \pi_{F,t}, \psi_{F,t}, a_t\}$, while the foreign block is given by three equations in the unknowns $\{ y_t^*, \pi_t^*, i_t^*\}$. When combined with processes for the exogenous disturbances and the definitions $\Delta s_t = s_t - s_{t-1}$ and $\Delta q_t = q_t - q_{t-1}$, these relations constitute a linear rational expectations model driven by ten shocks: $\{\varepsilon_{g,t}, \varepsilon_{a,t}, \varepsilon_{cp^H,t}, \varepsilon_{cp^F,t}, \varepsilon_{rp,t}, \varepsilon_{R,t}, \varepsilon_{g,t}^*, \varepsilon_{a,t}^*, \varepsilon_{cp,t}^*, \varepsilon_{R,t}^*\}$[26]. According to Justiniano and Preston (2010b), the following assumption is made: $\{\varepsilon_{R,t}, \varepsilon_{cp^H,t}, \varepsilon_{R,t}^*, \varepsilon_{cp,t}^*\}$ are *i.i.d* processes and $\{\varepsilon_{g,t}, \varepsilon_{a,t}, \varepsilon_{cp^F,t}, \varepsilon_{rp,t}, \varepsilon_{g,t}^*, \varepsilon_{a,t}^*\}$ follow AR(1) processes given by

$$\varepsilon_{x,t} = \rho_x \varepsilon_{x,t-1} + \epsilon_{x,t} \quad (2.24)$$

with $E\left[\epsilon_{x,t}\epsilon'_{x,t}\right] = \sigma_x^2$.

2.3 The model solution, data and estimation strategy

2.3.1 The model solution

Before the DSGE models can be estimated, it has to be solved. The model, consisting of linearized equations of the shown in Appendix 2.A, combining with processes for the shocks, can be solved using a variety of standard methods, including those developed by Blanchard and Kahn (1980), King and Watson (1998), Uhlig (1999), Klein (2000) and Sims (2002)[27]. Using a standard method (e.g., Sims 2002), the model could be rewritten in the following state-space form:

$$\xi_t = F(\theta)\xi_{t-1} + G(\theta)\epsilon_t, \quad \epsilon_t \sim NID(0, I) \quad (2.25)$$

$$Y_t = H(\theta)\xi_t \quad (2.26)$$

[26] All ε_x disturbances, log deviations from steady state, have zero means.
[27] All methods' general solution is same as the form of $\xi_t = \Phi(\xi_{t-1}, \varepsilon_t; \theta)$ when the parameter space leading to equilibrium determinacy is considered.

where $F(\theta)$, $G(\theta)$ and $H(\theta)$ are complicated nonlinear functions of the structural parameter vector θ; ξ_t denotes the 26×1 state vector of the system, including the model endogenous variables $\{c_{t,} y_t, i_t, q_t, s_t, \pi_t, \pi_{H,t}, \pi_{F,t}, \psi_{F,t}, a_t, y_t^*, \pi_t^*, i_t^*\}$, expectations at period t $\{c_{t+1,} q_{t+1}, \pi_{t+1}, \pi_{H,t+1}, \pi_{F,t+1}, y_{t+1}^*, \pi_{t+1}^*\}$, the all disturbance terms (that are not *i.i.d.*) following an AR(1) process $\{\varepsilon_{g,t}, \varepsilon_{a,t}, \varepsilon_{cp^F,t}, \varepsilon_{s,t}, \varepsilon_{g,t}^*, \varepsilon_{a,t}^*\}$; ϵ_t is a 10×1 vector of *i.i.d* innovations $\{\varepsilon_{R,t}, \varepsilon_{cp^H,t}, \varepsilon_{R,t}^*, \varepsilon_{cp,t}^*, \epsilon_{g,t}, \epsilon_{a,t}, \epsilon_{cp^F,t}, \epsilon_{rp,t}, \epsilon_{g,t}^*, \epsilon_{a,t}^*\}$. The state-space representation, consisting of the transition (2.25) and measurement (2.26) equations, is the basic for econometric analysis. A key step in estimation of a linearized model is evaluation of its likelihood. If the innovation ε_t is assumed to be Gaussian, then the likelihood of the model can be evaluated with the Kalman filter.

2.3.2 Data

The model is estimated using quarterly data, including three G7 and five Australian series over the period 1993:Q1-2013:Q4, noting that inflation-targeting commenced in Australia in 1991:Q1. The details of the data are given in Appendix 2.B.1. In this chapter, the rest of the world is reasonably proxied by the G7 economies. The G7 series include inflation (the log percentage change in the GDP deflator), output (i.e., real GDP) and nominal interest rate, measured by weighted average of immediate interest rates for G7 countries[28] (per cent per annum), all taken from the OECD.Stat database. Australian data is obtained from the statistical tables published by the Reserve Bank of Australia (RBA) and Australian Bureau of Statistics (ABS). Output is measured by non-farm GDP. As there is no reliable data for non-farm inflation, seasonally adjusted inflation based on consumer price index-all groups excluding interest and tax changes of 1999–2000 is used[29]. As interest rate effect is excluded, the measure helps to appropriately estimate the cost channel effects. The interest rate is the cash rate (per cent per annum). Following Robinson (2013), the terms of trade and G7 GDP-weighted real exchange rate indices are directly observed from official statistics. The officially published real exchange rate and the terms of trade are the inverse of same variables in the model, so that the observables are converted into the model definition. Prior to the empirical analysis, the data is

[28] Data for the G7 interest rate is combined using the CPI country weights in the OECD total: the United States (0.53), Japan (0.13), Germany (0.10), the United Kingdom (0.07), France (0.07), Italy (0.06), and Canada (0.04).

[29] In Australia, mortgage interest rate charges were used in the CPI to proxy the cost of housing during the period 1987:Q1 to1998:Q3. When examining the effect of monetary policy, inclusion of this variable in the CPI is problematic, as a tightening of monetary policy would automatically lead to an increase in the CPI. For this reason, inflation measure based on CPI, excluding interest rate tax changes of 1999-2000 is used.

transformed as follows. In order to ensure consistency with the model, nominal exchange rates are expressed in quarterly terms (annual interest rate is divided by four). The log-difference of the terms of trade and the real exchange rate (scaled by 100 to convert them into percentage) are used before the model is taken to the data. The output variables are taken logarithm, then linearly de-trended and all other series are demeaned. The de-trending and de-meaning ensure that the resulting variables used in the estimation are stationary as they represent the business cycle-related part of the original variable. In Figure 2.B.1 of the Appendix 2.B, the tick line illustrates the data used for empirical analysis.

2.3.3 Bayesian inference and priors

Bayesian methods are adopted to estimate non-calibrated parameters (θ) and to evaluate the quantitative importance of the cost channel and the UIP modification in the model[30]. In the framework, a prior distribution on parameters $p(\theta)$ is updated by sample information contained in the likelihood function $L(Y^T|\theta)$ to form a posterior distribution $p(\theta|Y^T)$[31]

$$p(\theta|Y^T) \propto L(Y^T|\theta)p(\theta) \tag{2.27}$$

The prior is based on 'non-sample' information, so that the Bayesian method provides an ideal framework for combining different sources of information (Del Negro and Schorfheide 2011). Since the mapping from the DSGE model to its $L(Y^T|\theta)$ is nonlinear in θ as shown in the state space representation of the model (equations (2.25) and (2.26)), the construction of the posterior distribution is too complicated to evaluate analytically. Therefore, simulation techniques such as Markov chain Monte Carlo (MCMC) methods, with the likelihood obtained at each draw through the Kalman filter, are used to obtain draws from the posterior distribution shown in equation (2.27). In the case of estimation of the structural DSGE model, the choice of MCMC procedure is usually the Random Walk Metropolis (RWM) algorithm which belongs to more general class of Metropolis-Hastings algorithms. A detailed discussion of numerical techniques such as the RWM and

[30] Bayesian methods help to estimate DSGE models with cross-equation restrictions by dealing well with both misspecification and identification problems. In the presence of those problems, advantages of the approach over alternatives are discussed by Canova (2007) and An and Schorfheide (2007).

[31] According to the Bayes theorem, $p(\theta|Y^T)$ is equal to $L(Y^T|\theta)p(\theta)/p(Y^T)$ where Y^T is a set of actual observable data; $p(Y^T) = \int L(Y^T|\theta)\, p(\theta) d\theta$ is the marginal data density (log-likelihood) represents the posterior distribution, with the uncertainty associated with parameters integrated out, and therefore it also reflects the model prediction performance. Since $p(Y^T)$ is not conditional on θ, the theorem can be reduced to equation (2.27).

Kalman filter algorithms is provided by An and Shorfheide (2007), Fernandez-Villaverde (2010), Guerrón-Quintana and Nason (2012) and Del Negro and Schorfheide (2011, 2013).

The Bayesian framework naturally focuses on the evaluation of relative model fit. Bayes factors or posterior odds ratios[32] are used to measure the relative merits amongst a number of competing models. The Bayes factor of model $\mathcal{M}_j$ versus model $\mathcal{M}_s$ is given by

$$\mathcal{BF}_{j,s|Y^T} = p(Y^T|\, \mathcal{M}_j)/p(Y^T|\, \mathcal{M}_s) \tag{2.28}$$

which summarizes the sample evidence in favour of $\mathcal{M}_j$ over $\mathcal{M}_s$. The terms $p(Y^T|\, \mathcal{M}_j)$ and $p(Y^T|\, \mathcal{M}_s)$ are the marginal likelihoods of $\mathcal{M}_j$ and $\mathcal{M}_s$, respectively. The marginal likelihood for $\mathcal{M}_i$ model is calculated as $p(Y^T|\, \mathcal{M}_i) = \int_\theta \; L(Y^T|\theta, \mathcal{M}_i) p_i(\theta|\mathcal{M}_i) d\theta$, where $L(Y|\theta, \mathcal{M}_i)$ is the likelihood function for the data Y^T conditional on the parameter vector and on the model. The marginal likelihood measure automatically penalizes models with additional parameters and increasing degrees of complexity.

Recently, posterior predictive analysis where the actual data are compared to artificial data generated from an estimated DSGE model have become an important tool to assess absolute fit of the model (An and Schorfheide 2007). In particular, it has been standard to assess whether the models correctly replicate the empirical moments such as variables' volatility, autocorrelation or their correlations. For this purpose, the model-implied moments are computed as follows. Let Y^{rep} be an artificial sample of observations of the same sample size as the actual data set that is generated from the estimated DSGE model. Then the predictive distribution of Y^{rep} can be derived by

$$p(Y^{rep}|Y^T) = \int p(Y^{rep}|\theta, Y^T)\, p(\theta|Y^T) d\theta \tag{2.29}$$

This predictive density reflects parameter uncertainty, captured by the posterior distribution $p(\theta|Y)$. The algorithm for generating draws from the predictive distribution is detailed by Del Negro and Schorfheide (2013)[33].

[32] If there are M competing models, and one does not have strong views on which model is the true one (i.e., hence chooses equal prior weight for each model, $1/M$), then the posterior odds ratio is reduced to the Bayes factor.

[33] Let $h(\cdot)$ be a model checking function (e.g., second moments). The posterior predictive distribution of $h(Y^{rep})$ can be computed based on draws from the posterior predictive distribution of Y^{rep} shown in (29). In doing so, n draws from $p(\theta|Y^T)$ are used to generate n artificial samples (Y^{rep} of length T). Then, for each of those n artificial samples, $h(Y^{rep})$ function is calculated. If n is large enough, someone can build a histogram of those retained values such that each bucket has infinitely small width. This smoothed

Christopher Sims's 'csminwel' optimization routine is used to obtain the posterior mode and to compute the Hessian matrix at the mode. To test the presence of the identification problem, over 40 optimization runs are launched, and different optimization routine always converges to the same mode value. Since a unique mode for the model is found, the Hessian from the optimization routine is used as a proposal density, properly scaled ($c = 0.3$) to attain an acceptance rate between 20-30 per cent. For the RWM results, two independent chains of 100,000 draws each, in which 40,000 are used as an initial burn-in phase. Convergence of two chains is monitored using both the univariate and the multivariate convergence diagnostics variants of Brooks and Gelman (1998)[34].

Similar models have been estimated by Justiniano and Preston (2010a, b) and Robinson (2013) using Bayesian methods in the case of Australia. Therefore calibration and priors for parameters, $p(\theta)$, are closely followed their specifications. Some parameters, not well identified, are calibrated by standard values in the literature. For example, foreign and domestic economy discount factors, $\beta^*$and β, are calibrated to be 0.99, which is associated with a real interest rate of 4.0 per cent (annually) in steady state. The openness parameter, α, is calibrated to 0.185, consistent with the share of imports in GDP (0.2) over the inflation-targeting period (Kuttner and Robinson 2010). Attempts to estimate the openness parameter give implausibly low values.

All remaining parameters are estimated and their prior assumptions are described in the first panel of Table 2.1. The priors are fairly uncontroversial with previous studies using Bayesian inference. The most priors for the G7 economy are specified as adopted by Justiniano and Preston (2010b). The only difference is that following Robinson (2013), slightly altered priors on the exogenous processes is used by assuming that a large economy would not be more volatile than its small economy counterparts. For Australia, the priors are deviated from those used by Justiniano and Preston (2010b) and Robinson (2013) in the following ways. First, similar to Justiniano and Preston (2010a), in order to keep structural parameters in positive values, gamma distributions are used instead of normal distributions. Second, the parameter governing the interest debt elasticity, ϕ_a, is estimated instead of calibrated. The prior on ϕ_a is chosen as an inverse-gamma distribution with a mean of 0.01, consistent with Adolfson et al. (2007). Third, fairly loose priors for parameters of Calvo prices and backward indexation are adopted to freely

histogram is eventually the posterior predictive distribution of $h(Y^{rep})$ and used to derive mean, median and percentiles of $h(Y^{rep})$.

[34] Convergence is generally occurred after around 25000 draws, but in few cases more draws were needed.

determine the influence of the cost channel and UIP modification on those parameters. Forth, relatively tight priors for the parameters of habit formation in consumption, h, elasticity of substitution between domestic and foreign goods, η, and the intertemporal elasticity of substitution, σ, are set. For instance, the parameter h has a beta distribution centered at 0.7, which is close to the values used by Jääskelä and McKibbin (2010), Jääskelä and Nimark (2011), with a standard deviation of 0.1. The prior for η is tightly centred at 1.5, which is the standard value used in the macro literature (e.g., Chari et al. 2002). Finally, prior densities for parameters regarding modifications in the model are chosen based on previous relevant studies. For instance, consistent with Rabanal (2007), prior beta distribution with mean of 0.5 and standard deviation of 0.25 is chosen for the parameters on cost channel (υ^*, υ_H and υ_F) to keep the parameters bounded between zero and one. Following Adolfson et al. (2008), a prior on the UIP modification parameter, ϕ_e, is specified as a beta distribution with mean 0.5 and a standard deviation of 0.1.

2.4 Empirical results

2.4.1 The model estimation

The posterior estimates of four versions of the models are reported in the last four panels of the Table 2.1. The model described in Section 2.2 is labelled the ‘full’ model where $\upsilon_H, \upsilon_F, \upsilon^*, \phi_e > 0$. The model, fixing cost channel parameters at zero, $\upsilon_H = \upsilon_F = \upsilon^* = 0$, is named the ‘no cost channel’ model, whereas the model without the assumption, implied by the forward premium puzzle where $\phi_e = 0$, is called the ‘no UIP modification’ model. Finally, the J-P model with $\upsilon_H = \upsilon_F = \upsilon^* = \phi_e = 0$ is labelled the ‘baseline’ model.

2.4.1.1 Posterior estimates of the full model

Data are informative about the estimated parameters and the estimates are in line with the existing literature (e.g., Justiniano and Preston 2010a, b, Jääskelä and Nimark 2011 and Robinson 2013). The estimated degree of habit persistence (0.46) implies that external habit formation plays a moderate role compared to other studies (e.g, Robinson 2013). The estimated elasticity of substitution between domestic and foreign goods (1.3) is closer to the estimates obtained by Jääskelä and Nimark (2011) and the calibrated value of 1.5 used by Chari et al. (2002). The degree of domestic price stickiness (0.82) implies that domestic firms re-optimize prices every 5.5 quarters in Australia. Prices in the imported sector are adjusted slightly more frequently than are home goods prices, being re-optimized on average every 4.3 quarters. As found by Langcake and Robinson (2013), the estimates of the parameters δ_H and δ_F present adequate source of endogenous persistence in both domestic and imported goods price dynamics. The estimated policy parameters imply that RBA implements a strong anti-inflationary policy ($\chi_\pi = 1.90$) and reflects concern for output growth ($\chi_{\Delta y} = 0.59$) and output movements ($\chi_y = 0.27$) in the inflation-targeting period. A reasonably high degree of interest-smoothing is estimated with a coefficient of 0.89. The posterior mean of the parameter ϕ_a, measuring the elasticity of the risk premium with respect to the net foreign asset, is estimated around 0.004, which is closer to the value (0.001) found by Jääskelä and Nimark (2011).

The posterior distributions of the cost channel parameters (υ_H and υ_F) shift to the left hand side compared to prior distributions[35], and 90 per cent posterior probability intervals of the parameters are [0.01, 0.71] and [0.06, 0.86], respectively. These positive and significant (different from zero) parameters provides evidence of the cost channel in Australia as obtained by Chang and Jansen (2014). However, the upper bounds of the intervals are far below one, implying that all firms (or all amounts of working capital for each firm) are not subject to the cost channel constraint. Another important parameter is ϕ_e, governing how much the expected depreciation is allowed to affect the risk premium in the UIP condition. A posterior mean of the parameter ϕ_e is 0.32, closer to the value of 0.30 estimated by Adolfson et al. (2013)[36]. The 90 per cent posterior probability interval of the parameter includes values between 0.25 and 0.37, indicating preliminary evidence for the violation of the standard UIP condition. The formal test on quantitative importance of the cost channel and the UIP modification is conducted in Section 2.4.2.

The risk premium, technology and preference shocks are highly persistent. In contrast to previous papers (e.g., Justiniano and Preston 2010a), the price markup shock in the import sector is less persistent ($\rho_{cp^F} = 0.31$), supporting the view that the presence of the cost channel captures the persistent part of the shock. Further evidence of the finding is that the estimated autoregressive coefficient is substantially increased when the cost channel is shut down. One standard deviation quarterly monetary policy shock, σ_R, is estimated to be 12 basis points, closer to the value reported by Robinson (2013). Estimates of standard deviations for other shocks are entirely consistent with the literature.

[35] Posterior modes are $\upsilon_H = 0.18$ and $\upsilon_F = 0.38$, with a relatively large standard deviation.
[36] The estimate is twice lower than the value found in Adolfson et al. (2008), showing that the suggested UIP modification produces a hump-shaped response of the real exchange rate to a monetary policy shock.

Table 2.1 Prior densities and posterior estimates for alternative models

		Australia										
	Parameters	Prior			Posterior							
		Density	Mean	Sd.	Full ($\upsilon_H, \upsilon_F, \upsilon^*, \phi_e > 0$)		No cost channel ($\upsilon_H = \upsilon_F = \upsilon^* = 0$, $\phi_e > 0$)		No UIP modification ($\phi_e = 0$, $\upsilon_H, \upsilon_F, \upsilon^* > 0$)		Baseline ($\upsilon_H = \upsilon_F = \upsilon^* = 0$, $\phi_e = 0$)	
					Mean	[5, 95] prob.	Mea n	[5, 95] prob.	Mean	[5, 95] prob.	Mea n	[5, 95] prob.
h	Habit	B	0.7	0.1	0.46	[0.36, 0.58]	0.62	[0.54, 0.71]	0.31	[0.22, 0.40]	0.31	[0.22, 0.40]
σ	Intertemporal ES	G	1.2	0.2	0.88	[0.65, 1.10]	0.76	[0.58, 0.97]	0.94	[0.72, 1.16]	0.94	[0.71, 1.17]
η	Elasticity H-F goods	G	1.5	0.1	1.30	[1.15, 1.44]	1.26	[1.11, 1.40]	1.30	[1.16, 1.45]	1.31	[1.17, 1.44]
θ_H	Calvo domestic prices	B	0.6	0.15	0.82	[0.74, 0.89]	0.93	[0.90, 0.97]	0.82	[0.76, 0.89]	0.82	[0.76, 0.89]
δ_H	Indexation domestic	B	0.5	0.2	0.40	[0.20, 0.60]	0.43	[0.24, 0.63]	0.38	[0.18, 0.57]	0.38	[0.20, 0.57]
φ	Inverse Frisch	G	1	0.3	1.09	[0.59, 1.60]	1.06	[0.57, 1.54]	0.87	[0.48, 1.25]	0.85	[0.45, 1.22]
υ_H	Domestic-cost channel	B	0.5	0.25	0.37	[0.01, 0.71]	-	-	0.33	[0.003, 0.65]	-	-
θ_F	Calvo import prices	B	0.6	0.15	0.77	[0.69, 0.85]	0.74	[0.54, 0.87]	0.74	[0.67, 0.82]	0.74	[0.66, 0.82]
δ_F	Indexation foreign	B	0.5	0.2	0.48	[0.13, 0.79]	0.35	[0.03, 0.65]	0.43	[0.12, 0.75]	0.42	[0.12, 0.72]
υ_F	Import-cost channel	B	0.5	0.25	0.47	[0.06, 0.86]	-	-	0.45	[0.05, 0.84]	-	-
ϕ_a	Interest debt elasticity	IG	0.01	1	0.004	[0.002, 0.007]	0.003	[0.002, 0.004]	0.004	[0.002, 0.006]	0.005	[0.002, 0.007]
ϕ_e	UIP modification	B	0.5	0.1	0.32	[0.25, 0.37]	0.35	[0.31, 0.39]	-	-	-	-
ρ_R	Taylor rule, smoothing	B	0.5	0.25	0.89	[0.86, 0.92]	0.89	[0.85, 0.92]	0.90	[0.88, 0.93]	0.90	[0.88, 0.93]
χ_π	Taylor rule, inflation	G	1.5	0.25	1.90	[1.55, 2.26]	1.34	[1.04, 1.67]	1.82	[1.49, 2.13]	1.77	[1.46, 2.07]
χ_y	Taylor rule, output	G	0.25	0.13	0.27	[0.14, 0.39]	0.28	[0.16, 0.38]	0.37	[0.24, 0.50]	0.38	[0.26, 0.51]
$\chi_{\Delta y}$	Taylor rule, output growth	G	0.25	0.13	0.59	[0.29, 0.88]	0.54	[0.25, 0.82]	0.61	[0.28, 0.94]	0.61	[0.26, 0.95]
ρ_a	Technology AR(1)	B	0.8	0.1	0.81	[0.69, 0.94]	0.99	[0.98, 0.99]	0.78	[0.65, 0.91]	0.78	[0.65, 0.90]
ρ_g	Preferences AR(1)	B	0.8	0.1	0.88	[0.81, 0.96]	0.81	[0.67, 0.95]	0.82	[0.73, 0.91]	0.82	[0.73, 0.91]
ρ_{cp^F}	Import-price markup AR(1)	B	0.5	0.25	0.31	[0.003, 0.64]	0.47	[0.08, 0.98]	0.33	[0.03, 0.61]	0.35	[0.03, 0.60]
ρ_{rp}	Risk premium AR(1)	B	0.8	0.1	0.98	[0.97, 0.99]	0.87	[0.79, 0.94]	0.98	[0.97, 0.99]	0.98	[0.97, 0.99]
σ_a	Sd technology	IG	1	1	0.88	[0.35, 1.43]	1.32	[0.56, 2.24]	0.92	[0.35, 1.54]	0.92	[0.35, 1.56]
σ_g	Sd preferences	IG	1	1	3.54	[1.88, 5.36]	1.07	[0.31, 2.12]	2.31	[1.55, 3.02]	2.33	[1.51, 3.12]
σ_{cp^F}	Sd import-price markup	IG	1	1	2.22	[1.38, 2.96]	2.16	[1.19, 2.86]	2.22	[1.48, 2.93]	2.20	[1.48, 2.88]
σ_{rp}	Sd risk premium	IG	1	1	0.33	[0.26, 0.41]	0.38	[0.26, 0.50]	0.30	[0.24, 0.36]	0.31	[0.25, 0.37]
σ_R	Sd monetary policy	IG	0.25	0.25	0.12	[0.10, 0.14]	0.11	[0.10, 0.13]	0.12	[0.10, 0.14]	0.12	[0.10, 0.14]
σ_{cp^H}	Sd domestic-price markup	IG	0.5	0.5	0.67	[0.54. 0.81]	0.66	[0.56, 0.76]	0.67	[0.55, 0.80]	0.67	[0.55, 0.80]

Table 2.1 Prior densities and posterior estimates for alternative models (Continued)

	Parameters	Prior Density	Prior Mean	Prior Sd.	Full ($\upsilon_H, \upsilon_F, \upsilon^*, \phi_e > 0$) Mean	Full [5, 95] prob.	No cost channel ($\upsilon_H = \upsilon_F = \upsilon^* = 0$, $\phi_e > 0$) Mean	No cost channel [5, 95] prob.	No UIP modification ($\phi_e = 0$, $\upsilon_H, \upsilon_F, \upsilon^*, \phi_e > 0$) Mean	No UIP modification [5, 95] prob.	Baseline ($\upsilon_H = \upsilon_F = \upsilon^* = 0$, $\phi_e = 0$) Mean	Baseline [5, 95] prob.
	G7 economy											
h^*	Habit	B	0.5	0.1	0.60	[0.49, 0.73]	0.61	[0.49, 0.73]	0.61	[0.50, 0.73]	0.61	[0.49, 0.74]
σ^*	Intertemporal ES	G	1.0	0.4	1.06	[0.62, 1.52]	1.08	[0.56, 1.53]	1.05	[0.62, 1.50]	1.05	[0.59, 1.50]
θ^*	Calvo prices	B	0.6	0.1	0.93	[0.91, 0.96]	0.93	[0.90, 0.97]	0.94	[0.91, 0.96]	0.94	[0.91, 0.97]
δ^*	Indexation prices	B	0.5	0.2	0.29	[0.07, 0.47]	0.29	[0.09, 0.51]	0.31	[0.09, 0.50]	0.30	[0.09, 0.51]
φ^*	Inverse Frisch	G	1	0.3	0.99	[0.82, 1.15]	0.98	[0.81, 1.15]	0.98	[0.82, 1.14]	0.98	[0.82, 1.14]
υ^*	Cost channel	B	0.5	0.25	0.47	[0.06, 0.86]	-	-	0.47	[0.06, 0.86]	-	-
ρ_R^*	Taylor rule, smoothing	B	0.6	0.2	0.90	[0.88, 0.92]	0.90	[0.88, 0.93]	0.90	[0.88, 0.92]	0.90	[0.88, 0.92]
χ_π^*	Taylor rule, inflation	G	1.8	0.3	1.94	[1.58, 2.30]	1.94	[1.54, 2.35]	1.92	[1.53, 2.29]	1.91	[1.52, 2.27]
χ_y^*	Taylor rule, output	G	0.25	0.13	0.04	[0.01, 0.07]	0.05	[0.01, 0.08]	0.04	[0.009, 0.07]	0.04	[0.01, 0.07]
$\chi_{\Delta y}^*$	Taylor rule, output growth	G	0.3	0.2	1.05	[0.73, 1.35]	1.00	[0.70, 1.32]	1.05	[0.74, 1.35]	1.05	[0.73, 1.36]
ρ_a^*	Technology AR(1)	B	0.8	0.1	0.94	[0.89, 0.99]	0.93	[0.88, 0.99]	0.94	[0.89, 0.99]	0.93	[0.86, 0.99]
ρ_g^*	Preferences AR(1)	B	0.8	0.1	0.88	[0.84, 0.93]	0.89	[0.84, 0.94]	0.88	[0.84, 0.93]	0.88	[0.84, 0.93]
σ_a^*	Sd technology	IG	1	1	1.08	[0.52, 1.65]	1.06	[0.50, 1.61]	1.03	[0.48, 1.57]	1.05	[0.43, 1.60]
σ_g^*	Sd preferences	IG	1	1	1.87	[1.26, 2.47]	1.97	[1.23, 2.68]	1.89	[1.25, 2.50]	1.92	[1.27, 2.56]
σ_R^*	Sd monetary policy	IG	0.25	0.25	0.08	[0.07, 0.09]	0.08	[0.07, 0.09]	0.08	[0.07, 0.09]	0.08	[0.07, 0.09]
σ_{cp}^*	Sd price markup	IG	0.25	1	0.16	[0.13, 0.19]	0.16	[0.13, 0.19]	0.16	[0.13, 0.19]	0.16	[0.13, 0.19]

Notes: Prior distributions: G-Gamma, B-Beta, IG-Inverse Gamma. Figures in brackets indicate 90 per cent posterior probability intervals.

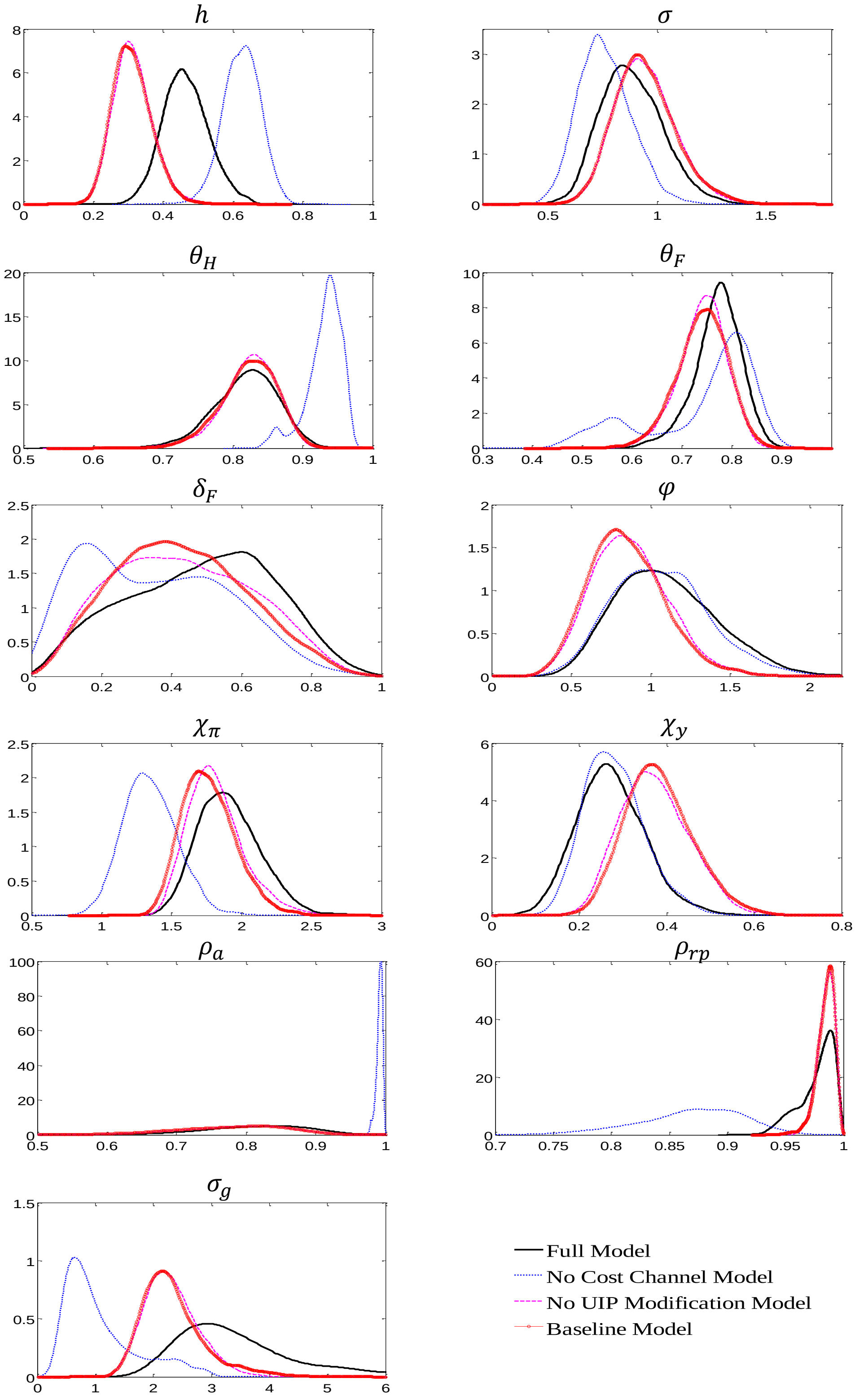
The estimates of the G7 economy are mostly similar to the findings obtained by Justiniano and Preston (2010b) and Robinson (2013), even though they estimate a slightly different model with labour market imperfections using the US data. The estimated degree of habit persistence, h^*, is 0.6, which is closer to the value used by Boldrin et al. (2001). The posterior mean of the inverse elasticity of labour supply, $\varphi^* = 0.99$, is entirely consistent with the value (one) calibrated by Robinson (2013). The parameter of price indexation is estimated with the value of $\delta^* = 0.29$, slightly lower than previous findings (e.g., 0.42 and 0.58 obtained by Robinson 2013 and Justiniano and Preston 2010b, respectively). The posterior mean of the cost channel parameter, υ^*, is very close to its prior, implying that there is not enough information in the data about the parameter. The possible explanation of the result can be the same as that as found by Chowdhurry et al. (2006), there is no significant impact of nominal interest rate on inflation dynamics in some of the G7 countries such as Germany, Japan and Italy. The estimated parameters of the policy rule for the G7 economy are consistent with conventional wisdom. The estimated degree of interest-smoothing, $\rho_R^* = 0.9$, the response to inflation, $\chi_\pi^* = 1.94$, and the response to the level of output, $\chi_y^* = 0.04$, are similar to those reported by Robinson (2013). The result suggests that monetary authorities of the G7 countries pursue a strong anti-inflationary policy with a high degree of interest-smoothing for the last two decades. Estimates of exogenous process for G7 economy are in line with the existing literature.

2.4.1.2 Sensitivity analysis of parameters with respect to alternative specifications

This section assesses how the structural parameters are affected by the presence of the cost channel and/or the UIP modification. The posterior estimates for all structural parameters under different specifications are shown in the last six columns of Table 2.1. Figure 2.1 shows the posterior distributions for selected parameters, which are more influenced by different specifications. The remaining parameters are quite robust to the alternative specifications. The presence of the cost channel and the UIP modification largely influences the estimates of the domestic parameters. In most of the figure, the distribution shifts are substantial when comparing alternative models.

There is a large variation in the estimate of the parameter h across specifications. The best fitting values are relatively low under baseline specification, with a mean around 0.31. When adding both extensions into the baseline model, the distribution shifts to right to assign larger probabilities to values closer to 0.45.

Figure 2.1 Comparison of selected posterior distributions



The posterior distribution for the parameter σ falls around 0.90-0.95 under the baseline and no UIP modification specifications, while the distribution moves to the left when the presented UIP modification is introduced into the model. The means of the parameters, θ_H and θ_F, are around 0.92 and 0.82 respectively under no cost channel model. This value of 0.92, corresponding to average duration of domestic price contracts is 3 years, is implausibly high in the context of available microeconomic evidence. However, the distributions of θ_H and θ_F move toward values around 0.8 and 0.75 for the models with the cost channel. This finding is in line with Christiano et al. (2005), showing that the presence of the cost channel reduces the model's reliance on sticky prices[37]. When adding both extensions into the baseline model, the posterior distribution for the parameter δ_F is shifted to a negatively skewed distribution, with mode around 0.6. The position of the distributions for the parameter φ heavily depends on the specification of the UIP condition.

It appears that the monetary policy reaction parameters toward inflation and output seem to be sensitive to the alternative specifications. The reaction toward inflation is estimated to be higher under the full specification compared to others. The posterior distributions for the parameter, ρ_a, show that the model with no cost channel has difficulty in capturing persistence in the technology shock. When the cost channel is introduced, the posterior distribution shifts to the left. If the UIP condition modification is introduced into the baseline model, then the posterior distributions for the parameter, ρ_{rp}, move towards a value around 0.87, consistent with the result shown by Adolfson et al. (2008) that the persistence in the risk premium shock decreases under the specification with the UIP modification.

The standard deviation of preference shock, σ_g, is the most heavily influenced standard deviation under different specifications. The posterior distribution for σ_g takes high probability mass around 2.3, and when introducing the cost channel and modifying the UIP condition, the distribution shifts to the right to assign larger probabilities to values around 3. As argued by Robinson (2013), this relatively high standard deviation may reflect the fact that the preference shock plays a vital role in capturing the volatility of output in the model, featuring a simple production process, and no financial and labour markets.

The results here are not intended to show that one specification has to be preferred to the alternatives. However, the results provide considerable evidence that the estimates for parameters in the presented model are far from robust to different specifications. The parameter sensitivity analysis suggests that the quantitative change in the estimated model's performance regarding alternative specifications comes from two sources such

[37] The explanation for the sensitivity of the price stickiness parameter is detailed by Del Negro et al. (2014).

as the difference in the equation forms (Phillips curves and UIP) and the change in the estimated parameters.

2.4.2 Model fit and evaluation

This section assesses whether the presence of the cost channel and the UIP modification improves the model fit using in-sample fit, relative fit and absolute fit assessments.

2.4.2.1 In-sample fit

In order to assess the in-sample fit of alternative models, Figure 2.B1 of the Appendix 2.B reports the actual data and alternative (full and baseline) models' Kalman filtered one-sided predicted values[38] of the observed variables, computed using the posterior mean of the estimated parameters. The in-sample fit of both models appears to be reasonably good, with the exception of the inflation and the change in real exchange rate in Australia. The inflation and change in real exchange rate are quite volatile at quarterly frequency and difficult to predict as discussed by Jääskelä and Nimark (2011).

However, the predicted inflation of both models shows co-movements with the actual inflation. The estimated models fit well with the G7 actual data. From the first visual diagnostic of the alternative models, the presence of both cost channel and UIP modification improves the in-sample fit of the model. For instance, the full model explains better the volatility of changes in the real exchange rate compared to the baseline model. However, the graphical inspection makes it difficult to assess the comparative measure of fit. Hence, the relative fit of the model is analysed in the next section.

2.4.2.2 Relative fit of alternative models: Bayes factor comparison

Table 2.2 reports the log marginal data densities[39] of the models, along with the Bayes factors, computed by considering the full model as the null hypothesis. Comparing posterior log marginal data densities, the baseline model yields the lowest fit. Regarding the Bayes factor as an evaluation criterion, the data strongly supports the full model with both cost channel and UIP modification compared to alternative models.

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[38] The Kalman filter estimates (one-step ahead predictions) can be interpreted as the fitted value of a regression.

[39] Considering that marginal log-likelihood penalizes over-parameterization, the full model does not necessarily rank better if the presence of cost channel and UIP modification does not sufficiently help in explaining the data.

Table 2.2 Model comparison: Cost channel and UIP modification vs. no cost channel and UIP modification

Models ($\mathcal{M}$)	Log marginal data densities ($ln\, p(Y^T \mid \mathcal{M})$)	Bayes factor ($\mathcal{BF}$)
$\mathcal{M}_0$: Full ($\upsilon_H, \upsilon_F, \upsilon^*, \phi_e > 0$)	-764.84	$\mathcal{BF}_{0,0\mid Y^T} = 1$
$\mathcal{M}_1$: No cost channel ($\upsilon_H = \upsilon_F = \upsilon^* = 0$, $\phi_e > 0$)	-769.95	$\mathcal{BF}_{0,1\mid Y^T} = 165.7$
$\mathcal{M}_2$: No UIP modification ($\phi_e = 0$, $\upsilon_H, \upsilon_F, \upsilon^* > 0$)	-770.68	$\mathcal{BF}_{0,2\mid Y^T} = 343.8$
$\mathcal{M}_3$: Baseline ($\upsilon_H = \upsilon_F = \upsilon^* = \phi_e = 0$)	-771.22	$\mathcal{BF}_{0,3\mid Y^T} = 578.2$

Notes: The table reports Bayes factor comparing the model $\mathcal{M}_0$ to $\mathcal{M}_1$(or $\mathcal{M}_2$ or $\mathcal{M}_3$). The log marginal data densities reported here are computed from the posterior draws using the modified harmonic mean approximation, described by Geweke (1999).

First, to evaluate the importance of the cost channel in the full model, the $\mathcal{M}_0$ model is compared to the no cost channel model, $\mathcal{M}_1$. The marginal data density of $\mathcal{M}_0$ is 5.11 larger than the densities of $\mathcal{M}_1$ on a log-scale that translates into a Bayes factor of 165.7. According to Kass and Raftery (1995)[40], a Bayes factor of this size offers 'very strong' evidence in favour of the full model with the cost channel ($\upsilon_H, \upsilon_F, \upsilon^* > 0$). This result is in line with the finding obtained by Chang and Jansen (2014) in the sense that the cost channel of monetary policy is operative in Australia. Second, when assessing a hypothesis $\phi_e > 0$ in the full model against the alternative $\phi_e = 0$, the Bayes factor comparing $\mathcal{M}_0$ to $\mathcal{M}_2$ amounts to 343.8. The result also shows 'very strong' evidence in favour of the presence of UIP modification. This is in line with the finding of Adolfson et al. (2008) that the modified UIP is strongly preferable to a standard UIP specification according to the Bayesian posterior odds. Finally, the full model $\mathcal{M}_0$: $\upsilon_H, \upsilon_F, \upsilon^*, \phi_e > 0$ is compared to the baseline model $\mathcal{M}_3$: $\upsilon_H = \upsilon_F = \upsilon^* = \phi_e = 0$. The Bayes factor of 578.2 offers 'very strong' evidence in favour of $\mathcal{M}_0$, hence the presence of both cost channel and UIP modification in the model is supported by the data.

2.4.2.3 Absolute fit of alternative models

Table 2.3 shows the second moments implied by the estimated models and compares with those measured in the actual data to evaluate each model's empirical performance.

[40] Kass and Raftery (1995) provide an interpretative scale to judge the strength of the evidence in favour of an alternative model with respect to the model in the null hypothesis. A Bayes factor between 1 and 3 is 'not worth more than a bare mention', between 3 and 20 suggests a 'positive' evidence, between 20 and 150 suggests a 'strong' evidence, and larger than 150 'very strong' evidence in favour of one of the two models.

Table 2.3 Data and model-implied moments

	Data		Full model		Baseline model	
	SD	Auto-correlation	SD	Auto-correlation	SD	Auto-correlation
Inflation (π)	0.4	0.23	0.9 [0.69, 1.26]	0.58 [0.39, 0.79]	1.3 [0.72, 2.05]	0.77 [0.62, 0.91]
Changes in real exchange rate (Δq)	4.2	0.18	4.4 [3.3, 5.3]	0.39 [0.29, 0.48]	4.7 [4.2, 5.9]	-0.01 [-0.03, 0.01]
Interest rate (i)	1.2	0.90	3.1 [2.0, 4.9]	0.96 [0.39, 0.99]	4.7 [1.8, 7.9]	0.99 [0.41, 1]
Output (y)	1.8	0.92	2.5 [1.46, 3.78]	0.94 [0.91, 0.98]	3.0 [1.6, 4.2]	0.96 [0.93, 0.98]
Changes in terms of trade (Δs)	3.0	0.46	3.2 [2.5, 3.9]	0.64 [0.52, 0.75]	3.1 [2.5, 3.7]	0.60 [0.54, 0.67]
G7 inflation (π^*)	0.21	0.54	0.38 [0.25, 0.52]	0.81 [0.65, 0.98]	0.27 [0.17, 0.34]	0.54 [0.40, 0.79]
G7 output (y^*)	3.0	0.98	3.3 [1.6, 6.2]	0.98 [0.76, 1]	2.4 [1.4, 3.4]	0.97 [0.75, 0.98]
G7 interest rate (i^*)	1.8	0.98	1.4 [0.96, 1.85]	0.97 [0.95, 1]	1.2 [0.9, 1.5]	0.94 [0.92, 0.96]

Notes: The model columns report medians and 90 per cent posterior probability bands for the moments computed from $p(Y^{rep}|Y^T)$. In order to build this distribution, 1200 draws from the posterior distribution of parameters are used to generate artificial samples (conditional on each draw) of observed variables of the same sample size as the actual data set from the model. For each of those 1200 artificial samples, the moment statistics are calculated, and the median, 5th and 95th percentiles are derived.

From Table 2.3, the volatility and autocorrelation in most observables are reasonably well captured by both models. In particular, the model matches well the second moments of the G7 data. The medians of standard deviation (SD) for the change in terms of trade implied by the models are very close to its actual counterpart. The 90 per cent posterior bands for Australian output and the change in real exchange rate generated by the models contain their actual standard deviations. Both models tend to overestimate the standard deviation of inflation and interest rate in Australia.

However, the ability of the models to accurately replicate the volatility of the observables does not provide a predetermined conclusion since a likelihood-based estimator attempts to match entire auto-covariance function of the data. Therefore it is necessary to carry out the predicative check analysis for other moments such as autocorrelation and cross-correlation. As for persistence, both models predict well for interest rate, and output, with the 90 per cent intervals for the change in terms of trade.

The full model replicates the volatility and persistence in the data relatively well compared to the baseline model. In particular, the full model accounts for both volatility and persistence in the change of real exchange rate, which has been a challenge for open-economy models (Chari et al. 2002 and Justiniano and Preston 2006). The baseline specification fails to generate the persistence in the first difference of real exchange rate. Moreover, the median standard deviations and median autocorrelations under the full specification are closer to their actual moments compared to the statistics under the baseline specification.

Figure 2.B.2 in Appendix 2.B, displaying the cross-correlation among domestic observables, supports the full specification in the sense that its cross-correlation is somewhat closer to those measured in the actual data. The 90 per cent posterior predictive intervals for the serial correlation of output, inflation and interest rate contain their actual counterparts. In addition, the shape of autocorrelation functions for the first-differences in the real exchange rate and terms of trade is qualitatively similar to their actual statistics. For the cross-correlations, the full model is quite successful in replicating the lead-lag relationships among most observables. The model reproduces the relationship that current inflation leads to higher interest rate in the future, presented in the data. In addition, the absolute fit for the cross-correlation between the change in real exchange rate/terms of trade and other variables are improved under the full specification.

Overall, introducing the cost channel and the UIP modification into the model improves in-sample, relative and absolute fits. Therefore, these extensions should not be ignored in terms of model fit, particularly when someone with priors displayed in Table 2.1 employs a simple small open economy DSGE model for conducting monetary policy analysis.

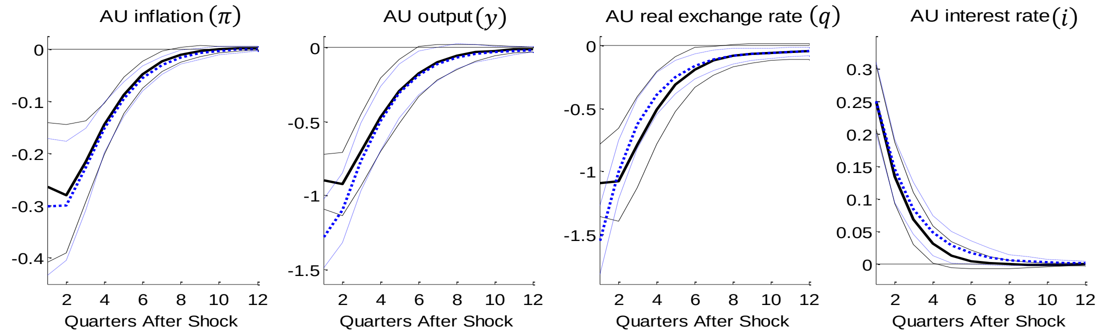
2.4.3 Impulse response functions

This section assesses the dynamics of the full and baseline models using impulse responses. The purpose is to evaluate how the transmission mechanism of monetary policy and other structural shocks is influenced by the presence of the cost channel and the UIP modification in the estimated model.

2.4.3.1 Transmission of a monetary policy shock

This section addresses the question, does the presence of both the cost channel and the UIP modification help the model to reproduce empirical responses of key macroeconomic variables (inflation, output and the real exchange rate) to a monetary policy shock? Figure 2.2 displays the impulse responses of the full and baseline models to an unexpected 25 basis point increase to the (quarterly) Australian cash rate for selected endogenous variables.

Figure 2.2 Impulse responses to a tightening AU monetary policy shock



Notes: For each plot, the blue dashed and black solid lines represent the responses at the posterior mean and 5th, 95th percentiles of the posterior distribution under the baseline and full specification, respectively.

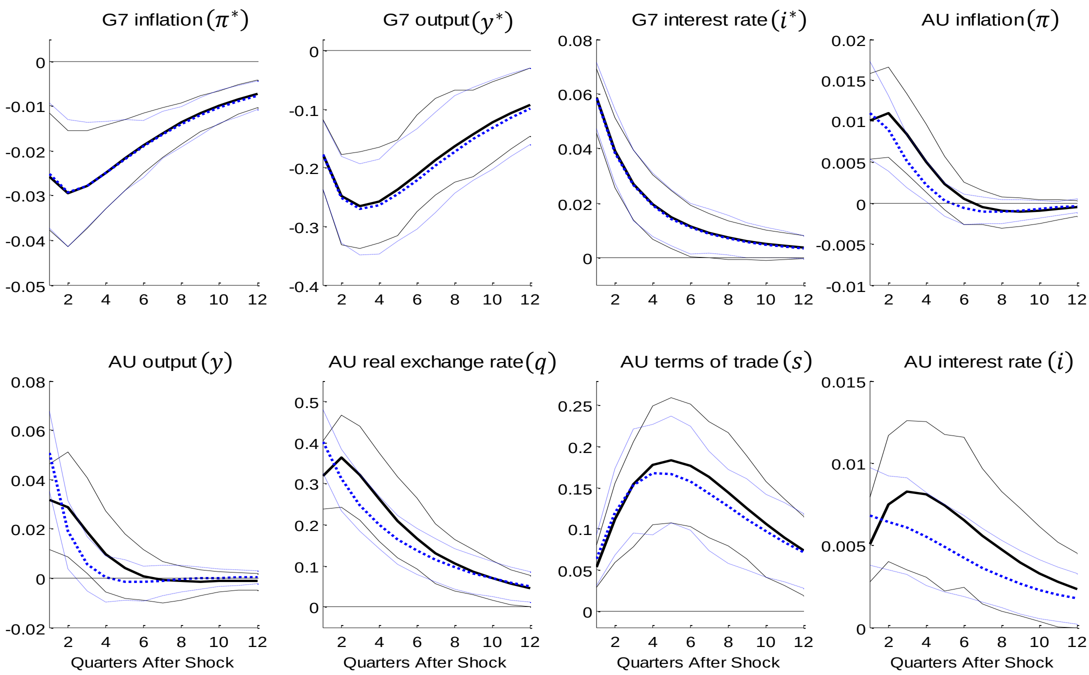
The unexpected monetary policy shock increases nominal interest rate temporarily. There is some degree of interest-rate inertia in both models as the shock is only offset by a gradual lowering of the interest rate. The interest rate returns to its steady state value after 1.5 years. In the baseline model, the shape of real exchange rate response is in line with Dornbusch's (1976) well-known exchange rate overshooting hypothesis, stating that an increase in the interest rate should cause the exchange rate to appreciate instantaneously, and then depreciate. The combination of increase in real interest rate and the real exchange rate appreciation reduces output by lowering both domestic and external demands. The lower domestic demand decreases real marginal cost, which in turn immediately lowers domestic goods inflation. An appreciation in exchange rate also lowers the imported goods inflation, and hence overall inflation decreases in the impact period.

However, the co-existence of the cost channel and the UIP modification in combination with the estimated parameters affects to the size of responses in the impact period and time lags of the maximum effect. For instance, the peak response of inflation to the shock in the full model is a fall of approximately 0.28 percentage points in one quarter after the impact period. The shape of inflation response implies that the estimated demand side effects of monetary policy strongly dominate the supply side effects. This result in combination with the analysis of the relative fit suggests that though there is evidence for the cost channel in Australia over the inflation-targeting period, its strength is not sufficient to produce the price puzzle. The shape of inflation response obtained in the full model is in line with the existing empirical studies for Australia (e.g., Hodge et al. 2008, Robinson 2013, Jääskelä and Jennings 2010, Leu 2011 and Dungey et al. 2013).

In the full model, the response of real exchange rate is a little hump-shaped, but not as pronounced as that shown by Adolfson et al. (2008)[41]. The shape of the response is more consistent with the existing empirical results for Australia (e.g., Dungey and Pagan 2000, Liu 2010, and Jääskelä and McKibbin 2010). The results suggest that the standard UIP condition is violated in Australia, and the presented UIP modification has a potential to reproduce the delayed overshooting response of the real exchange rate in response to a monetary policy shock. Consistent with empirical evidence provided in data-driven VAR models (e.g., Dungey and Pagan 2000 and Jääskelä and Jennings 2010), the policy shock leads to output contraction in the hump-shaped manner. As discussed by Christiano et al. (2011b), the hump-shaped response of the output emerges from the persistent responses of real interest rate and real exchange rate to the shock.

Figure 2.3 displays impulse responses of both models to an unexpected 25 basis point increase to the (quarterly) G7 interest rate.

Figure 2.3 Impulse responses to a tightening G7 monetary policy shock



Notes: For each plot, the blue dashed and black solid lines represent the responses at the posterior mean and 5th, 95th percentiles of the posterior distribution under the baseline and full specification, respectively.

The impact of monetary policy tightening on the G7 economy is estimated to be similar in both models. The policy tightening leads to a fall in inflation and output in the G7

[41] The shape of real exchange rate responses to a monetary policy shock depends on the value of the parameter ϕ_e, which is estimated as 0.32, implying relatively less impact on the country risk premium from exchange rate changes.

economy. The shape of the responses shows more persistence and inertia. For instance, the peak response of inflation and output to the shock occurs after 1-2 and 3-4 quarters, respectively and the effects on the economy are more prolonged.

The hump-shaped responses of Australian variables to the G7 monetary policy shock in the full model are in line with the VAR-based results (e.g., Liu 2010 and Dungey et al. 2013). The monetary contraction decreases the interest rate difference between Australian and the G7 economies, which leads to a current depreciation of the Australian exchange rate. The depreciation makes imported goods more expensive, and hence increases the terms of trade and overall inflation. In addition, the shock reduces the real interest rate in the initial periods. The lower real interest rate and real exchange rate depreciation boost the domestic and external demands, which increase the domestic output.

2.4.3.2 Transmission of other shocks

Figures 2.B.3-2.B.8 in Appendix 2.B compare the impulse responses of the full and baseline models to other structural shocks, including consumption preference, technology, risk premium and price markup shocks in Australia and the G7. The results reveal the importance of the cost channel and the UIP modification in reproducing amplified, more persistent and prolonged responses, which are in line with the empirical evidence. In both models, the response to a positive demand shock (i.e., preference shock) in Australia instantaneously increases both output and inflation. The nominal interest rate increases accordingly responding to the rise in inflation and output, and then gradually decreases to the steady state. The impact rise in the interest rate leads to an appreciation of nominal exchange rate, which ultimately decreases the terms of trade. Both higher inflation and the appreciation of nominal exchange rate explain the appreciation in real exchange rate. The differences in the responses of the Australian variables to a positive AU and G7 consumption preference shocks come from the different impacts on the real exchange rate.

Impulse responses to a positive technology shock in Australia are standard in the sense that output increases persistently and inflation decreases. The nominal interest rate is reduced in a hump-shaped manner. The fall in the interest rate depreciates the nominal exchange rate, which consequently increases the terms of trade. The full model's responses of output, real exchange rate and terms of trade to the shock are also amplified and more prolonged compared to those in the baseline model. The hump-shaped responses of output, interest rate and real exchange rate are in line with findings obtained by Jääskelä and McKibbin (2010) who estimate a small open economy DSGE model with learning rules for expectations using Australian data. When comparing the models' responses, there is a difference in the shape of real exchange rate response. For the full model, both lower inflation and nominal exchange rate depreciation lead to a depreciation of real exchange rate in the impact period. However, for the baseline model, as found by Nimark (2009), the real exchange rate appreciates initially since the negative impact of law of one price gap ($\psi_{F,t}$) dominates the terms of trade effect.

In both models, the response to a positive price markup shock to domestic producers is characterized similar to those found by Liu (2010) in the sense that the temporary negative supply shock drives up domestic goods' inflation immediately and decreases output[42]. However, the full model's responses of real exchange rate and output are more persistent compared to those in the baseline model.

The full model's responses of Australian variables to the risk premium shock are entirely consistent with the existing VAR-based responses to an exchange rate shock found by Manalo et al. (2014). However, there are a couple of differences in the responses of the models. First, as obtained by Liu (2010) and Leu (2011), responses of output, real exchange rate, terms of trade and interest rate are more persistent and stronger in the full model. A likely reason is that the presented risk premium function (2.3) in combination with the estimated parameters leads to a hump-shaped response of real exchange rate, thereby affects the other variables' responses through endogenous propagation in the full model. Second, overall inflation responds differently to the shock, though the responses of inflation are statistically insignificant: inflation tends to increase in the full model, while it likely decreases in the baseline model.

A positive G7 preference shock leads to a rise in inflation, output and interest rate in the G7 economy. The response of G7 variables to the G7 technology shock is standard: inflation decreases immediately and then slowly recovers, output increases and interest rate is decreased gradually. The impacts of a positive G7 price markup shock on the G7 economy are estimated to be similar in both models: inflation increases immediately, and

[42] Responding to this situation, the nominal interest rate increases accordingly. Because of the rising inflation and the nominal exchange rate appreciation, the real exchange rate appreciates, reducing the imported goods' inflation. Consequently, the fall in the imported goods' inflation and the rise in domestic goods' inflation leads to a fall in terms of trade.

output decreases persistently. Responding to the stagflation, G7 interest rate increases accordingly and then decreases gradually to the equilibrium.

There is evidence of the international transmission from the G7 economy to Australia. As shown by Dungey and Fry (2003) and Liu (2010), the positive external demand shock also drives a rise in Australian output, inflation, interest rate, terms of trade and real exchange rate depreciation with the maximum positive response occurring after 3-5 quarters[43]. When comparing the models, the shock causes hump-shaped responses of inflation and real exchange rate in the full model. When considering the impact of the G7 technology shock on Australia, both models suggest a fall in the terms of trade and a real exchange rate appreciation. For the baseline model, the impact on inflation, interest rate and output are insignificant, whereas the full model suggests a fall in output. The controversial response of the output is a consequence of two opposite effects. First, the G7 output instantaneously increases Australian output by improving the demand for export. Second, the real exchange rate appreciation reduces Australian output through weakening domestic goods' competiveness in the international market.

Turning to the impact of a positive G7 price markup shock on Australia, the real exchange rate plays a key role in the propagation of the shock as reported by Dungey et al. (2013). The rise in G7 inflation leads to a depreciation of real exchange rate, increasing the demand for Australian export. The strength in export demand drives a rise in both output and the terms of trade. However, the impacts on inflation and interest are very weak. The responses of Australian variables in the full model are more amplified.

2.4.4 Variance decomposition

Table 2.B.1 of Appendix 2.B reports the variance decompositions of the full and baseline models, measuring the importance of individual shocks to fluctuations in the Australian observables, at the mean, 5th and 95th percentiles of the posterior distribution. The purpose here is to assess whether the variance shares of the observed series attributed to the individual shock is affected by the presence of the cost channel and the UIP modification.

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[43] The shock leads to nominal exchange rate depreciation through raising the G7 interest rate. Since the nominal depreciation combined with the rise in G7 inflation dominates the effect of Australian inflation, the Australian real exchange rate depreciates consequently. Australian output is increased due to the higher external demand.

In general, the full model contains a reasonable endogenous transmission mechanism. Introducing both the cost channel and the UIP modification into the model improves internal propagation of shocks within the model, and hence significantly affects the variance shares of Australian observables attributed to the individual shock. As obtained by Manalo et al. (2014), Australia's exchange rate acts as a shock absorber in the sense that the real exchange rate movements have served to mitigate the impact of the risk premium shock on the Australian economy. For instance, the real exchange rate movement is mainly driven by the risk premium shock (more than 70 per cent), which explains 21-38 per cent of the variance of output in the short-to-medium run[44]. In line with the existing literature (e.g., Voss and Willard 2009, Nimark 2009 and Liu 2010), a small fraction (up to 15 per cent) of the output variance is attributed to a monetary policy shock. In addition, the monetary policy shock provides a very small contribution to the exchange rate fluctuations as shown by Faust and Rogers (2003) for the US, and Jääskelä and Nimark (2011), Dungey et al. (2013) and Rees et al. (2015) for Australia. Similar to Justiniano and Preston (2010b), both models suggest that all G7 shocks account for a small share (less than 7 per cent) of the variation in Australian observables. Although the presence of the cost channel and the UIP modification increases the variance shares attributed to all G7 shocks, the variance share of the full model is still small compared to those obtained by Liu (2010) and Robinson (2013)[45].

In the context of the estimated full model, Australian output is mainly driven by preference, risk premium and domestic producer's price markup shocks in the short-to-medium run. The preference and price markup shocks account for 45-58 per cent of the output fluctuations in the short-run, and then gradually decrease to about 20 per cent in the long-run. The risk premium shock accounts for one-third of the output fluctuations in the medium-run. The highest contribution of the technology shock in output fluctuations (about 13 per cent) is observed in the medium-run as found by Liu (2010) and Nimark (2009) for Australia. When comparing the models' variance decompositions, there are significant changes in the variance share attributed to technology and monetary policy shocks[46]. In both models, price markup shocks account for 74-88 per cent of Australian

[44] Short-run is defined as 1-4 quarters, medium-run is defined as 8 quarters, and the variance in the long-run refers to stationary variance (or unconditional variance).

[45] In general, as discussed by Robinson (2013), the relatively low contribution of foreign economy shocks may be because the foreign sector is being modelled as the G7 economy, whereas in recent years strong demand for commodities from China has been a key factor explaining the rapid rise in Australia's term of trade.

[46] The baseline model suggests that the technology shock accounts for an implausibly small share (less than 2 per cent) of the Australian output.

inflation fluctuations, which is a consequence of the small estimates of the parameter on the marginal cost ($k_H/(1+\beta\delta_H)$. This result is in line with the finding shown by Liu (2010) that the shocks explain about 65 per cent of inflation volatility. The endogenous transmission in the full model is improved compared to the baseline model in the sense that the variance share attributed to the technology and preference shocks is raised to 20 per cent in the medium-run.

The real exchange rate movements (about 70-80 per cent) are mainly determined by the risk premium shock. The superior role of the risk premium shock suggests that the Australian dollar moves mainly in response to shocks to the foreign exchange, commodity and capital markets as exogenous shifts in the risk premium rather than reacting to shocks originating in the domestic economy. The result is consistent with the observation discussed by Meese and Rogoff (1983) that movements in the exchange rate cannot be explained by the macroeconomic fundamentals. However, there is evidence that the presence of both the cost channel and the UIP modification in the model improves the endogenous propagation of other shocks passing through the real exchange rate dynamics. For example, the real exchange rate's variance share attributed to the preference and the import's price markup shocks is increased from 5 per cent to 25 per cent. As found by Voss and Willard (2009), only a small share of Australia's exchange rate movements is attributable to foreign variable shocks. The terms of trade movements are mostly explained by risk premium and import's price markup shocks.

Preference, price markup and monetary policy shocks are major sources (explaining 65-80 per cent) of interest rate volatility in the short-to-medium run. This result supports the view that the cash rate systematically responds to the inflation and changes in real activity following the Taylor-type rule. In the medium-to-long run, the risk premium shock is predominantly important for interest rate volatility since monetary policy and price markup shocks are less persistent, and the risk premium shock is an important driver of the Australian business cycle.

2.5 Conclusion

This chapter has examined the quantitative role of the cost channel and the UIP modification in an estimated small open economy DSGE model, consisting of a small economy (Australia) and a large economy (the G7 economy). For this purpose, the model developed by the Justiniano and Preston (2010a) is augmented to include two novel features, namely (i) the cost channel of monetary policy and (ii) the UIP modification allowing the risk premium is negatively correlated with the expected depreciation. Alternatives to the model have been estimated using Bayesian methods based on the data for Australia and the G7 covering the period 1993:Q1 to 2013:Q4.

A number of interesting results emerge from the empirical analysis. First, the estimates for structural parameters of the model are sensitive to variations in model specifications, implying that quantitative changes in the model performance are associated with both the difference in the equation form (Phillips curves and UIP condition) and the changes in the estimated parameters. Second, the analysis of the model comparison based on Bayes factor and second moments suggest that the presence of the cost channel and the presented UIP modification improves the model fit. The results provide empirical evidence for the existence of the cost channel and the violation of the standard UIP in Australia over the inflation-targeting period. The primary role played by the cost channel in the full model is to generate inflation inertia without obtaining a very high degree of domestic price stickiness. The UIP modification enables the full model to generate both persistence and volatility in real exchange rate dynamics. Third, the impulse response analysis reveals (i) no evidence for the cost channel interpretation of the price puzzle, supporting a view that the puzzle obtained in VARs likely comes from misspecification, and (ii) evidence of the delayed overshooting puzzle, possibly resolved by the presented UIP modification. Finally, Australia's real exchange rate movements over the inflation-targeting period have broadly played a stabilising role in the economy. In addition, monetary policy shocks have been mainly absorbed by the output, and play a minor role in accounting for the real exchange rate volatility. The slight effect of monetary policy shock in explaining variations of macroeconomic variables is in line with findings of other DSGE models developed in the case of the Australian economy (e.g., Voss and Willard 2009, Nimark 2009, Jääskelä and Nimark 2011 and Rees et al. 2015).

This chapter has also provided implications for designing optimal monetary policy that helps to stabilize the macroeconomy. First, the strong dominance of the demand side effects of monetary policy over its supply side effect in Australia suggests that implementing the Taylor principle[47] promotes macroeconomic stability by avoiding self-fulfilling inflation expectations in an emerging economy, having similar characteristics

[47] The Taylor principle states that 1 per cent rise in inflation should be met by greater than 1 per cent rise in the nominal interest rate. If the cost channel was strong enough, then the Taylor principle could actually destabilize fluctuations in inflation expectations (Christiano et al. 2011a).

with Australia. Second, in the developing countries, it is more likely that the cost channel is strong and the standard UIP condition is violated due to weak financial market development. In such cases, policy makers should employ an open economy model with both the cost channel and presented UIP modification in proposing monetary policy actions.

The estimated full model has provided significant insights about the transmission of shocks and their relevance in the business cycle. However, the present model remains stylised and can be further developed. To improve the model performance, future extensions may include (i) incorporating alternative modelling of expectations (e.g., news shocks, sticky information and adaptive learning) and (ii) introducing labour market and financial frictions into the model. It is left for the next chapter to assess the importance of news shocks in explaining labour market and business cycle fluctuations using an estimated small open economy model, augmented with the theory of involuntary unemployment proposed by Galí (2011).

2.6 References

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Appendix 2.A Equations of the log-linearized model

The steady state of the model is characterized by zero inflation and balanced trade. All variables are to be interpreted as log-deviation from their respective steady state values ($x_t = log(X_t/X)$)[48].

2.A.1 Domestic economy (Australia)

Euler equation:

$$c_t - hc_{t-1} = E_t(c_{t+1} - hc_t) - \sigma^{-1}(1-h)(i_t - E_t\pi_{t+1}) + \sigma^{-1}(1-h)(\varepsilon_{g,t} - E_t\varepsilon_{g,t+1}) \quad (2.A.1)$$

Goods market clearing:

$$y_t = (1-\alpha)c_t + \alpha\eta(2-\alpha)s_t + \alpha\eta\psi_{F,t} + \alpha y_t^* \quad (2.A.2)$$

where $\psi_{F,t} = (e_t + p_t^*) - p_{F,t}$ denotes the law of one price gap, and $s_t = p_{F,t} - p_{H,t}$ is the terms of trade.

Time differences in the terms of trade:

$$\Delta s_t = \pi_{F,t} - \pi_{H,t} \quad (2.A.3)$$

where $\pi_{F,t} = p_{F,t} - p_{F,t-1}$ and $\pi_{H,t} = p_{H,t} - p_{H,t-1}$ respectively denote the inflation of imported goods and domestic goods.

The real exchange rate:

$$q_t = e_t + p_t^* - p_t = \psi_{F,t} + (1-\alpha)s_t \quad (2.A.4)$$

The real exchange rate therefore depends on deviations from the law of one price and the terms of trade.

Domestic firms' Phillips curve, extended with the cost channel:

$$\pi_{H,t} - \delta_H\pi_{H,t-1} = \beta E_t\left(\pi_{H,t+1} - \delta_H\pi_{H,t}\right) + k_H mc_t + \varepsilon_{cp^H,t} \quad (2.A.5)$$

where $k_H = \frac{(1-\theta_H)(1-\theta_H\beta)}{\theta_H}$;

Real marginal cost:

$$mc_t = \varphi y_t - (1+\varphi)\varepsilon_{a,t} + \alpha s_t + \sigma(1-h)^{-1}(c_t - hc_{t-1}) + \upsilon_H i_t$$

Retailers' Phillips curve, extended with the cost channel:

$$\pi_{F,t} - \delta_F\pi_{F,t-1} = \beta E_t\left(\pi_{F,t+1} - \delta_F\pi_{F,t}\right) + k_F\left(\psi_{F,t} + \upsilon_F i_t\right) + \varepsilon_{cp^F,t} \quad (2.A.6)$$

where $k_F = \frac{(1-\theta_F)(1-\theta_F\beta)}{\theta_F}$.

CPI inflation:

$$\pi_t = \pi_{H,t} + \alpha\Delta s_t \quad (2.A.7)$$

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[48] Exceptions are: the nominal and real exchange rate are defined as $e_t = \log(\tilde{e}_t/\tilde{e})$, $q_t = \log(\tilde{q}_t/\tilde{q})$; interest rates are specified as $i_t = \log(R_t^M/R^M) = \log((1+\tilde{\imath}_t)/(1+\tilde{\imath})) = \tilde{\imath}_t - \tilde{\imath}$, $\upsilon_{H,F}i_t = \log\left(R_{H,F,t}/R_{H,F}\right) = \log\left((1+\upsilon_{H,F}\tilde{\imath}_t)/(1+\upsilon_{H,F}i)\right) = \upsilon_{H,F}\left(\tilde{\imath}_t - \tilde{\imath}\right)$; the net foreign asset is denoted as $a_t = A_t - A$ and the shocks are described as $\varepsilon_{x,t} = \log(\tilde{\varepsilon}_{x,t}/\tilde{\varepsilon}_x)$, $\varepsilon_{rp,t} = \tilde{\varepsilon}_{rp,t} - \tilde{\varepsilon}_{rp}$.

The CPI inflation depends on the inflation of domestically produced goods and the terms of trade weighted by the importance of imported goods in the CPI basket.

The modified UIP condition:

$$i_t - i_t^* = (1 - \phi_e)E_t\Delta e_{t+1} - \phi_e \Delta e_t - \phi_a a_t + \varepsilon_{rp,t} \qquad (2.A.8)$$

where $\Delta e_t = \pi_t - \pi_t^* + \Delta q_t$ is the nominal exchange rate.

Net foreign assets:

$$a_t = \frac{1}{\beta} a_{t-1} - \alpha\left(s_t + \psi_{F,t}\right) + y_t - c_t \qquad (2.A.9)$$

Monetary policy rule:

$$i_t = \rho_R i_{t-1} + (1 - \rho_R)\left(\chi_\pi \pi_t + \chi_y y_t + \chi_{\Delta y}\Delta y_t\right) + \varepsilon_{R,t} \qquad (2.A.10)$$

where $\varepsilon_{R,t}$ is a domestic monetary policy shock.

2.A.2 Foreign (G7) economy

When applying $\alpha^* = 0$ condition and $P_t^* = P_{F,t}^*$ assumptions into (2.A.1)-(2.A.10), equations describing the foreign economy can be described as follows:

IS curve:

$$y_t^* - h^* y_{t-1}^* = E_t(y_{t+1}^* - h^* y_t^*) - \sigma^{*-1}(1 - h^*)(i_t^* - E_t \pi_{t+1}^*) + \sigma^{*-1}(1 - h^*)(\varepsilon_{g,t}^* - \varepsilon_{g,t+1}^*) \qquad (2.A.11)$$

Phillips curve:

$$\pi_t^* - \delta^* \pi_{t-1}^* = \beta E_t(\pi_{t+1}^* - \delta^* \pi_t^*) + k^*\left(mc_t^* + \varepsilon_{cp,t}^*\right) \qquad (2.A.12)$$

where $k^* = \frac{(1-\theta^*)(1-\theta^*\beta^*)}{\theta^*}$; $\varepsilon_{cp,t}^*$ is a foreign price markup shock, and

Real marginal cost:

$$mc_t^* = \varphi^* y_t^* - (1 + \varphi^*)\varepsilon_{a,t}^* + \sigma^*(1 - h^*)^{-1}(y_t^* - h^* y_{t-1}^*) + \nu^* i_t^*$$

Monetary policy rule:

$$i_t^* = \rho_R^* i_{t-1}^* + (1 - \rho_R^*)\left(\chi_\pi^* \pi_t^* + \chi_y^* y_t^* + \chi_{\Delta y}^* \Delta y_t^*\right) + \varepsilon_{R,t}^* \qquad (2.A.13)$$

where $\varepsilon_{R,t}^*$ is a foreign monetary policy shock.

Appendix 2.B Data definitions, tables and figures

2.B.1 Data Definitions

2.B.1.1 Australia

Output: real non-farm GDP, chain volume, seasonally adjusted; Reserve Bank of Australia (RBA) Statistical Table G10 (since 2014, the table is changed to H1) Gross Domestic Product and Income

Inflation: quarterly inflation, excluding interest payments (prior to the September quarter 1998) and tax changes of 1999-2000; RBA Statistical Table G1 Measures of Consumer Price Inflation

Interest rates: cash rate, quarterly average; RBA Statistical Table F13 International Official Interest Rates

Real exchange rate: real G7 GDP-weighted index; RBA Statistical Table F15 Real Exchange Rate Measures

Terms of trade: terms of trade index, seasonally adjusted; Australian Bureau of Statistics (ABS) Cat No 5206: A2304200A

2.B.1.2 G7 economy

Output: G7 GDP, VIXOBSA: volume index, OECD reference year, seasonally adjusted; OECD.Stat, Quarterly National Accounts

Inflation: G7 GDP deflator index, DOBSA: Deflator, OECD reference year, seasonally adjusted; OECD.Stat, Quarterly National Accounts

Interest rates: Immediate interest rates, Call Money, Interbank Rate, Per cent per annum; OECD.Stat, Monthly Monetary and Financial Statistics (MEI)

G7 country weights: CPI country weights in percentage of OECD Total; OECD.Stat, Prices country weights

Figure 2.B.1 Data and one-sided predicted values from alternative models

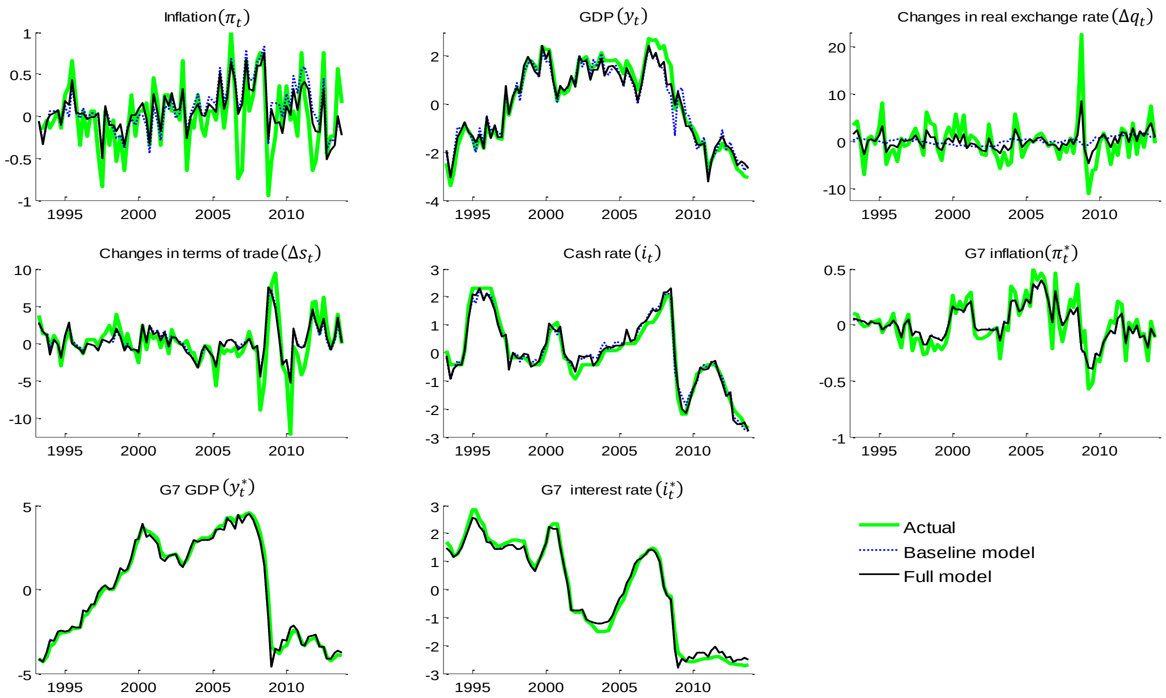
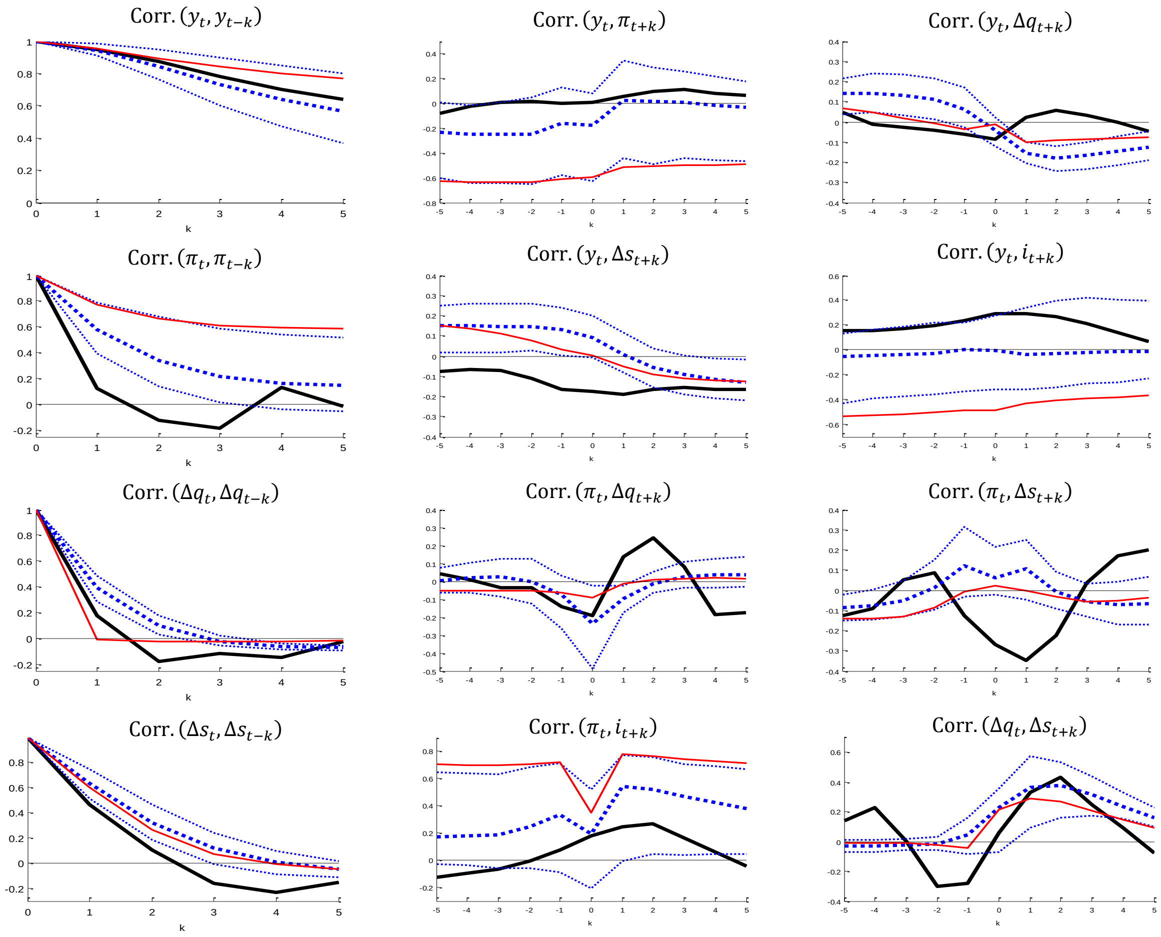
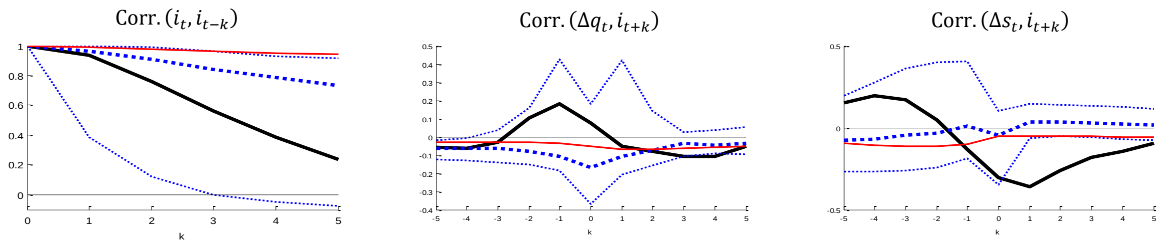


Figure 2.B.2 Posterior predictive autocorrelation and cross-correlation





Notes: The black line represents the statistics computed from the data; the dashed blue lines represent the full model's posterior predictive median and interval between the 5th and 95th percentiles of the statistics; the solid red line represents the baseline model's posterior predictive median of the statistics. Each statistic is calculated at horizons $k = 0, \ldots, 5$ for autocorrelation and at horizons $k = -5, \ldots, 0, \ldots, 5$ for cross-correlation. For $k = 0$, the medians and intervals of the statistics are approximated using the posterior predictive median and intervals of the covariance between variables, respectively.

Figure 2.B.3 Responses to a positive AU consumption preference shock

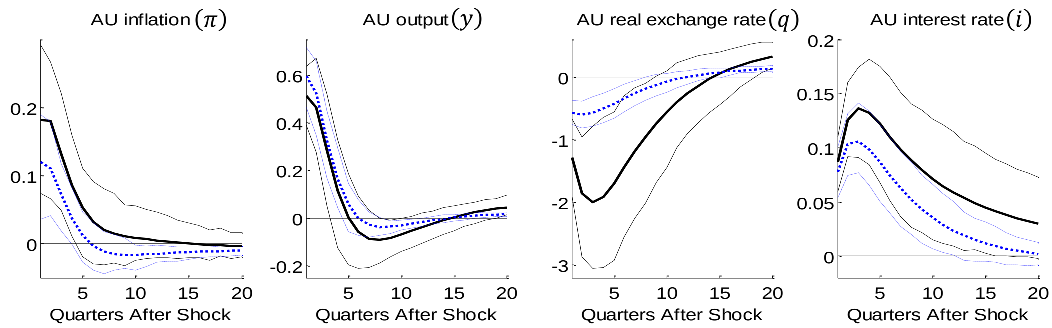


Figure 2.B.4 Responses to a positive AU technology shock

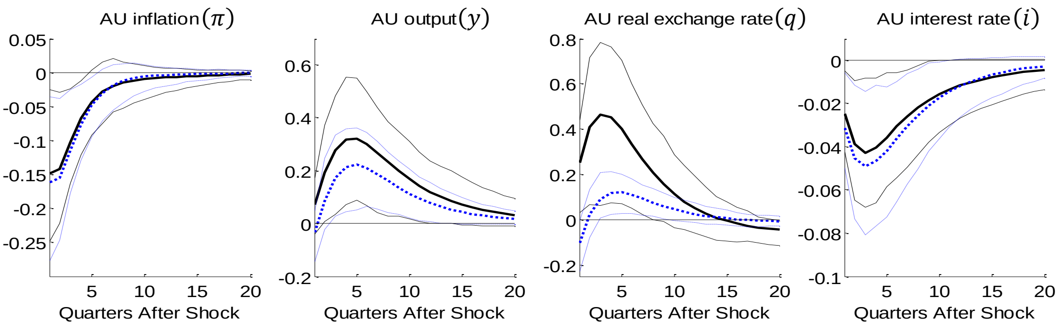
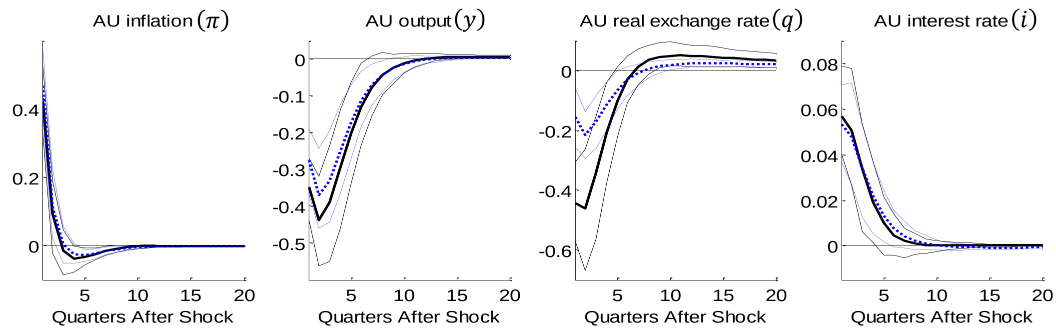


Figure 2.B.5 Responses to a positive AU producer's cost push shock



Notes: For each plot, the blue dashed and black solid lines represent the responses at the posterior mean and 5th, 95th percentiles of the posterior distribution under baseline and full models, respectively.

Figure 2.B.6 Responses to a positive AU risk premium shock

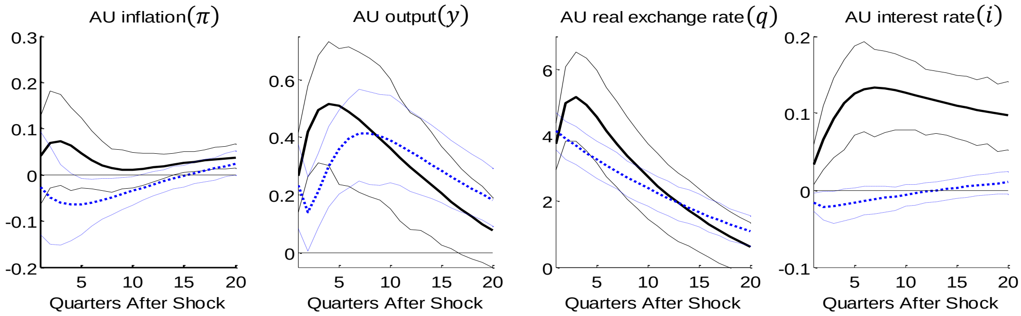


Figure 2.B.7 Responses to a positive G7 consumption preference shock

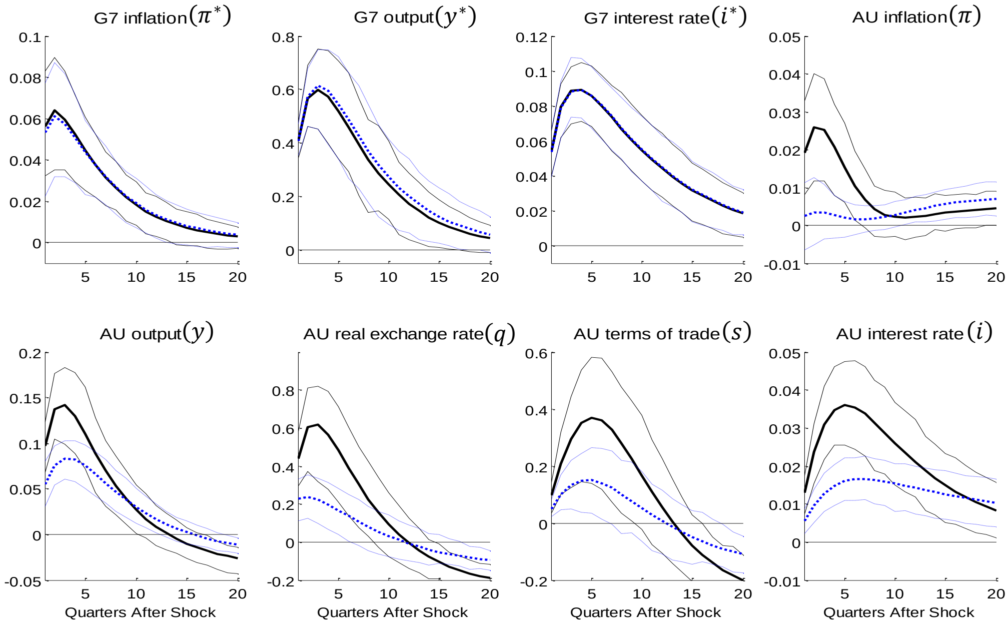
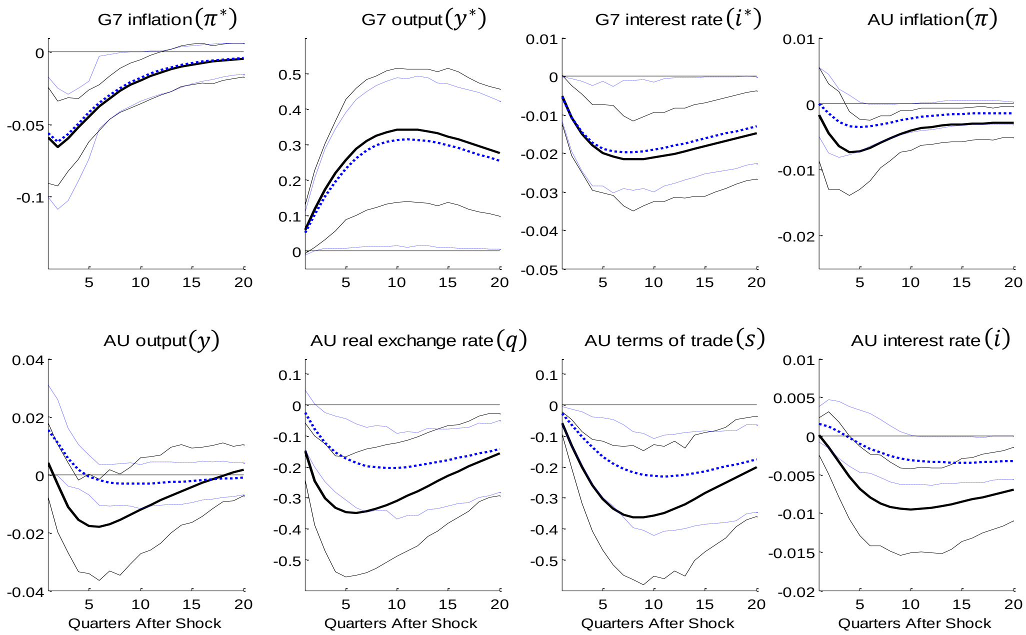


Figure 2.B.8 Responses to a positive G7 technology shock



Notes: For each plot, the blue dashed and black solid lines represent the responses at the posterior mean and 5th, 95th percentiles of the posterior distribution under baseline and full models, respectively.

Table 2.B.1 Variance decomposition: mean variance shares and [5, 95] posterior bands

Series	Quarters	Full Model							Baseline Model						
		Structural shocks							Structural shocks						
		FR	PR	TE	MP	RP	ICP	DCP	FR	PR	TE	MP	RP	ICP	DCP
Inflation	1	0 [0-0]	0.05 [0-0.11]	0.04 [0-0.09]	0.01 [0-0.03]	0.01 [0-0.03]	0.33 [0.2-0.49]	0.55 [0.38-0.75]	0 [0-0]	0.03 [0-0.06]	0.02 [0-0.03]	0.02 [0-0.04]	0.01 [0-0.03]	0.31 [0.19-0.44]	0.61 [0.47-0.77]
	4	0.01 [0-0.02]	0.09 [0-0.18]	0.08 [0-0.17]	0.03 [0-0.06]	0.05 [0-0.10]	0.30 [0.14-0.46]	0.44 [0.25-0.64]	0 [0-0]	0.05 [0-0.10]	0.03 [0-0.07]	0.04 [0.01-0.07]	0.05 [0-0.11]	0.31 [0.18-0.44]	0.52 [0.35-0.70]
	8	0.01 [0-0.02]	0.10 [0-0.19]	0.09 [0-0.18]	0.03 [0-0.06]	0.06 [0-0.11]	0.30 [0.14-0.46]	0.41 [0.24-0.61]	0 [0-0]	0.05 [0-0.10]	0.04 [0-0.07]	0.04 [0.01-0.07]	0.08 [0-0.17]	0.30 [0.18-0.44]	0.49 [0.32-0.66]
	SV (iv)	0.01 [0-0.02]	0.08 [0-0.16]	0.06 [0-0.14]	0.03 [0-0.05]	0.31 [0.04-0.64]	0.23 [0.05-0.4]	0.28 [0.11-0.44]	0 [0-0]	0.02 [0-0.06]	0.02 [0-0.04]	0.02 [0-0.04]	0.64 [0.35-0.96]	0.12 [0.01-0.23]	0.18 [0.04-0.33]
Output	1	0.04 [0.01-0.08]	0.30 [0.05-0.54]	0.01 [0-0.03]	0.15 [0.09-0.21]	0.21 [0-0.44]	0.01 [0-0.02]	0.28 [0.14-0.40]	0.01 [0-0.02]	0.44 [0.30-0.62]	0 [0-0.01]	0.25 [0.16-0.32]	0.14 [0.01-0.25]	0 [0-0.01]	0.15 [0.07-0.24]
	4	0.05 [0.01-0.09]	0.18 [0.01-0.31]	0.08 [0-0.17]	0.11 [0.05-0.15]	0.30 [0.13-0.47]	0.02 [0-0.05]	0.27 [0.16-0.38]	0.02 [0-0.03]	0.33 [0.21-0.44]	0.01 [0-0.03]	0.19 [0.12-0.25]	0.17 [0.04-0.28]	0.01 [0-0.01]	0.27 [0.19-0.34]
	8	0.04 [0.01-0.08]	0.13 [0.02-0.24]	0.13 [0-0.30]	0.08 [0.03-0.13]	0.38 [0.16-0.60]	0.02 [0-0.05]	0.21 [0.10-0.34]	0.02 [0-0.03]	0.22 [0.11-0.32]	0.02 [0-0.05]	0.13 [0.08-0.19]	0.41 [0.23-0.59]	0 [0-0.01]	0.20 [0.12-0.27]
	SV (iv)	0.03 [0-0.06]	0.08 [0.02-0.14]	0.10 [0-0.26]	0.04 [0.01-0.08]	0.60 [0.31-0.89]	0.02 [0-0.05]	0.12 [0.03-0.21]	0.01 [0-0.01]	0.07 [0.01-0.14]	0.01 [0-0.03]	0.04 [0.01-0.08]	0.79 [0.64-0.95]	0.01 [0-0.01]	0.07 [0.01-0.11]
Real exchange rate	1	0.04 [0.01-0.07]	0.10 [0.02-0.26]	0.01 [0-0.01]	0.01 [0-0.02]	0.72 [0.47-0.90]	0.11 [0.02-0.23]	0.02 [0.01-0.03]	0.01 [0-0.02]	0.01 [0.01-0.01]	0 [0-0]	0.01 [0-0.01]	0.93 [0.90-0.97]	0.03 [0.01-0.06]	0 [0-0]
	4	0.04 [0.01-0.07]	0.11 [0.02-0.26]	0.01 [0-0.01]	0.01 [0-0.02]	0.71 [0.44-0.90]	0.11 [0.02-0.24]	0.02 [0.01-0.03]	0.01 [0-0.02]	0.01 [0.01-0.02]	0 [0-0]	0.01 [0.01-0.02]	0.93 [0.90-0.96]	0.03 [0.01-0.06]	0 [0-0]
	8	0.04 [0.01-0.08]	0.11 [0.02-0.25]	0.01 [0-0.01]	0.01 [0-0.02]	0.70 [0.44-0.89]	0.12 [0.03-0.24]	0.02 [0.01-0.03]	0.02 [0-0.03]	0.01 [0.01-0.02]	0 [0-0]	0.01 [0.01-0.02]	0.93 [0.89-0.96]	0.04 [0.01-0.06]	0 [0-0]
	SV (iv)	0.03 [0.01-0.06]	0.07 [0.03-0.11]	0.01 [0-0.01]	0.01 [0-0.01]	0.77 [0.63-0.90]	0.10 [0.03-0.24]	0.02 [0.01-0.03]	0.01 [0-0.02]	0.01 [0.01-0.02]	0 [0-0]	0.01 [0.01-0.02]	0.93 [0.90-0.96]	0.04 [0.01-0.06]	0 [0-0]

Table 2.B.1 Variance decomposition: mean variance shares and [5, 95] posterior bands (Continued)

Series	Quarters	Full Model							Baseline Model						
		Structural shocks							Structural shocks						
		FR	PR	TE	MP	RP	ICP	DCP	FR	PR	TE	MP	RP	ICP	DCP
Terms of Trade	1	0.01 [0-0.01]	0.03 [0-0.06]	0.01 [0-0.01]	0 [0-0]	0.15 [0.01-0.27]	0.74 [0.60-0.89]	0.07 [0.03-0.11]	0 [0-0]	0.01 [0-0.01]	0 [0-0]	0 [0-0]	0.26 [0.11-0.41]	0.67 [0.53-0.83]	0.06 [0.03-0.09]
	4	0.02 [0-0.03]	0.06 [0.01-0.14]	0.01 [0-0.02]	0 [0-0]	0.32 [0.03-0.55]	0.55 [0.32-0.80]	0.04 [0.01-0.07]	0 [0-0]	0.01 [0-0.01]	0 [0-0]	0 [0-0]	0.43 [0.25-0.61]	0.52 [0.34-0.72]	0.04 [0.02-0.06]
	8	0.02 [0-0.03]	0.06 [0.01-0.13]	0.01 [0-0.02]	0 [0-0]	0.30 [0.03-0.53]	0.55 [0.33-0.80]	0.04 [0.01-0.07]	0 [0-0]	0.01 [0-0.02]	0 [0-0]	0 [0-0]	0.40 [0.22-0.57]	0.55 [0.37-0.74]	0.04 [0.02-0.05]
	SV[(iv)]	0.02 [0-0.04]	0.05 [0.01-0.08]	0.01 [0-0.02]	0 [0-0]	0.41 [0.19-0.63]	0.49 [0.26-0.72]	0.03 [0.01-0.07]	0 [0-0]	0.01 [0-0.02]	0 [0-0]	0 [0-0]	0.44 [0.26-0.61]	0.51 [0.34-0.71]	0.03 [0.02-0.05]
Interest rate	1	0.02 [0-0.05]	0.23 [0.04-0.40]	0.02 [0-0.04]	0.22 [0.01-0.38]	0.16 [0-0.59]	0.22 [0.01-0.35]	0.13 [0-0.22]	0.01 [0-0.01]	0.24 [0.07-0.43]	0.01 [0-0.03]	0.31 [0.12-0.46]	0.03 [0-0.08]	0.21 [0.11-0.31]	0.18 [0.10-0.26]
	4	0.04 [0.01-0.09]	0.30 [0.12-0.48]	0.03 [0-0.07]	0.07 [0.01-0.12]	0.29 [0.03-0.58]	0.22 [0.01-0.38]	0.06 [0-0.13]	0.01 [0-0.02]	0.37 [0.20-0.56]	0.03 [0-0.06]	0.12 [0.03-0.20]	0.04 [0-0.10]	0.31 [0.15-0.48]	0.12 [0.03-0.20]
	8	0.06 [0.01-0.10]	0.25 [0.13-0.42]	0.03 [0-0.07]	0.03 [0.01-0.06]	0.42 [0.22-0.63]	0.15 [0.02-0.28]	0.04 [0-0.07]	0.02 [0-0.04]	0.4 [0.21-0.57]	0.04 [0-0.09]	0.09 [0.02-0.15]	0.08 [0-0.19]	0.28 [0.10-0.46]	0.09 [0.02-0.16]
	SV[(iv)]	0.04 [0-0.07]	0.15 [0.01-0.28]	0.02 [0-0.04]	0.01 [0-0.02]	0.71 [0.50-0.96]	0.06 [0-0.13]	0.02 [0-0.03]	0.01 [0-0.02]	0.05 [0-0.12]	0.01 [0-0.01]	0.01 [0-0.01]	0.89 [0.77-0.99]	0.03 [0-0.08]	0.01 [0-0.02]

Notes: i) FR represents four G7 shocks, including preference, technology, price markup and monetary polish shocks; PR denotes the domestic consumption preference shock; TE indicates the domestic technology shock; MP stands for the domestic monetary policy shock; ICP indicates the price markup shock in the import sector; DCP denotes the price markup shock in the domestic producers.

ii) Variance shares are shown in [0,1] interval, hence 0.01 corresponds to 1 per cent.

iii) For FR shock, posterior mean and [5, 95] bands are computed by simple sum of the share of relevant shocks' mean, lower and upper bands of 90 per cent interval.

iv) SV denotes Stationary Variance (or unconditional variance), which refers to the long-horizon variance.

v) Figures in brackets indicate 90 per cent posterior probability intervals.

Appendix 2.C Derivation of key equations

2.C.1 The domestic household

The households face two step optimization problems. In the first step, the household chooses the combination of domestic and foreign goods bundles that minimize costs for any given level of aggregate consumption[49]. The optimization gives the demand functions, shown in (2.4.1) and (2.4.2):

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \text{ and } C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t \tag{2.C.1}$$

In the second step, the household chooses optimally how much to consume, work and invest by maximizing lifetime utility. The optimization problem is solved using stochastic Lagrangian multiplier approach. The Lagrangian function is:

$$\mathcal{L}_t = E_t \sum_{t=0}^{\infty} \beta^t \Bigg(\tilde{\varepsilon}_{g,t}\left[\frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}\right] - \Lambda_t\big(P_t C_t + D_t + \tilde{e}_t B_t - D_{t-1}(1+\tilde{\iota}_{t-1}) - \tilde{e}_t B_{t-1}(1+\tilde{\iota}^*_{t-1})\phi_t - W_t N_t - \Pi_{H,t} - \Pi_{F,t} - \mathrm{T}_t\big)\Bigg) \tag{2.C.2}$$

First order conditions are:

$$\frac{\partial \mathcal{L}_t}{\partial C_t} = \beta^t\big(\tilde{\varepsilon}_{g,t}(C_t - H_t)^{-\sigma} - \Lambda_t P_t\big) = 0 \tag{2.C.3}$$

$$\frac{\partial \mathcal{L}_t}{\partial N_t} = \beta^t\big(-\tilde{\varepsilon}_{g,t} N_t^{\varphi} + \Lambda_t W_t\big) = 0 \tag{2.C.4}$$

$$\frac{\partial \mathcal{L}_t}{\partial D_t} = -\beta^t \Lambda_t + \beta^{t+1} E_t\big(\Lambda_{t+1}(1+\tilde{\iota}_t)\big) = 0 \tag{2.C.5}$$

$$\frac{\partial \mathcal{L}_t}{\partial B_t} = -\beta^t \Lambda_t \tilde{e} + \beta^{t+1} E_t(\Lambda_{t+1}\tilde{e}_{t+1}(1+\tilde{\iota}^*_t)\phi_{t+1}) = 0 \tag{2.C.6}$$

Solving the system of (2.C.3) and (2.C.4) yields equation (2.6), and equation (2.C.5) is itself equation (2.7) and substituting (2.C.5) into (2.C.6) returns equation (2.8).

2.C.2 Pricing decision of domestic firms

A firm, re-setting its price in period t as $P'_{H,t}$, maximizes the present value of profits by taking into account the probability of not being able to re-set prices in the future. The optimization problem can be solved using the Lagrangian multiplier approach as follows:

$$\mathcal{L}_t = \sum_{\tau=0}^{\infty} \theta_H^{\tau} E_t \Bigg\{ Q_{t,t+\tau} Y_{H,t+\tau|t} \left[P'_{H,t}\left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}}\right)^{\delta_H} - P_{H,t+\tau} MC_{t+\tau}\right] - \lambda_t \Bigg(C_{H,t+\tau|t} - \left(\frac{P'_{H,t}}{P_{H,t+\tau}}\left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}}\right)^{\delta_H}\right)^{-\varepsilon} \left(C_{H,t+\tau} + C^*_{H,t+\tau}\right)\Bigg)\Bigg\} \tag{2.C.7}$$

First order conditions are

$$\frac{\partial \mathcal{L}_t}{\partial P'_{H,t}} = \sum_{\tau=0}^{\infty} \theta_H^{\tau} E_t \Bigg\{ Q_{t,t+\tau} Y_{H,t+\tau|t} \left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}}\right)^{\delta_H} - \lambda_t \varepsilon \left(\frac{1}{P_{H,t+\tau}}\left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}}\right)^{\delta_H}\right)^{-\varepsilon} {P'_{H,t}}^{-\varepsilon-1}\big(C_{H,t+\tau} + C^*_{H,t+\tau}\big)\Bigg\} = 0 \tag{2.C.8}$$

[49] Regarding the duality condition, the cost minimization problem can be solved using the following Lagrangian function: $\mathcal{L}_t = \left[(1-\alpha)^{\frac{1}{\eta}}(C_{H,t})^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}}(C_{F,t})^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} - \lambda_t(P_{H,t}C_{H,t} + P_{F,t}C_{F,t} - P_t C_t)$.

$$\frac{\partial \mathcal{L}_t}{\partial C_{H,t+\tau|t}} = \sum_{\tau=0}^{\infty} \theta_H^\tau E_t \left\{ Q_{t,t+\tau} \left[P'_{H,t} \left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}} \right)^{\delta_H} - P_{H,t+\tau} MC_{t+\tau} \right] - \lambda_t \right\} = 0 \tag{2.C.9}$$

$$\frac{\partial \mathcal{L}_t}{\partial \lambda_t} = \left(\frac{P'_{H,t}}{P_{H,t+\tau}} \left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}} \right)^{\delta_H} \right)^{-\varepsilon} \left(C_{H,t+\tau} + C^*_{H,t+\tau} \right) - Y_{H,t+\tau|t} = 0 \tag{2.C.10}$$

Substituting (C.9) and (C.10) into (C.8) yields

$$\sum_{\tau=0}^{\infty} \theta_H^\tau E_t \left\{ Q_{t,t+\tau} Y_{H,t+\tau|t} \left(\left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}} \right)^{\delta_H} - \varepsilon \left[P'_{H,t} \left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}} \right)^{\delta_H} - P_{H,t+\tau} MC_{t+\tau} \right] {P'_{H,t}}^{-1} \right) \right\} = 0$$

$$\Rightarrow \sum_{\tau=0}^{\infty} \theta_H^\tau E_t \left\{ Q_{t,t+\tau} Y_{H,t+\tau|t} \left(P'_{H,t} \left(\frac{P_{H,t+\tau-1}}{P_{H,t-1}} \right)^{\delta_H} - \frac{\varepsilon}{\varepsilon-1} P_{H,t+\tau} MC_{t+\tau} \right) \right\} = 0 \tag{2.C.11}$$

(2.C.11) is the equation (2.14), combined condition of the first order conditions. The derivation of optimal price setting condition for the retail firm (2.18) is analogous to the case of the domestic firm, which has been conducted above.

2.C.3 Log-linear approximation to equilibrium conditions[50]

Euler equation: A log-linear approximation to Euler equation (2.7) gives

$$\tilde{\varepsilon}_g (C - hC)^{-\sigma} P^{-1} \left(1 + \varepsilon_{g,t} - \frac{\sigma}{1-h} (c_t - hc_{t-1}) \right) = \beta E_t \Big[\tilde{\varepsilon}_g (C - hC)^{-\sigma} (1 + \tilde{\imath}) P^{-1} \left(1 + \varepsilon_{g,t+1} - \frac{\sigma}{1-h} (c_{t+1} - hc_t) + i_t - \pi_{t+1} \right) \Big] \tag{2.C.12}$$

Combining (2.C.12) with the steady state relation, $\tilde{\varepsilon}_g (C - hC)^{-\sigma} P^{-1} = \beta E_t \left[\tilde{\varepsilon}_g (C - hC)^{-\sigma} (1 + \tilde{\imath}) P^{-1} \right]$, the linearized Euler equation (2.A.1) can be found as

$$c_t - hc_{t-1} = E_t(c_{t+1} - hc_t) - \sigma^{-1}(1-h)(i_t - E_t \pi_{t+1}) + \sigma^{-1}(1-h)(\varepsilon_{g,t} - E_t \varepsilon_{g,t+1}) \tag{2.C.13}$$

The law of one price gap, real exchange rate and inflation relations: A log-linear approximation to the CPI equation (2.5) around a zero inflation steady state in which $P = P_H = P_F$ yields

$$p_t = (1-\alpha) p_{H,t} + \alpha p_{F,t} = p_{F,t} - (1-\alpha) s_t \tag{2.C.14}$$

where $s_t = p_{F,t} - p_{H,t}$. A log-linearization of the law of one price gap is given by

$$\psi_{F,t} = e_t + p_t^* - p_{F,t} \tag{2.C.15}$$

Using (2.C.14) and (2.C.15), the real exchange rate can be obtained as

$$q_t = e_t + p_t^* - p_t = \psi_{F,t} + p_{F,t} - p_t = \psi_{F,t} + (1-\alpha) s_t \tag{2.C.16}$$

From (2.C.14), the CPI inflation is found as

$$\pi_t = \pi_{H,t} + \alpha \Delta s_t \tag{2.C.17}$$

where $\Delta s_t = \pi_{F,t} - \pi_{H,t}$.

Resource constraint: In contrast to the domestic economy, it is assumed that the law of one price holds for imports of domestic goods to the foreign economy, for instance, $P_{H,t} = \tilde{e}_t P^*_{H,t}$. Using (2.4.1), (2.22) and (2.23) equations and the notation of $Y_t = Y_{H,t}$, the resource constraint ($Y_{H,t} = C_{H,t} + C^*_{H,t}$) can be written as

[50] The log-linear approximation is used to transform the equilibrium conditions into a linear form. The log-linearization transforms the domain with a log function, and then approximates with a linear function. By definition of the log-linearization, if $\mathbb{R} \to \mathbb{R}$ is differentiable, and x^* is some point in $\mathbb{R}$, then the log-linearization $\hat{f}$ of f around x^* is $\hat{f}(x) = f(X^*) + X^* f'(X^*) x$, where $x = \log X - \log X^*$.

$$Y_t = C_{H,t} + C^*_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t + \varsigma\left(\Psi_{F,t} S_t\right)^{\eta^*} Y^*_t \tag{2.C.18}$$

A log-linear approximation to the above equation around the zero inflation steady state in which $P = P_H = P_F$ yields

$$\mathrm{Y}(y_t + 1) = C_H\left(1 - \eta\left(p_{H,t} - p_t\right) + c_t\right) + C^*_H\left(1 + \eta^*\left(\psi_{F,t} + s_t\right) + y^*_t\right)$$

where C_H and C^*_H are steady state values of $C_{H,t}$ and $C^*_{H,t}$, respectively and $C_H = (1-\alpha)C$, $C^*_H = \varsigma Y^*$. Since the resource constraint in the steady state is $Y = C_H + C^*_H$, above equation can be rewritten as

$$\mathrm{Y} y_t = C_H\left(\eta\left(p_t - p_{H,t}\right) + c_t\right) + C^*_H\left(\eta^*\left(\psi_{F,t} + s_t\right) + y^*_t\right).$$

From the steady state version of equations (2.4.1) and (2.4.2), it is found that $C_H = (1-\alpha)C$ and $C_F = \alpha C$, where C_F is the steady state level of imports. Assuming balanced trade, export of domestic economy (C^*_H) is equal to its import (C_F) in the steady state, $C^*_H = C_F = \alpha C$. Inserting this into the resource constraint yields $\mathrm{Y} = C_H + C^*_H = (1-\alpha)C + \alpha C = C$. Thus using the resource constraint and (2.C.14) equation, linearized the resource constraint can be obtained as

$$y_t = (1-\alpha)c_t + \alpha\left((1-\alpha)\eta + \eta^*\right)s_t + \alpha\eta^*\psi_{F,t} + \alpha y^*_t \tag{2.C.19}$$

If the condition $\eta = \eta^*$is assumed, then (2.C.19) is same as equation (2.A.2).

Optimal price setting for domestic firms: Log-linear approximations to (2.12) and (2.14) equations yield a hybrid Phillips curve. Log-linearization of the domestic price index (2.12) around the zero steady state ($P = P_H = P'_H$) is

$$p_{H,t} = (1-\theta_H)p'_{H,t} + \theta_H\left((1+\delta_H)p_{H,t-1} - \delta_H p_{H,t-2}\right) \tag{2.C.20}$$

Substituting $p_{H,t-1}$ from both sides of (2.C.20) equation returns

$$p'_{H,t} - p_{H,t-1} = \frac{1}{1-\theta_H}\pi_{H,t} - \frac{\theta_H\delta_H}{1-\theta_H}\pi_{H,t-1} \tag{2.C.21}$$

At the zero inflation steady state ($P = P_H = P'_H$), equation (2.13) and equation (2.14) provide $Y = Y_H$=$C_H + C^*_H$ and $MC = (\varepsilon - 1)/\varepsilon$, respectively. Moreover, the steady state stochastic discount factor is $Q_{t,t+\tau} = \beta^{\tau}$[51]. Therefore, a log-linear approximation to equation (2.14) yields

$$p'_{H,t} = (1-\theta_H\beta)E_t\left[\textstyle\sum_{\tau=0}^{\infty}(\theta_H\beta)^{\tau}\left(p_{H,t+\tau} + mc_{t+\tau} - \delta_H p_{H,t+\tau-1}\right)\right] + \delta_H p_{H,t-1} \tag{2.C.22}$$

or

$$p'_{H,t} = (1-\theta_H\beta)\left[\left(p_{H,t} + mc_t - \delta_H p_{H,t-1}\right) + (\theta_H\beta)E_t\left[\textstyle\sum_{\tau=0}^{\infty}(\theta_H\beta)^{\tau}\left(p_{H,t+1+\tau} + mc_{t+1+\tau} - \delta_H p_{H,t+\tau}\right)\right]\right] + \delta_H p_{H,t-1} \tag{2.C.23}$$

Equation (2.C.22) can be rewritten in the period $t+1$:

$$p'_{H,t+1} = (1-\theta_H\beta)E_t\left[\textstyle\sum_{\tau=0}^{\infty}(\theta_H\beta)^{\tau}\left(p_{H,t+1+\tau} + mc_{t+1+\tau} - \delta_H p_{H,t+\tau}\right)\right]$$

[51] According to financial economics, under the assumption that households have access to a complete set of state-contingent claims, $Q_{t,t+\tau}$ is the pricing kernel of such a security maturing in $t+\tau$ and is given by $Q_{t,t+\tau} = \beta^{\tau}\Lambda_{t+\tau}/\Lambda_t$ with $\Lambda_t = \mu_t/\rho_t$, which is the marginal utility of consumption at the time t state s^t budget constraint, where μ_t is the Lagrange multiplier attached to time t state s^t budget constraint and ρ_t is the probability of observing history s^t. Hence, at the steady state, the stochastic discount factor is $Q_{t,t+\tau} = \beta^{\tau}$.

$$+\delta_H p_{H,t} \tag{2.C.24}$$

Inserting (2.C.24) into (2.C.23) yields

$$p'_{H,t} = (1-\theta_H\beta)\left(p_{H,t} + mc_t - \delta_H p_{H,t-1}\right) + (\theta_H\beta)E_t\left[p'_{H,t+1} - \delta_H p_{H,t}\right] + \delta_H p_{H,t-1}$$

Subtracting $p_{H,t-1}$ from both sides of above equation and re-arranging yields the following first order difference equation:

$$p'_{H,t} - p_{H,t-1} = (1-\theta_H\beta)mc_t + (1-\delta_H\theta_H\beta)\pi_{H,t}$$
$$+(\theta_H\beta)E_t\left[p'_{H,t+1} - p_{H,t}\right] \tag{2.C.25}$$

Combining (2.C.21) with (2.C.25) gives the hybrid Phillips curve (2.15) as

$$\pi_{H,t} - \delta_H\pi_{H,t-1} = \beta E_t\left(\pi_{H,t+1} - \delta_H\pi_{H,t}\right) + \frac{(1-\theta_H)(1-\theta_H\beta)}{\theta_H}mc_t \tag{2.C.26}$$

Marginal costs: When the labour market is in equilibrium (2.6), real marginal cost in symmetric equilibrium can be expressed as $MC_t = (C_t - hC_{t-1})^{\sigma}N_t^{\varphi}P_t R_{H,t}P_{H,t}^{-1}\tilde{\varepsilon}_{a,t}{}^{-1}$ where $R_{H,t} \equiv 1 + \upsilon_H\tilde{\imath}_t$ from the equation (2.10). A log-linear approximation yields[52]

$$mc_t = \varphi n_t + p_t - p_{H,t} + \upsilon_H i_t - \varepsilon_{a,t} + \sigma(1-h)^{-1}(c_t - hc_{t-1}) \tag{2.C.27}$$

Combining (2.C.27) with (2.C.17) and $n_t = y_t - \varepsilon_{a,t}$, the real marginal cost can be derived as

$$mc_t = \varphi y_t - (1+\varphi)\varepsilon_{a,t} + \alpha s_t + \sigma(1-h)^{-1}(c_t - hc_{t-1}) + \upsilon_H i_t \tag{2.C.28}$$

Optimal price setting for domestic retail firms: At zero inflation steady state, $\Psi_F R_F = (\varepsilon-1)/\varepsilon$ is obtained from equation (2.18), and steady state stochastic discount factor is assumed as $Q_{t,t+\tau} = \beta^{\tau}$. A log-linear approximation to the import price index (2.16) around zero inflation steady state ($P = P_F = P_F'$) gives

$$p'_{F,t} - p_{F,t-1} = \frac{1}{1-\theta_F}\pi_{F,t} - \frac{\theta_F\delta_F}{1-\theta_F}\pi_{F,t-1} \tag{2.C.29}$$

A log-linear approximation to optimality condition (2.18) yields

$$p'_{F,t} - p_{F,t-1} = (1-\theta_F\beta)\left(\psi_{F,t} + \upsilon_F i_t + \varepsilon_{cp^F,t}\right) + (1-\delta_F\theta_F\beta)\pi_{F,t} +$$
$$(\theta_F\beta)E_t\left[p'_{F,t+1} - p_{F,t}\right] \tag{2.C.30}$$

Combining (2.C.29) with (2.C.30) and collecting terms return the hybrid Phillips curve (2.19) as

$$\pi_{F,t} - \delta_F\pi_{F,t-1} = \beta E_t\left(\pi_{F,t+1} - \delta_F\pi_{F,t}\right) + \frac{(1-\theta_F)(1-\theta_F\beta)}{\theta_F}\left(\psi_{F,t} + \upsilon_F i_t\right) \tag{2.C.31}$$

Modified UIP: Linear approximation to equations (2.3) and (2.7) yields[53]:

$$\frac{(1+i)}{(1+i^*)}(i_t - i_t^* + 1) = \frac{\tilde{e}}{\tilde{e}}\phi\left(1 - \phi_a a_t + (1-\phi_e)(E_t e_{t+1} - e_t) - \phi_e(e_t - e_{t-1}) + \varepsilon_{rp,t}\right)$$

When using the steady state relation, the modified UIP shown in (2.19) can be found as

$$i_t - i_t^* = (1-\phi_e)E_t\Delta e_{t+1} - \phi_e\Delta e_t - \phi_a a_t + \varepsilon_{rp,t} \tag{2.C.32}$$

where $\Delta e_t = \pi_t - \pi_t^* + \Delta q_t$ is change in the nominal exchange rate.

[52] At the zero inflation steady state, the relation in (E.40) is as follows: $MC = (C - hC)^{\sigma}N^{\varphi}R_H\varepsilon_a{}^{-1}$.

[53] Since net-foreign asset (A_t) can take on negative values and country risk premium shock ($\tilde{\varepsilon}_{rp,t}$) has zero mean, Taylor expansion is used instead of log-linearization for $\tilde{\varepsilon}_{rp,t}$ and A_t, using the expression $\varepsilon_{rp,t} = \tilde{\varepsilon}_{rp,t} - \tilde{\varepsilon}_{rp}$ and $a_t = A_t - A$. All other variables are log-linearized and the conventional notation introduced above is used.

Policy reaction function: A log-linear approximation to equation (2.21) returns

(2.A.10): $R^M(1+i_t) = R^M + R^M\rho_R i_{t-1} + R^M(1-\rho_R)\chi_\pi\pi_t + R^M(1-\rho_R)\chi_y y_t + (1-\rho_R)\chi_{\Delta y}\Delta y_t + R^M\varepsilon_{R,t} \Rightarrow$

$$i_t = \rho_R i_{t-1} + (1-\rho_R)\big(\chi_\pi\pi_t + \chi_y y_t + \chi_{\Delta y}\Delta y_t\big) + \varepsilon_{R,t} \qquad (2.C.33)$$

Budget constraint: The domestic bond market clearing requires $D_t = 0$ for all t. It is assumed that the government transfers (T_t) are used to neutralize the distortions stemming from monopolistic competition in domestic good and retail markets. The profits from the final goods producing firm (that works in perfectly competitive market, hence makes zero profit) is $\Pi_{f,g,t} = P_tC_t - P_{F,t}C_{F,t} - P_{H,t}C_{H,t}$. For the whole domestic economy, all profits with lump sum transfer are equal to net revenue from domestic and foreign economies, denoted by local currency

$$\Pi_{f,g,t} + \Pi_{H,t} + \Pi_{F,t} + \mathrm{T}_t = P_tC_t - W_tN_t + \tilde{e}_tP^*_{H,t}C^*_{H,t} - \tilde{e}_tP^*_tC_{F,t}$$

Inserting this relation into budget constraint (2.2) yields

$$\tilde{e}_tB_t = \tilde{e}_tB_{t-1}(1+\tilde{\imath}^*_{t-1})\phi_t + \tilde{e}_tP^*_{H,t}C^*_{H,t} - \tilde{e}_tP^*_tC_{F,t} \qquad (2.C.34)$$

Domestic goods are sold at the law of one price in the foreign economy, thus $P_{H,t} = \tilde{e}_tP^*_{H,t}$ is hold. When dividing (2.C.34) equation by P_tY and using the definition $A_t \equiv \tilde{e}_tB_t/\bar{Y}P_t$, $\tilde{q}_t = \tilde{e}_tP^*_t/P_t$ and the demand functions (2.4.2) and (2.23), the net foreign asset is obtained as

$$A_t = A_{t-1}\frac{\tilde{q}_t}{\tilde{q}_{t-1}}\frac{(1+\tilde{\imath}^*_{t-1})}{\Pi^*_t}\phi_t + \frac{1}{Y}\left(\left(\frac{P_{H,t}}{P_t}\right)\varsigma\big(\Psi_{F,t}S_t\big)^{\eta^*}Y^*_t - \tilde{q}_t\alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta}C_t\right) \quad (2.C.35)$$

where $\Pi^*_t = P^*_t/P^*_{t-1}$ is the gross foreign inflation rate. Since net-foreign asset (A_t) can take on negative values, the first-order Taylor expansion is used for A_t instead of log-linearization[54]. The linearization of the first term of the right hand side in (2.C.35) is

$$A_{t-1}\frac{\tilde{q}_t}{\tilde{q}_{t-1}}\frac{(1+\tilde{\imath}^*_{t-1})}{\Pi^*_t}\phi_t = A(1/\beta) + (1/\beta)a_{t-1} + A/\beta\left(q_t - q_{t-1} + i_{t-1} - \pi^*_t + \hat{\phi}_t\right) \qquad (2.C.36)$$

When assuming net-foreign debt in the steady state is zero ($A = 0$), the equation (2.C.36) is equal to $(1/\beta)a_{t-1}$. The relation $C^*_H = \varsigma Y^* = \alpha C = \alpha Y$ and the law of one price are hold in the steady state. Therefore, a log-linear approximation to the second-term of the right hand side in (2.C.35) yields

$$\frac{1}{Y}\left(\left(\frac{P_{H,t}}{P_t}\right)\varsigma\big(\Psi_{F,t}S_t\big)^{\eta^*}Y^*_t - \tilde{q}_t\alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta}C_t\right) = \alpha\big(p_{H,t} - p_t + \eta^*(\psi_{F,t}+s_t) + y^*_t - q_t + \eta(p_{F,t}-p_t) - c_t\big) \qquad (2.C.37)$$

Inserting (2.C.36) and (2.C.37) into (2.C.35) returns

$$a_t = (1/\beta)a_{t-1} + \alpha\big(p_{H,t} - p_t + \eta^*(\psi_{F,t}+s_t) + y^*_t - q_t + \eta(p_{F,t}-p_t) - c_t\big) \quad (2.C.38)$$

Combining (2.C.38) with (2.C.19) and definitions $p_{H,t} - p_t = -\alpha s_t$, $p_{F,t} - p_t = (1-\alpha)s_t$ and $q_t = \psi_{F,t} + (1-\alpha)s_t$ yield the equation (2.A.9) as follows:

$$a_t = (1/\beta)a_{t-1} - \alpha\big(\psi_{F,t}+s_t\big) + y_t - c_t.$$

[54] In the linearization, $A_t = A + a_t$ is assumed. Combining the Euler equation and uncovered interest rate parity condition in the steady state gives $1/\beta = (1-i^*)/\Pi^*$.

Chapter 3

News shocks and unemployment in an estimated small open economy DSGE model

Abstract

This chapter examines the importance of news shocks in a small open economy DSGE model for analysing business cycle properties of macroeconomic aggregates, including labour market variables. In doing so, the chapter augments a standard small open economy DSGE model (e.g., Justiniano and Preston 2010a) to include the theory of involuntary unemployment proposed by Galí 2011(a) and endogenous preference shifter used by Galí et al. (2011). The model is also driven by both unanticipated and news shocks, and estimated using Bayesian methods with data for Australia and the US. The results show that the estimated model is able to qualitatively replicate the existing results of the VAR analyses on news-driven business cycles, and news shocks have been the main drivers of the Australian business cycle in the inflation-targeting period.

Keywords: News shocks, Business cycles, Open economy macroeconomics, unemployment, New Keynesian DSGE model, Bayesian estimation.

JEL classification: C11, C52, D58, E24, E32, F41

3.1 Introduction

The literature on business cycles emphasizes the importance of news shocks[55] in driving macroeconomic fluctuations. The news view of business cycles can be traced back to the early literature on macroeconomics (e.g., Pigou 1927 and Keynes 1936). According to the news-driven business cycle, macroeconomic fluctuations can be driven by optimistic expectations about a future economic activity that are not realized. In particular, news shocks change agents' expectations, influencing their current decisions on consumption, investment and labour supply, and hence lead to business cycles (Jaimovich and Rebelo 2009). For example, favourable news about future productivity (or demand) can set off a boom today as a result of the similar behaviour of many agents with optimistic expectations (e.g., increasing current consumption and investment). However, a realization of productivity (or demand) which is worse than anticipated can induce a bust without any actual changes in economic fundamentals (Barsky and Sims 2011, and Beaudry and Portier 2013). For the literature on business cycle, Coachrane (1994) has revived the news view of business cycle by addressing the necessity of models that explain business cycle fluctuations with news shocks. The news-driven business cycle has been empirically studied using two alternative approaches. First, Beaudry and Portier (2006), Beaudry et al. (2011), Barsky and Sims (2011) and Forni et al. (2011) have developed a reduced-form approach by proposing vector autoregression (VAR) methodologies to assess the role of news shocks in driving business cycle fluctuations. Second, a number of papers (e.g., Davis 2007, Jaimovich and Rebelo 2008, 2009, Christiano et al. 2008, 2010a, Fujiwara et al. 2011, Schmitt-Grohé and Uribe 2012, Milani and Treadwell 2012, Khan and Tsoukalas 2012) employ a structural approach based on a fully specified DSGE model to evaluate the prominence of news shocks in explaining business cycle fluctuations.

More recently, the literature on the news-driven business cycle has focused on the role of news shocks in driving national and international business cycle fluctuations using DSGE models with some extensions, such as nominal and real rigidities, financial frictions, housing and asset markets (e.g., Krusell and McKay 2010, Lorenzoni 2011 and Beaundry and Portier 2013 for a recent survey). Though recent papers have considered extensions to an international setting, the papers on the international business cycle have focused

[55] In this chapter, the word 'news' refers to exogenous changes in the information sets that agents use to form their perceptions about future realization of economic fundamentals.

exclusively on the effects of news shocks about technology using calibrated two-country DSGE models (e.g., Jaimovich and Rebelo 2008, Matsumoto et al. 2008, Den Haan and Lozej 2011, Beaudry et al. 2011 and Kosaka 2013). Moreover, a very limited number of papers (e.g., Den Haan and Kaltenbrunner 2009, Theodoridis and Zanetti 2014) have examined the effect of news shocks on labour market variables. On the news horizon, the previous papers (e.g., Schmitt-Grohé and Uribe 2012, Khan and Tsoukalas 2012 and Gomes et al. 2013), simultaneously allowing several types of news shocks, have selected the same news horizon(s) for each type of structural shocks.

The existing literature raises some interesting questions: (i) does the presence of news shocks (i.e., several types of shocks announced in different horizons) improve the overall fit of an estimated small open economy DSGE model? (ii) do news shocks drive domestic and international business cycles? and (iii) how important are news shocks as sources of labour market and macroeconomic fluctuations? By addressing these questions, this chapter contributes to the growing literature on the news-driven business cycle in distinct ways. First, the chapter assesses the importance of news shocks in analysing business cycle properties of macroeconomic aggregates, including labour market variables, using an estimated New Keynesian DSGE model in a two-country setting (i.e., Australia and the US). Second, the chapter allows different news horizon(s) for each structural shock based on the best-fitting news horizon approach proposed by Fujiwara et al. (2011). Finally, it is one of the first attempts to study the effect of news shocks on real exchange rate dynamics and to examine the role of news about future country risk premium in explaining business cycle fluctuations.

To address these questions, the model developed in the chapter 2 is further augmented in three dimensions. First, following a series of papers (Galí 2011a,b and Galí et al. 2011), involuntary unemployment is introduced in the model[56]. In recent years, a number of papers (e.g., Gertler et al. 2008, Christoffel et al. 2009, Casares 2010, Christiano et al. 2010b, 2011 2013, Blanchard and Galí 2010, Galí 2011 a,b,c, and Galí et al. 2011) have focused on incorporating unemployment into New Keynesian DSGE models. In most of the papers, unemployment is introduced based on the labour market search and matching framework of Mortensen and Pissaridis (1994). However, this chapter relies on the theory

[56] Unemployment is a central focus of policy debate and a key macro indicator. However, as highlighted by Galí and Gertler (2007), New Keynesian DSGE models have neglected the problem of unemployment for long time.

of involuntary unemployment proposed by Galí (2011a, b)[57], which is an alternative to the search and skills mismatch model of the labour market. Though Galí's approach assumes no structural unemployment in the model, it helps to overcome the problem of incomplete identification between labour supply and wage markup shocks, pointed out by Chari et al. (2009), through including the unemployment rate as an observable variable in the empirical analysis. Differentiating the wage markup shock from the labour supply shock is important because these two sources of fluctuations have very different policy implications. The Galí's approach to introduce unemployment is more appropriate for economies where labour unions are influential in setting the wage rate since the modelling approach assumes that higher union power produces higher unemployment rates. Though Christiano (2011) depicts some drawbacks to the approach, a couple of papers (e.g., Galí et al. 2011 and Grabek and Kłos 2013) have shown that the estimated model embedding Galí's (2011a,b) approach offers a better understanding of labour market fluctuations.

Second, an endogenous preference shifter presented by Galí et al. (2011) is included in the model to mitigate the strong wealth effects of shocks on the labour supply. Beaudry and Portier (2006) provide the VAR-based evidence supporting the 'Pigou cycle' in which major macroeconomic aggregates (e.g., output, consumption, investment and employment) move up and down together in response to news shocks. Standard real business cycle (RBC) models fail to generate the business cycle co-movements in response to good news about future productivity (e.g., Coachrane 1994, Danthine et al. 1998, Beudry and Portier 2007, Jaimovich and Rebelo 2008 and Christiano et al. 2008). In both closed and open economy RBC models, this failure is mainly attributed to the strong wealth effect of news on the labour supply[58]. To prevent the counterfactual response of labour supply, Jaimovich and Rebelo (2008, 2009) originally propose a hybrid utility function with preference shifter, featuring a weak wealth effect on labour supply, which allows their RBC models to generate the aggregate co-movement in response to both unanticipated and news shocks. Moreover, based on their findings, Christiano et al. (2010b) suggest that the household utility function must be modified in ways that dampen wealth effects on labour supply when the theory of involuntary unemployment proposed by Galí (2011a) is integrated into the New Keynesian DSGE

[57] In Galí's approach, unemployment is an equilibrium phenomenon and a consequence of worker's market power (i.e. wage markup), resulting from imperfect substitution between different types of labour. Therefore, unemployment fluctuations are due to the slow adjustment of wages and shocks to wage markup.
[58] In standard RBC models, good news about future productivity makes agents wealthier, and hence agents increase their consumption and reduce their labour supply. This decline in labour supply may lead to fall in output. As a result, good news about tomorrow can cause a recession today (Jaimovich and Rebelo 2009).

model[59]. Galí et al. (2011), using related but not identical reference the specifications to Jaimovich and Rebelo (2008, 2009), have shown that the presence of an endogenous preference shifter improves the performance of their New Keynesian DSGE model in matching with the VAR-based results on responses of labour market variables to an unanticipated monetary policy shock.

Third, each of structural shocks in the model is allowed to feature both news and unanticipated components. In the model, business cycles in a small open economy are driven by thirteen structural shocks, namely three demand shocks (preference, risk premium and monetary policy shocks), two supply shocks (technology and price markup shocks), two labour market shocks (labour supply and wage makup shocks) and six foreign shocks (the US preference, monetary policy, technology, price markup, labour supply and wage makup shocks). Following results of the VAR analyses[60], most of the previous studies based on RBC and DSGE models (e.g., Jaimovich and Rebelo 2008, 2009, Christiano et al. 2008, 2010a and Fujiwara et al. 2011) have focused exclusively on news shock about technology. However, various studies have moved away from news about only technology and allow for incorporating various news shocks into the model. For instance, a number of papers (e.g., Milani and Treadwell 2012 and Gomes et al. 2013) consider news shocks on monetary policy, and find that the news shock improves the model fit and plays a larger role in business cycle fluctuations relative to unanticipated policy shocks. Recent papers (e.g., Badarinza and Margaritov 2011, Khan and Tsoukalas 2012, Schmitt-Grohé and Uribe 2012) have examined the role of news about several supply, demand and labour markets shocks in explaining business cycle fluctuations. Though news about future country risk premium has not been considered in the literature, existing papers (e.g., Nimark 2009, Liu 2010 and Leu 2010) find that the unanticipated risk premium shock is an important source of business cycle fluctuations in a small open economy (i.e., Australia).

[59] Recent studies (e.g., Christiano et al. 2010b and Christiano 2011) have argued that with the standard preference (e.g., used by Smets and Wouters 2007), wealth effects on labour supply are excessively strong, leading to counterfactual implications for unemployment and labour force in response to unanticipated monetary policy and technology shocks.

[60] The VAR-based results (e.g., Beaudary and Porter 2006 and Beaudry and Lucke 2010) have shown that news about future technology lead to positive co-movement among macroeconomic aggregates on impact, and explain a substantial portion of the variances in aggregate variables at business cycle frequencies. The original studies in the literature mainly focus on features that help the model to replicate the VAR-based results.

The model is estimated using Bayesian methods with data for Australia and the US over the period 1993:Q1-2013:Q4, covering the inflation-targeting period in Australia and the recent global financial crisis (GFC). The result reveals the importance of news shocks in driving the Australian business cycle over the inflation-targeting period. News shocks account for exceeding half of the variances in Australian output, employment and interest rate. Moreover, the estimated model is able to qualitatively replicate the existing results of the VAR analyses on news-driven business cycles in small open economies (e.g., Kosaka 2013 and Kamber et al. 2014). For instance, news about future technology, country risk premium and preference in Australia can lead to domestic business cycle fluctuations, whereas the US news shocks on technology and preference do propagate to Australia, generating international business cycles. As found by Theodoridis and Zanetti (2014), a positive technology news shock leads to a counter-cyclical unemployment rate and a rise in wages, and news shocks account for exceeding one-third of variance in unemployment rate in both countries. In addition, the real exchange rate dynamics play an important role in the transmission of news shocks in the sense that one-third of variance in the real exchange rate is attributable to news shocks.

The remainder of the chapter is structured as follows. Section 3.2 describes the model, and explains how to introduce news shocks into the model. Section 3.3 presents the model solution and estimation, consisting of the data and priors for parameters of the model. Section 3.4 contains the discussion on the importance of news shocks as sources of business cycle fluctuations in the US and Australia. Finally, section 3.5 concludes the chapter with a review of results and provides directions for future research.

3.2 The model

3.2.1 The basic structure of the model

The basic structure of the model is built on the model built in Chapter 2 that is in turn based on the J-P model[61]. The basic structure slightly deviates from the J-P model in the sense that it also includes the cost channel of monetary policy and the uncovered interest

[61] The J-P model is based on Monacelli (2005) and Galí and Monacelli (2005), and allows for incomplete asset markets, habit formation and indexation of prices to past inflation. The J-P model assumes (i) fully flexible wages and perfect competition in labour markets, (ii) a standard household utility function, a preference of the class discussed by King et al. (1988), and (iii) shocks are unanticipated by agents until they are realized and, hence, observed. Justiniano and Preston (2010b) incorporate staggered wage setting following Erceg et al. (2000) into the J-P model, however they do not consider unemployment and labour force.

rate parity (UIP) modification. For instance, as suggested by Adolfson et al. (2008) and Adolfson et al. (2013), the UIP condition is modified by allowing for a negative correlation between the country risk premium and the expected depreciation in the nominal exchange rate. As discussed by Christiano et al. (2011), the cost channel of monetary policy is incorporated by assuming that producer firms borrow from the financial institutions to pay for inputs (i.e., wage bills), whereas the retail firms borrow their imported goods from foreign sellers at the foreign currency interest rate. As a result, CPI inflation depends on domestic and the foreign interest rates. Moreover, in the model, the foreign economy is specified as the closed economy version of the open economy model following Monacelli (2005) and Justiniano and Preston (2010b).

The model is augmented to introduce an endogenous preference shifter, some imperfections in the labour market and news shocks.

3.2.2 Introducing reference shifter and involuntary unemployment

Following Galí (2011a)[62] and Galí et al. (2011), this section introduces (i) an endogenous reference shifter and a variant of the staggered wage setting, originally developed by Erceg et al. (2000), and (ii) involuntary unemployment into the model. The utility function with preference shifter employed by Galí et al. (2011) does not change the main features of the model, and the preference allows us to parameterize the strength of short-run wealth effects on labour supply. The Galí's approach on introducing involuntary unemployment into New Keynesian DSGE model allows us to examine the effects of shocks on labour market fluctuations. The approach assumes that labour is indivisible, with all variations in hired labour input taking place at the extensive margin[63]. The assumption leads to a notion of unemployment consistent with its formal definition. In what follows, new features introduced in the model are explained in a detail. A derivation of the optimization problem for workers unions and log-linear approximations of main equations are shown in Appendix 3.C.

[62] The paper provides a re-interpretation of the New Keynesian model in which variations in the number of hours worked by the representative household are interpreted as variations in the number of people working.
[63] The overall level of work can be decomposed into the number of individuals in work and the intensity of work supplied by those in work. This reflects the distinction between whether to work and how much to work at the individual level and is referred to, respectively, as the extensive and intensive margin of labour supply (Blundell et al. 2011).

3.2.2.1 Staggered wage setting and endogenous reference shifter

3.2.2.1.1 Household's utility function with reference shifter

The Galí's approach considers a representative household, having a large number of members, with a continuum of members represented by the unit square and indexed by a pair $(k, j) \in [0,1] \times [0,1]$, where k indicates the specific labour service (specialization) of a member and j determines a member's disutility from work. The disutility is given by $\tilde{\varepsilon}_{n,t} j^{\varphi}$ if the member is employed and zero otherwise, where the stochastic term $\tilde{\varepsilon}_{n,t} > 0$ denotes a labour supply shock, and $\varphi \geq 0$ denotes the elasticity of marginal disutility of work ($1/\varphi$ is sometimes called Frisch elasticity of labour). In addition, as discussed by Merz (1995), full risk sharing of consumption among household members is assumed, implying $C_t(k, j) = C_t$ for all $(k, j) \in [0,1] \times [0,1]$ and t. This assumption implies that members (i.e., workers) of the household enjoy perfect consumption insurance. Employed workers send their wages directly to the household in exchange for consumption insurance. The representative household's utility function with endogenous preference shifter Θ_t (as the integral over its members' utilities) is given by[64]

$$E_0 \sum_{t=0}^{\infty} \beta^t U\big(C_t, N_t(k), \tilde{\varepsilon}_{g,t}, \tilde{\varepsilon}_{l,t}, \Theta_t\big) \equiv E_0 \sum_{t=0}^{\infty} \beta^t \, \tilde{\varepsilon}_{g,t} \left[\frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \Theta_t \tilde{\varepsilon}_{n,t} \int_0^1 \int_0^{N_t(k)} j^{\varphi} \, dj dk\right] = E_0 \sum_{t=0}^{\infty} \beta^t \, \tilde{\varepsilon}_{g,t} \left[\frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \Theta_t \tilde{\varepsilon}_{n,t} \int_0^1 \frac{N_t(k)^{1+\varphi}}{1+\varphi} dk\right]$$

where C_t indicates household consumption; $H_t \equiv hC_{t-1}$, with $h \in [0,1]$ implies external habit formation term taken as exogenously by the household; $N_t(k) \in [0,1]$ denotes the fraction of members specialized in type k labour who are employed in period t; σ indicates the elasticity of intertemporal substitution; and $\tilde{\varepsilon}_{g,t}$ and $\tilde{\varepsilon}_{n,t}$ denote preference and labour supply shocks, respectively. As suggested by Galí et al. (2011), the endogenous preference shifter (Θ_t) is defined as follows:

$$\Theta_t \equiv Z_t U_{c,t}, \; Z_t = Z_{t-1}^{1-\vartheta_z} U_{c,t}^{-\vartheta_z}$$

where $U_{c,t} = \tilde{\varepsilon}_{g,t}(C_t - hC_{t-1})^{-\sigma}$ denotes the marginal utility of consumption. The reference specification indicates a 'consumption externality' on individual labour supply in the sense that during an aggregate consumption boom (i.e., $\tilde{\varepsilon}_{g,t}(C_t - hC_{t-1})^{\sigma} > Z_t$),

[64] Utility of the household, supplying $N_t(k)$ labour, is determined by the sum of utilities of employed workers and non-employed workers: $\int_0^1 \left\{\int_0^{N_t(k)} f(j) \, \tilde{\varepsilon}_{g,t}[U(C_t) - \Theta_t \tilde{\varepsilon}_{n,t} j^{\varphi}] dj + \int_{N_t(k)}^1 f(j) \, \tilde{\varepsilon}_{g,t} U(C_t) \, dj\right\} dk = \int_0^1 \left\{\tilde{\varepsilon}_{g,t}\left(N_t(k) U(C_t) - \Theta_t \tilde{\varepsilon}_{n,t} \int_0^{N_t(k)} j^{\varphi} dj\right) + (1 - N_t(k)) \tilde{\varepsilon}_{g,t} U(C_t)\right\} dk = \int_0^1 \tilde{\varepsilon}_{g,t} \left\{U(C_t) - \Theta_t \tilde{\varepsilon}_{n,t} \frac{N_t(k)^{1+\varphi}}{1+\varphi}\right\} dk = \tilde{\varepsilon}_{g,t} \left\{U(C_t) - \Theta_t \tilde{\varepsilon}_{n,t} \int_0^1 \frac{N_t(k)^{1+\varphi}}{1+\varphi} dk\right\}$, where $U(C_t) = \frac{(C_t - H_t)^{1-\sigma}}{1-\sigma}$, $f(j)$ denotes 'number' of workers with disutility of working for each k, $f(j) = 1$ for all $j \in (0,1)$.

individual (as well as household level) marginal disutility from work goes down at any given level of employment. The importance of the shifter in generating the empirical response of labour supply to exogenous shocks depends on the size of parameter, $\vartheta_z \in (0,1]$. When $\vartheta_z = 1$, the obtained preference is attributed to the class discussed by King et al. (1988), featuring strong short-run wealth effects on labour supply. When $\vartheta_z \longrightarrow 0$, the preference will be closer to that discussed by Greenwood et al. (1988), which features no short-run wealth effects on labour supply.

Under the preference, the marginal rate of substitution (MRS) between consumption and employment for type k workers in period t is given by

$$MRS_t(k) \equiv -\frac{U_{n(k),t}}{U_{c,t}} = \frac{\tilde{\varepsilon}_{n,t}\Theta_t N_t(k)^{\varphi}}{U_{c,t}} = \tilde{\varepsilon}_{n,t} Z_t N_t(k)^{\varphi} \quad (3.1)$$

Using lower-case letters to denote log deviation from steady state values (i.e., $x_t \equiv log(X_t/X)$), the average MRS in terms of log deviation from its steady state, $mrs_t \equiv \int_0^1 mrs_t(k)dk$ can be derived by integrating over all labour types

$$mrs_t = z_t + \varphi n_t + \varepsilon_{n,t} \quad (3.2)$$

where $n_t \equiv \int_0^1 n_t(k)dk$ implies aggregate employment and $\varepsilon_{n,t} \equiv \log(\tilde{\varepsilon}_{n,t}/\tilde{\varepsilon}_n)$.

3.2.2.1.2 Domestic firms' demand for labour

A continuum of domestic firms is assumed, indexed by $i \in [0,1]$, each of which produces a differentiated good i with a technology represented by the production function

$$y_{H,t}(i) = \tilde{\varepsilon}_{a,t} N_t(i) \quad (3.3)$$

where $y_{H,t}(i)$ is the output of good i, $\tilde{\varepsilon}_{a,t}$ denotes a technology shock common to all firms, and $N_t(i)$ is an index of labour input used by firm i and given by the Dixit-Stiglitz aggregator

$$N_t(i) = \left[\int_0^1 N_t(i,k)^{\frac{\zeta_{\omega,t}-1}{\zeta_{\omega,t}}} dk\right]^{\frac{\zeta_{\omega,t}}{\zeta_{\omega,t}-1}}$$

where $N_t(i,k)$ is firm i's demand for each type of labour k in period t, determined from the labour cost minimization of firm i, $min_{\{N_t(i,k)\}} \int_0^1 W_t(k)\, N_t(i,k)$, subject to the above labour demand. The solution of the minimization results the demand for labour type k of the form

$$N_t(i,k) = \left(\frac{W_t\,(k)}{W_t}\right)^{-\zeta_{\omega,t}} N_t(i) \tag{3.4}$$

for all $i, k \in [0,1]$, where W_t is an aggregate wage index and given by

$$W_t = \left[\int_0^1 W_t(k)^{1-\zeta_{\omega,t}} dk\right]^{\frac{1}{1-\zeta_{\omega,t}}} \tag{3.5}$$

and $\zeta_{\omega,t}$ is the period t wage elasticity of the relevant labour demand, which varies exogenously over time, hence leading to changes in the worker's market power (i.e., the desired wage markup). Using the wage elasticity notation used by Smets and Wouters (2003), it can be written as $\zeta_{\omega,t} = \frac{1+\lambda_{\omega,t}}{\lambda_{\omega,t}}$, where $\lambda_{\omega,t} = \lambda_\omega + \varepsilon_{\omega,t} = \frac{1}{\zeta_\omega - 1} + \varepsilon_{\omega,t}$. Here $\lambda_{\omega,t}$ is a stochastic parameter that determines the time-varying markup in labour market, ζ_ω is non-stochastic component of wage elasticity, and shocks to this parameter will be interpreted as a wage markup shock, $\varepsilon_{\omega,t}$, to the wage inflation equation.

3.2.2.1.3 Staggered wage setting

Workers' unions, setting nominal wages, act in an uncoordinated way, and each union represents workers who specialize in a given type of labour. As discussed by Erceg et al. (2000), Calvo (1983) framework is also considered in the wage setting. Since the labour is heterogeneous (i.e., imperfect substitutes), unions representing each type of labour have monopolistic power to set nominal wages for the given type of labour. The unions face Calvo-style wage setting, having the opportunity to re-optimize their wages with probability, $1 - \theta_\omega$, each period, where $0 < \theta_\omega < 1$. The unions, not re-optimizing, adjust their wages according to the indexation rule given by

$$W_t(k) = W_{t-1}(k)\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\delta_\omega}$$

where $0 \leq \delta_\omega \leq 1$ indicates the degree of indexation to the previous period's inflation rate. The model only considers a symmetric equilibrium in which all unions behave identically, and hence the index k is omitted in what follows. All unions, re-optimizing their wage, choose an identical wage, W'_t, since they face the same problem. Under the Calvo-style wage setting assumptions, the aggregate wage index in equation (3.5) can be rewritten as

$$W_t = \left[(1-\theta_\omega){W'_t}^{1-\zeta_{\omega,t}} + \theta_\omega\left(W_{t-1}\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\delta_\omega}\right)^{1-\zeta_{\omega,t}}\right]^{\frac{1}{1-\zeta_{\omega,t}}} \tag{3.6}$$

When nominal wages are set, the firms determine their demand for the given type of labour, and households send their members with the lowest work disutility. Regarding equation (3.4), the labour demand in period $t+\tau$ for workers whose wage was last re-optimized in period t by W'_t is as follows:

$$N_{t+\tau|t} = \left(\frac{W'_t}{W_{t+\tau}}\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega}\right)^{-\zeta_{\omega,t}} N_{t+\tau} \quad (3.7)$$

where $N_{t+\tau} \equiv \int_0^1 N_{t+\tau}(i)di$ denotes aggregate employment in period $t+\tau$. Similar to Woodford (2003), it is assumed that the unions, resetting the optimal wage in period t, maximize their perspective households' utility generated from the wage income after taking into account the disutility of labour and the probability of not being able to re-set wages in the future periods $t+\tau$. Thus the unions choose W'_t by maximizing the utility

$$E_t \sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau \left[\Lambda_{t+\tau} W'_t \left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega} N_{t+\tau|t} - \Theta_{t+\tau}\tilde{\varepsilon}_{n,t+\tau}\frac{N_{t+\tau|t}^{1+\varphi}}{1+\varphi}\right] \quad (3.8)$$

subject to a sequence labour demand given by equation (3.7)[65]. $\Lambda_{t+\tau}$ denotes marginal utility of income[66]. The first-order condition associated with the optimization is

$$E_t \sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau \left[\Lambda_{t+\tau} N_{t+\tau|t}\left(W'_t\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega} - \mathcal{M}^n_{\omega,t+\tau} P_{t+\tau} MRS_{t+\tau|t}\right)\right] = 0$$

where $MRS_{t+\tau|t} \equiv -\frac{U_{n,t+\tau|t}}{U_{c,t+\tau}} = \tilde{\varepsilon}_{n,t+\tau} Z_{t+\tau} N^{\varphi}_{t+\tau|t}$ denotes the MRS between consumption and employment in period $t+\tau$, and $\mathcal{M}^n_{\omega,t} \equiv \zeta_{\omega,t}/(\zeta_{\omega,t}-1) = 1+\lambda_{\omega,t}$ is natural (or desired) wage markup in period t. From this condition, the optimal wage in period t to be found as

$$W'_t = \frac{\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau E_t\left[\Lambda_{t+\tau} N_{t+\tau|t}\mathcal{M}^n_{\omega,t+\tau} P_{t+\tau} MRS_{t+\tau|t}\right]}{\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau E_t\left[\Lambda_{t+\tau} N_{t+\tau|t}(P_{t+\tau-1}/P_{t-1})^{\delta_\omega}\right]} \quad (3.9)$$

Log-linearizing (3.6) and (3.9) equations around a zero inflation steady state and combining the resulting expressions give the following equation for wage inflation, defined by $\pi^\omega_t = w_t - w_{t-1}$:

$$\pi^\omega_t - \delta_\omega \pi_{t-1} = \beta E_t(\pi^\omega_{t+1} - \delta_\omega \pi_t) - \varrho_\omega(\mu_{\omega,t} - \mu^n_{\omega,t}) \quad (3.10)$$

[65] Erceg et al. (2000) and Galí (2008, 2011a) employ slightly different optimization setting for the optimal wage. However, their combined first-order condition associated with the wage-setting is exactly same with the condition found from the presented setting.
[66] Households have the same marginal utility of income, $\Lambda_{t+\tau} = U_{c,t+\tau}/P_{t+\tau}$, where $U_{c,t+\tau}$ denotes the marginal utility of consumption (see Woodford 2003). This is derived from the household optimization.

with $\varrho_\omega \equiv \frac{(1-\theta_\omega)(1-\beta\theta_\omega)}{\theta_\omega(1+\varphi\zeta_\omega)}$, and

$$\mu_{\omega,t} \equiv (w_t - p_t) - mrs_t \tag{3.11}$$

which denotes average wage markup that is the difference between the average real wage and the average MRS, and $\mu_{\omega,t}^n \equiv \log\left(\mathcal{M}_{\omega,t}^n/\mathcal{M}_\omega^n\right) = \varepsilon_{\omega,t}$ is the (log) natural wage markup deviated from its steady state.

3.2.2.2 Introducing involuntary unemployment

Following the theory of involuntary unemployment proposed by Galí (2011a), unemployment, employment and labour force are explicitly introduced into the model. As discussed in section 3.2.2.1.1, the household member (k,j) has disutility of work, $\tilde{\varepsilon}_{n,t}\Theta_t j^\varphi$. Based on household welfare as a criterion, and taking as given labour market conditions, a member will work in period t if and only if the following condition is satisfied:

$$\Lambda_t W_t(k) = U_{c,t}\left(\frac{W_t(k)}{P_t}\right) \geq \tilde{\varepsilon}_{n,t}\Theta_t j^\varphi$$

From the above condition at the symmetric equilibrium and equation (3.1), the marginal supplier of type k labour (both employed and unemployed), denoted by $L_t(k)$, can be determined as[67]

$$\frac{W_t(k)}{P_t} = \tilde{\varepsilon}_{n,t} Z_t L_t(k)^\varphi \tag{3.12}$$

Log-linear approximation to equation (3.12) and integrating over k results in the labour supply equation

$$w_t - p_t = z_t + \varphi l_t + \varepsilon_{n,t} \tag{3.13}$$

where $l_t \equiv \int_0^1 l_t(k)dk$ can be interpreted as labour force, $w_t \equiv \int_0^1 w_t(k)dk$ is a log-linear approximation to the average wage index in equation (3.5), and $z_t = (1-\vartheta_z)\, z_{t-1} + \vartheta_z\left(\varepsilon_{g,t} + (\sigma/(1-h))(c_t - hc_{t-1})\right)$. If the preference shifter parameter takes the value closer to zero ($\vartheta_z \longrightarrow 0$), then changes in consumption (or welfare) will have a weak effect on the labour supply. Therefore, the model is able to generate the co-movement between employment, labour supply and output.

[67] Under the symmetric equilibrium, the condition can be derived from the following optimization: members who supply k type of labour, taking their wage as given, set labour supply, $L_t(k)$, by maximizing household's utility, $\max_{L_t(k)} \; E_t \sum_{\tau=0}^{\infty} \beta^\tau \left[\Lambda_{t+\tau} W_{t+\tau}(k) L_{t+\tau}(k) - \tilde{\varepsilon}_{l,t+\tau}\Theta_{t+\tau}\frac{L_{t+\tau}(k)^\varphi}{1+\varphi}\right]$.

As assumed by Casares (2010), unemployment is described as an excess supply of labour, thus the unemployment rate is defined as

$$u_t \equiv l_t - n_t \tag{3.14}$$

Equation (3.14) is an approximation to the conventional measure of unemployment rate, $(L_t - N_t)/L_t$, where L_t and N_t respectively denote the labour force and the number of workers who are employed.

Combining equation (3.14) with equations (3.13), (3.11) and (3.2), the relationship between the average markup and the unemployment rate can be found as follows:

$$u_t = \frac{\mu_{\omega,t}}{\varphi} \tag{3.15}$$

From equation (3.15), it is clear that unemployment is a consequence of a worker's market power (which is implied by a positive difference between the real average wage and its perfectly competitive level), and unemployment rate fluctuations emerge from the slow adjustment of wages. For example, positive unemployment implies that the union exploits its power to increase the wage rate, and the rise in wage leads to the fall in the number of employed workers. A graphical illustration of the relation (3.15) is shown by Galí (2011a) and its economic intuition is provided by Galí (2013).

From equations (3.10) and (3.15), the original wage Phillips curve equation can be derived as

$$\pi_t^{\omega} - \delta_{\omega}\pi_{t-1}^{p} = \beta E_t\left(\pi_{t+1}^{\omega} - \delta_{\omega}\pi_t^{p}\right) + \varrho_{\omega}\varphi u_t + \upsilon_t \tag{3.16}$$

where $\upsilon_t \equiv \varrho_{\omega}\mu_{\omega,t}^{n}$. Note that in contrast to the specification of the wage inflation equation (3.10)[68] and other related papers (e.g., Justiniano and Preston 2006, Smet and Wouters 2007), the error term, υ_t, in equation (3.16) captures exclusively shocks to the wage markup. Therefore, the wage Phillips curve, found by reformulating the wage equation in terms of observable unemployment rate, allows the model to overcome the identification problem pointed out by Chari at el. (2009).

3.2.3 The log-linearized model

The log-linearized equations of the estimated model are shown in Appendix 3.A. The remaining equations, not discussed in section 3.2.2, are similar to those shown in the J-P model. The domestic block is described by seventeen equations in the unknowns

[68] The error term in equation (10) is given by $\upsilon'_t \equiv \lambda_{\omega}\left(\mu_{\omega,t}^{n} + \varepsilon_{n,t}\right)$ which is influenced by both wage markup shocks and labour supply shocks. Thus the model with equation (10) is critiqued by Chari at el. (2009) due to the identification problem between labour supply and wage markup shocks.

$\{c_{t,}y_t, i_t, q_t, s_t, \pi_t, \pi_{H,t}, \pi_{F,t}, \ \pi_t^w, \omega_t, u_t, u_t^n, n_t, l_t, \psi_{F,t}, a_t, z_t\}$, while the foreign block is given by ten equations in the unknowns $\{\ y_t^*, \pi_t^*, i_t^*, \omega_t^*, \pi_t^{w^*}, u_t^*, u_t^{n*}, n_t^*, l_t^*, z_t^*\}$.

When combined with processes for the exogenous disturbances and the definitions $\Delta s_t = s_t - s_{t-1}$ and $\Delta q_t = q_t - q_{t-1}$, these relations constitute a linear rational expectations model driven by the fourteen shocks: $\varepsilon_{x,t} = \{\varepsilon_{g,t}, \varepsilon_{a,t}, \varepsilon_{cp^H,t}, \varepsilon_{cp^F,t}, \varepsilon_{n,t}, \varepsilon_{\omega,t}, \varepsilon_{rp,t}, \varepsilon_{i,t}, \varepsilon_{g^*,t}, \varepsilon_{a^*,t}, \varepsilon_{cp^*,t}, \varepsilon_{n^*,t}, \varepsilon_{\omega^*,t}, \varepsilon_{i^*,t}\}$. All structural disturbances are assumed to follow an independent AR(1) process

$$\varepsilon_{x,t} = \rho_x \varepsilon_{x,t-1} + \epsilon_{x,t} \tag{3.17}$$

with $\sigma_x^2 = E[\epsilon_{x,t}\epsilon'_{x,t}]$[69].

3.2.4 Introducing news shocks

3.2.4.1 Expectations with news

Introducing news changes the information structure in the model. Agents can now receive news in period t about future shocks that may materialize only in h periods ahead. Though agents still form rational expectations, their information set is enlarged to include news about future shocks in fundamentals. News shocks are introduced into the model as discussed in previous studies (e.g., Davis 2007, Fujiwara et al. 2011 and Schmitt-Grohé and Uribe 2012). To formulate the information structure, each of the fourteen innovations, $\epsilon_{x,t}$, include both unanticipated component, $\epsilon_t^{x,0}$, and news component, $\epsilon_t^{x,news}$. To allow for the variation in the timing of the arrival of the news, $\epsilon_t^{x,news}$ can be further decomposed in to a summation of news shocks. Therefore $\epsilon_{x,t}$ can be rewritten as

$$\epsilon_{x,t} = \epsilon_t^{x,0} + \epsilon_t^{x,news} = \epsilon_t^{x,0} + \sum_{h=1}^{H} \epsilon_{t-h}^{x,h}$$

where H denotes the longest horizon over that news shocks are anticipated by agents, and $\epsilon_{t-h}^{x,h}$ denotes news about future changes in x fundamentals, known to agents at period $t-h$, however, may materialize only h periods ahead, $0 < h \leq H$. Hence, $\epsilon_{t-h}^{x,h}$ is also referred as h-period ahead news shock in x fundamental. For identification purposes, $\epsilon_{t-h}^{x,h} \sim i.i.d.\ \ N(0, \sigma_{x,h}^2)$, for $h = 0,1, \dots, H$ is assumed. This assumption implies that $\epsilon_{t-h}^{x,h}$ is uncorrelated across time (i.e., zero correlation between contemporaneous and

[69] All $\tilde{\varepsilon}_x$ shocks, except $\tilde{\varepsilon}_{rp}$ have unit means, while all ε_x disturbances have zero means.

news shocks) and across anticipated horizons (i.e., zero cross-correlation among news shocks of different horizons). Thus the mean and variance of the error term, $\epsilon_{x,t}$, is found to be $E(\epsilon_{x,t})$=0 and $\sigma_x^2 = \sum_{h=0}^{H} \sigma_{x,h}^2$, respectively. As an example, let us consider the simple case of $H = 3$. Then the law of motion of $\varepsilon_{x,t}$ in equation (3.17) can be written as

$$\varepsilon_{x,t} = \rho_x \varepsilon_{x,t-1} + \epsilon_t^{x,0} + \epsilon_{t-1}^{x,1} + \epsilon_{t-2}^{x,2} + \epsilon_{t-3}^{x,3} \tag{3.18}$$

In this case, agents have a larger information set than information containing current and past realization of $\epsilon_{x,t}$. For instance, agents now observe current and past values of innovations $\epsilon_t^{x,0}$, $\epsilon_{t-1}^{x,1}$, $\epsilon_{t-2}^{x,2}$ and $\epsilon_{t-3}^{x,3}$ in period t. Moreover, news shocks have an impact on agents' expectations about the future.

Since agents are forward-looking, they use the information contained in the realizations of the various news shocks, $\epsilon_t^{x,h}$, in their current decisions about consumption, investment, labour supply and asset holdings. Schmitt-Grohé and Uribe (2012)[70] argue that this forward-looking behaviour of agents allows an econometrician to identify the horizon-specific news shocks, $\epsilon_t^{x,h}$, even though the econometrician cannot directly observe the shocks. Particularly, in Bayesian or maximum likelihood estimation, news shocks are identified through their effects on future expectations of structural disturbances, which influence agents' economic decisions (Milani and Rajbhandari 2012). For example, assuming again $H = 3$, agents' expectation about disturbances, $\varepsilon_{z,t+m}$, for $m \geq 4$ at the period t can be written as

$$E_t\varepsilon_{x,t+m} = \rho_x E_t \varepsilon_{x,t+m-1} = \rho_x^{m+1}\varepsilon_{x,t-1} + \rho_x^m\left(\epsilon_{t-1}^{x,1} + \epsilon_{t-2}^{x,2} + \epsilon_{t-3}^{x,3}\right) + \rho_x^{m-1}\left(\epsilon_t^{x,1} + \epsilon_{t-1}^{x,2} + \epsilon_{t-2}^{x,3}\right) + \rho_x^{m-2}\left(\epsilon_t^{x,2} + \epsilon_{t-1}^{x,3}\right) + \rho_x^{m-3}\epsilon_t^{x,3}$$

The relation implies that agents' expectations are influenced by the information set $\{\varepsilon_{x,t-1}, \epsilon_{t-1}^{x,1}\epsilon_t^{x,1}, \epsilon_{t-2}^{x,2}, \epsilon_{t-1}^{x,2}, \epsilon_t^{x,2}, \epsilon_{t-3}^{x,3}, \epsilon_{t-2}^{x,3}, \epsilon_{t-1}^{x,3}, \epsilon_t^{x,3}\}$, consisting both current and past news. Addition of the information set (i.e., news shocks) expands the state space system of the model. The law of motion of $\varepsilon_{x,t}$ can be added in the state-space representation as follows[71]:

[70] They illustrate how to identify the standard deviation of the unanticipated and news shocks using full-information, and the likelihood-based (i.e., Bayesian and Maximum Likelihood) econometric approach, and suggest that the identification of the standard deviation is possible when there are fewer observables than shocks.

[71] This recursive representation involves only as many exogenous state variables as the longest horizons, H, which are much fewer than those in an alternative representation (i.e., canonical form of $\varepsilon_{x,t}$ process)

$$\tilde{x}_t = M\tilde{x}_{t-1} + G\tilde{\epsilon}_t^x \qquad (19)$$

where $\tilde{x}_t = \left(\varepsilon_{x,t}, u_t^{x,1}, u_t^{x,2}, u_t^{x,3}\right)'$, $M = \begin{bmatrix} \rho_x & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix}$, $G = \begin{bmatrix} \sigma_{x,0} & 0 & 0 & 0 \\ 0 & \sigma_{x,1} & 0 & 0 \\ 0 & 0 & \sigma_{x,2} & 0 \\ 0 & 0 & 0 & \sigma_{x,3} \end{bmatrix}$ and $\tilde{\epsilon}_t^x = \left(\tilde{\epsilon}_t^{x,0}, \tilde{\epsilon}_t^{x,1}, \tilde{\epsilon}_t^{x,2}, \tilde{\epsilon}_t^{x,3}\right)'$. The variables, $u_t^{x,1}, u_t^{x,2}, u_t^{x,3}$ are auxiliary variables. The vector of innovations $\tilde{\epsilon}_t^x$ is normal *i.i.d.* with zero mean and variance-matrix equal to the identity matrix $\left(\tilde{\epsilon}_t^x \sim i.i.d. N(0, \mathrm{I})\right)$. The coefficients, $\{\sigma_{x,0}, \sigma_{x,1}, \sigma_{x,2}, \sigma_{x,3}\}$ respectively denote the standard deviations of the unanticipated shock and one, two and three periods ahead news shocks. In the estimation procedure, both unanticipated and news shocks in the state-space presentation are considered as unobserved and the best estimates of how they evolve over the sample are obtained using the Kalman filter. A main interest here is to estimate the nonzero elements of G, given by the standard deviations, $\sigma_{x,0}$, $\sigma_{x,1}$, $\sigma_{x,2}$ and $\sigma_{x,3}$.

In this simple example, $H = 3$ is considered. However, an important decision in the estimation is the choice of the news horizon, h[72]. In Section 3.3, the best-fitting news horizon for each type of x is searched using the approach proposed by Fujiwara et al. (2011).

3.2.4.2 Revisions in agents' expectations and business cycle

As discussed by Schmitt-Grohé and Uribe (2012), the structural approach to identify news shocks provides the possibility of accommodating revisions in news. News about a future economic activity can be fully realized or it can fail to materialize, leading to revisions in expectations. The upward or downward revisions in agents' expectations can be sources of business cycle fluctuations. Let us consider revisions of the news in period t about productivity improvements, which will take place in period $t + 5$, $\epsilon_t^{a,5}$. In case of $h = \{1,5\}$, obtained in Section 3.3, this news is subject to two revisions. Suppose, for example, that the realization of $\epsilon_t^{a,5}$ is positive. This news builds up optimistic expectations about the future, thereby leading the economy into a boom today. The first revision occurs in

commonly used in the literature (Schmitt-Grohé and Uribe 2012). This is the matrix from of the following representation: $\varepsilon_{x,t} = \rho_x \varepsilon_{x,t-1} + \tilde{\epsilon}_t^{x,0} + u_{t-1}^{x,1}$, $u_t^{x,1} = \tilde{\epsilon}_t^{x,1} + u_{t-1}^{x,2}$, $u_t^{x,2} = \tilde{\epsilon}_t^{x,2} + u_{t-1}^{x,3}$, and $u_t^{x,3} = \tilde{\epsilon}_t^{x,3}$.

[72] Schmitt-Grohé and Uribe (2012) and Khan and Tsoukalas 2012 directly choose $h = \{4,8\}$ in their specifications. However, a number of papers (e.g., Fujiwara et al. 2011and Milani and Treadwell 2012) use an approach that selects the 'best-fitting' horizons from a wide set of horizon combinations in terms of model fit.

period $t+4$, and suppose that the realization of $\epsilon_{t+4}^{a,1}$ is negative. This is equivalent to the news that the productivity improvement announced in period t will not materialize as expected. This news causes a downward revision in agents' expectations, and thereby may induce a bust without any changes in economic fundamentals. The second revision of the news of period t takes place in period $t+5$. Suppose that the realization of $\epsilon_{t+5}^{a,0}$ is negative and offsets the earlier two news shocks, $\epsilon_t^{a,5}+\epsilon_{t+4}^{a,1}$. In this circumstance, agents realize that the former optimistic outlook for productivity did not turn out at all. At this point, the economy may experience a double dip recession, even though there are no changes in observed economic fundamentals. Therefore, DSGE models with news shocks are attractive in explaining business cycles and recessions[73].

3.3 The model solution, data and estimation

3.3.1 The model solution

The model consists of log-linear equations shown in Appendix 3.A, and the exogenous driven forces presented in equation (3.19). Using standard methods for solving the linear rational expectations model (e.g., Sims 2002), the model can be written in the following state-space form[74] :

$$\xi_t = F(\theta)\xi_{t-1} + G(\theta)\epsilon_t, \quad \epsilon_t \sim NID(0,I) \tag{3.20}$$

$$Y_t = H(\theta)\xi_t \tag{3.21}$$

where ξ_t denotes the vector of state variables, consisting the model endogenous variables $\{c_{t,}y_t, i_t, q_t, s_t, \pi_t, \pi_{H,t}, \pi_{F,t}, \pi_t^{\omega}, \omega_t, u_t, u_t^n, n_t, l_t, \psi_{F,t}, a_t, y_t^*, \pi_t^*, i_t^*, \omega_t^*, \pi_t^{\omega*}, u_t^*, u_t^{n*}, n_t^*, l_t^*\}$, expectations at t $\{c_{t+1,}q_{t+1}, \pi_{t+1}, \pi_{H,t+1}, \pi_{F,t+1}, \pi_{t+1}^{w}, y_{t+1}^*, \pi_{t+1}^*, \pi_t^{w*}\}$, and all disturbances (that are not *i.i.d.*) following an AR(1) process $\{\varepsilon_{x,t}\}$; ϵ_t is the vector of structural *i.i.d.* innovations distributed $N(0,I)$ $\{\epsilon_{x,t}, \tilde{\epsilon}_t^z\}$ in the case of $H=3$; Y_t denotes the vector of observables; and v_t is the vector of *i.i.d.* measurement error distributed $N(0,I)$. The matrices $F(\theta)$, $G(\theta)$ and $H(\theta)$ are complicated nonlinear functions of the structural parameters of the model, implied by the vector θ.

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[73] The RBC or DSGE models without news shocks necessarily require volatile and often negative unanticipated shocks of fundamentals (e.g., technology and aggregate demand) to explain a recession (Milani 2012). However, the models with news shocks do not require the volatile and negative unanticipated shocks, which are difficult to occur.

[74] Here, the parameter space for which the stable solution is unique is only considered.

3.3.2 Data

The model is estimated using the US and Australian data over the period 1993:Q1-2013:Q4. The sample period starts in 1993:Q1 to (i) cover an inflation-targeting period in Australia, and (ii) provide the consistency between Australian data and the monopoly power hypothesis in Galí (2011a)'s approach[75]. The details of the observed data are given in Appendix 3.B.1. The US observables include quarterly percentage changes in the chain-type price index of gross domestic product (GDP), non-farm real GDP and the federal funds rate (per cent per annum), quarterly percentage changes in non-farm compensation per employee, the unemployment rate, and employment, taken from the U.S. Bureau of Labor Statistics and the Federal Reserve Bank of St. Louis, FRED database. Australian data includes non-farm real GDP, quarterly inflation in percentage rates, excluding interest rate tax changes of 1999-2000, the cash rate (per cent per annum), terms of trade and G7 GDP-weighted real exchange rate, quarterly percentage changes in average non-farm compensation per employee, the unemployment rate and employment obtained from the statistical tables prepared by the Reserve bank of Australia (RBA) and Australian Bureau of Statistics (ABS). The published real exchange rate and the terms of trade are the inverse of the same variables in the model, so that the observables are converted into the model definition. Prior to empirical analysis, the data is transformed as follows. The nominal interest rate is expressed in quarterly terms (the annual interest rate is divided by four). Logarithm is taken from GDP and employment, and then the log-variables are linearly de-trended (scaled by 100 to convert them into percentage). The real exchange rate and terms of trade are first log-differenced (scaled by 100) and then demeaned. The unemployment rate is de-trended, and all remaining series are demeaned separately in order to ensure both stationarity of variables and consistency between the data and variables in the model. The used data is plotted in Figure 3.B.1 of Appendix 3.B.

3.3.3 Bayesian inference and priors

Structural parameters of the model, θ, are estimated using Bayesian methods. The state-space representation of the model shown in equations (3.20) and (3.21) is used in evaluation of the likelihood function, $L(Y_t|\theta)$, performed by the Kalman filter. Given a

[75]As stated by Christiano (2011), the main assumption of the approach would fail to be rejected if there is a strong relationship between union power (imperfectly measured by union density) and unemployment rate. In the case of Australia, correlation between union density and unemployment rate over the sample period 1993-2013 is 0.95, therefore the main assumption of Galí's approach is satisfied in the Australian economy over the inflation-targeting period.

prior distribution of parameter $p(\theta)$, the posterior likelihood function of parameters, $\mathcal{L}(\theta|Y_t)$, is proportional to the product, $L(Y_t|\theta)\ p(\theta)$. This formulation for the posterior function is the basis of the Bayesian estimation. The Bayesian techniques such as Random Walk Metropolis (RWM) and Kalman filter algorithms used to obtain draws from the posterior distribution of parameters are detailed well by An and Shorfheide (2007) and Guerrón-Quintana and Nason (2012). Christopher Sims's 'csminwel' optimization routine is used to obtain the posterior mode and to compute the Hessian matrix at the mode. To test the presence of the identification problem, over 50 optimization runs are launched, and the different optimization routine always converges to the same mode value. Since a unique mode for the model is found, the Hessian from the optimization routine is used as a proposal density, properly scaled (i.e., choosing $c = 0.175$) to attain an acceptance rate between 20-30 per cent. For the RWM results, two independent chains of 100,000 draws are generated, where the initial 40,000 draws are discarded. Convergence of the chains is monitored using both the univariate and the multivariate convergence diagnostics variants of Brooks and Gelman (1998).

In what follows, specifications of priors are discussed. Priors for the parameters consist of two sets. The first set includes parameters that are fixed by standard values in the literature. The foreign and domestic discount factors, $\beta^*$and β, are fixed at 0.99 associated with a real interest rate of 4.0 per cent (annually) in the steady state. The parameter governing openness, α, is assigned the value of 0.185 (Justiniano and Preston 2010a), consistent with the share of imports in GDP (0.2) over the inflation-targeting period (Kuttner and Robinson 2010). Attempts to estimate the parameter give implausibly low values.

The second set of parameters to be estimated consists of 76 parameters and their prior assumptions are listed in the first panel in Table 3.1. Most priors for both Australia and the US are selected fairly consistent with those used in the related literature (e.g., Justiniano and Preston 2010a,b, Robinson 2013 and Galí et al. 2011). An exception is the preference shifter parameter, ϑ_z, governing the wealth elasticity of labour supply. Following the estimates obtained by Galí et al. (2011) and Schmitt-Grohé and Uribe (2012), the beta prior distribution for ϑ_z, with the mean of 0.05 and the standard deviation of 0.025 is adopted to reduce the short-term wealth effect on labour supply. For all standard deviations of innovations of the estimated model, inverse-gamma distributions are used.

Table 3.1 Prior densities and posterior estimates

	Parameters	Australia				
		Prior Distribution			Posterior Distribution	
		Density	Mean	Sd.	Mean	[5, 95] prob.
Structural parameters						
h	Habit	B	0.7	0.1	0.52	[0.43, 0.61]
σ	Intertemporal ES	G	1.2	0.2	1.13	[0.87, 1.36]
η	Elasticity H-F goods	G	1.5	0.1	1.31	[1.18,1.44]
θ_H	Calvo domestic prices	B	0.6	0.15	0.54	[0.45,0.63]
δ_H	Indexation domestic	B	0.5	0.2	0.47	[0.20, 0.73]
φ	Inverse Frisch	N	2.0	1.0	5.61	[4.70, 6.65]
υ_H	Domestic-cost channel	B	0.5	0.25	0.36	[0.01, 0.70]
θ_F	Calvo import prices	B	0.6	0.15	0.80	[0.73, 0.86]
δ_F	Indexation foreign	B	0.5	0.2	0.39	[0.11, 0.64]
υ_F	Import-cost channel	B	0.5	0.25	0.53	[0.16, 0.95]
ϕ_a	Interest debt elasticity	IG	0.01	1.0	0.004	[0.002, 0.006]
ϕ_e	UIP modification	B	0.5	0.1	0.32	[0.27, 0.38]
θ_ω	Calvo wages	B	0.6	0.15	0.53	[0.40, 0.71]
δ_ω	Indexation wages	B	0.5	0.2	0.22	[0.13, 0.32]
$\mathcal{M}_\omega$	Steady state wage-markup	N	1.25	0.25	1.32	[1.04, 1.57]
ϑ_z	Reference shifter	B	0.05	0.025	0.06	[0.02, 0.10]
ρ_R	Taylor rule, smoothing	B	0.5	0.25	0.92	[0.89, 0.94]
χ_π	Taylor rule, inflation	G	1.5	0.25	2.00	[1.66, 2.35]
χ_y	Taylor rule, output	G	0.25	0.13	0.52	[0.26, 0.81]
$\chi_{\Delta y}$	Taylor rule, output growth	G	0.25	0.13	0.23	[0.05, 0.39]
Persistence of the exogenous processes						
ρ_a	Technology AR(1)	B	0.5	0.2	0.92	[0.88, 0.96]
ρ_g	Preferences AR(1)	B	0.8	0.1	0.88	[0.79, 0.97]
ρ_{cp^F}	Import-cost push AR(1)	B	0.5	0.2	0.24	[0.05, 0.43]
ρ_{cp^H}	Domestic-cost push AR(1)	B	0.5	0.2	0.29	[0.08, 0.50]
ρ_{rp}	Risk premium AR(1)	B	0.8	0.1	0.98	[0.97, 0.99]
ρ_n	Labour disutility AR(1)	B	0.8	0.1	0.93	[0.90, 0.97]
ρ_ω	Wage-markup AR(1)	B	0.5	0.2	0.10	[0.01, 0.18]
ρ_i	Monetary policy AR(1)	B	0.5	0.2	0.48	[0.31, 0.64]
Standard deviations, shock innovations						
$\sigma_{a,0}$	Sd technology, unanticipated	IG	0.7	0.7	0.34	[0.22, 0.46]
$\sigma_{a,1}$	Sd technology, 1qt ahead	IG	0.5	0.5	0.46	[0.28, 0.62]
$\sigma_{a,5}$	Sd technology, 5qt ahead	IG	0.5	0.5	0.33	[0.19, 0.48]
$\sigma_{g,0}$	Sd preferences, unanticipated	IG	1.4	0.7	1.56	[0.68, 2.42]
$\sigma_{g,3}$	Sd preferences, 3qt ahead	IG	1	0.5	0.89	[0.47, 1.27]
$\sigma_{g,9}$	Sd preferences, 9qt ahead	IG	1	0.5	0.87	[0.45, 1.26]
$\sigma_{n,0}$	Sd labour disutility, unanticipated	IG	1.4	0.7	1.38	[0.77, 1.91]
$\sigma_{n,1}$	Sd labour disutility,1qt ahead	IG	1	0.5	1.12	[0.50, 1.71]
$\sigma_{n,4}$	Sd labour disutility, 4qt ahead	IG	1	0.5	0.92	[0.44, 1.44]
$\sigma_{i,0}$	Sd monetary policy, unanticipated	IG	0.18	0.18	0.09	[0.07, 0.11]
$\sigma_{i,2}$	Sd monetary policy, 2qt ahead	IG	0.18	0.18	0.07	[0.05, 0.09]
$\sigma_{rp,0}$	Sd risk premium, unanticipated	IG	0.7	0.7	0.25	[0.18, 0.32]
$\sigma_{rp,11}$	Sd risk premium, 11qt ahead	IG	0.7	0.7	0.67	[0.40, 0.95]
$\sigma_{cp^H,0}$	Sd domestic-cost push, unanticipated	IG	0.7	0.7	0.79	[0.55, 1.04]
$\sigma_{cp^H,1}$	Sd domestic-markup, 1qt ahead	IG	0.7	0.7	0.47	[0.23, 0.71]
$\sigma_{cp^F,0}$	Sd import-markup, unanticipated	IG	1.4	0.7	1.88	[1.31, 2.40]
$\sigma_{cp^F,1}$	Sd import-cost push, 1qt ahead	IG	1.4	0.7	0.91	[0.61, 1.25]
$\sigma_{\omega,0}$	Sd wage-markup, unanticipated	IG	1.0	1.0	0.58	[0.29, 0.90]

Notes: G: Gamma distribution, B: Beta distribution, N: Normal distribution, IG: Inverse-Gamma distribution. Figures in brackets indicate 90 per cent posterior probability intervals.

Table 3.1 Prior densities and posterior estimates (Continued)

Parameters		The US economy				
		Prior Distribution			Posterior Distribution	
		Density	Mean	Sd.	Mean	[5, 95] prob.
Structural parameters						
h^*	Habit	B	0.5	0.1	0.40	[0.32, 0.49]
σ^*	Intertemporal ES	G	1.0	0.4	2.00	[1.41, 2.65]
θ^*	Calvo prices	B	0.6	0.1	0.87	[0.85, 0.90]
δ^*	Indexation prices	B	0.5	0.2	0.21	[0.04, 0.37]
φ^*	Inverse Frisch	N	2.0	1.0	4.98	[4.11, 5.92]
υ^*	Cost channel	B	0.5	0.25	0.49	[0.09, 0.89]
θ_ω^*	Calvo wages	B	0.5	0.15	0.51	[0.25, 0.69]
δ_ω^*	Indexation wages	B	0.5	0.15	0.12	[0.05, 0.19]
$\mathcal{M}_\omega^*$	Steady state wage-markup	N	1.25	0.25	1.25	[1.02, 1.52]
ϑ_z^*	Reference shifter	B	0.05	0.025	0.11	[0.07, 0.15]
ρ_R^*	Taylor rule, smoothing	B	0.75	0.1	0.87	[0.84, 0.91]
χ_π^*	Taylor rule, inflation	G	1.5	0.25	2.14	[1.79, 2.48]
χ_y^*	Taylor rule, output	G	0.25	0.13	0.04	[0.02, 0.07]
$\chi_{\Delta y}^*$	Taylor rule, output growth	G	0.25	0.13	0.46	[0.30, 0.62]
Persistence of the exogenous processes						
ρ_a^*	Technology AR(1)	B	0.8	0.1	0.98	[0.97, 0.99]
ρ_g^*	Preferences AR(1)	B	0.8	0.1	0.98	[0.97, 0.99]
ρ_{cp}^*	Cost push AR(1)	B	0.5	0.2	0.15	[0.03, 0.26]
ρ_n^*	Labour disutility AR(1)	B	0.8	0.1	0.91	[0.82, 0.98]
ρ_ω^*	Wage-marlup AR(1)	B	0.5	0.2	0.07	[0.01, 0.12]
ρ_i^*	Monetary policy AR(1)	B	0.5	0.2	0.54	[0.41, 0.68]
Standard deviations, shock innovations						
$\sigma_{a,0}^*$	Sd technology, unanticipated	IG	0.7	0.7	0.63	[0.52, 0.72]
$\sigma_{a,9}^*$	Sd technology, 9qt ahead	IG	0.7	0.7	0.29	[0.21, 0.38]
$\sigma_{g,0}^*$	Sd preferences, unanticipated	IG	1.4	0.7	4.91	[3.34, 6.64]
$\sigma_{g,6}^*$	Sd preferences, 6qt ahead	IG	1.0	0.5	0.68	[0.42, 0.95]
$\sigma_{g,8}^*$	Sd preferences, 8 qt ahead	IG	1.0	0.5	0.86	[0.51, 1.21]
$\sigma_{n,0}^*$	Sd labour disutility, unanticipated	IG	1.4	0.7	1.10	[0.69, 1.44]
$\sigma_{n,2}^*$	Sd labour disutility, 2qt ahead	IG	1.4	0.7	1.09	[0.70, 1.42]
$\sigma_{i,0}^*$	Sd monetary policy, unanticipated	IG	0.18	0.18	0.07	[0.05, 0.08]
$\sigma_{i,2}^*$	Sd monetary policy, 2qt ahead	IG	0.18	0.18	0.07	[0.05, 0.09]
$\sigma_{cp,0}^*$	Sd price markup, unanticipated	IG	0.35	0.7	0.14	[0.11, 0.16]
$\sigma_{cp,10}^*$	Sd price markup, 10qt ahead	IG	0.35	0.7	0.12	[0.08, 0.15]
$\sigma_{\omega,0}^*$	Sd wage markup, unanticipated	IG	1.0	1.0	0.83	[0.38, 1.30]

Notes: G: Gamma distribution, B: Beta distribution, N: Normal distribution, IG: Inverse Gamma distribution. Figures in brackets indicate 90 per cent posterior probability intervals.

The prior distributions of the standard deviations of news components are assumed to be identical for each of the fourteen shocks in the model. As used by Fujiwara et al. (2011) and Gomes et al. (2013), for each shock, the variance of the unanticipated component is assumed to be equal to the sum of variance of the news components. This is equivalent to that the variance of the unanticipated component equals 50 per cent of the total variance of the shock[76].

[76] For example, in the case of $h = \{1,2\}$, mean values of the prior distributions for the standard deviations are selected according to the rule, $\sigma_{x,0}^2/(\sigma_{x,0}^2 + \sigma_{x,1}^2 + \sigma_{x,2}^2) = 0.5$.

The total prior variances of the shocks are chosen as fairly diffuse to ensure that the second moments of the variables in the model are consistent with those in the data.

3.3.4 News horizon selection: How many quarters in advance are news shocks anticipated?

The news horizon for each of the fourteen shocks in the model is selected based on the overall fit of the models under different news horizon specifications as measured by the log marginal data density[77]. The following searching procedure is conducted. First, for comparison purpose, the log marginal data density of the model with no news shock is estimated. Second, for each of the fourteen shocks, log marginal data densities of models with news shock at each single horizon from 1 to 12 (i.e., $h = 1$, $h = 2$,…, $h = 12$) are computed. For each shock, if all models with single news shock underperform the model with no news shock in terms of the log marginal data density, then the news component is not included in the shock structure. Third, for each of the fourteen shocks, if several models with single news shock perform better than the model with no news, then multiple news horizons are considered. In this case, for each type of shock, multiple news horizon specifications are based on the rank of the log marginal data densities, obtained from the second step. For instance, the combination of two news horizons, giving the highest values of log marginal data densities (e.g., for technology shock in Australia, the models with news at $h = 1$ and $h = 5$ are respectively ranked in the first and the second in terms of model fit) is considered as the initial multiple horizon specification (e.g., $h = \{1,5\}$). Subsequent multiple horizon specifications are built by combining either the news horizon allowing next highest model fit with the previous multiple horizon specification or with the news horizon allowing the highest model fit (e.g., $h = \{1,3,5\}$ and $h = \{1,3\}$). For each multiple horizon specification, the log marginal data densities are computed. Finally, for each of the fourteen shocks, the news horizon(s) (h, single horizon or multiple horizons), providing the maximum log marginal data density, is selected.

The log marginal data densities calculated for the model under different news horizon specifications are shown in Table 3.B.1 of Appendix 3.B. The results show that for most shocks, the specification with news shock(s) is preferred to the specification with no news

[77] A similar approach is used by Fujiwara et al. (2011), Milani and Treadwell (2012) and Gomes et al. (2013) who focus on a single shock. Some others (e.g., Khan and Tsoukalas 2012 and Schmitt-Grohé and Uribe 2012) directly select same news horizons (e.g., $h = \{4,8\}$) for all different shocks. This undertaking approach in this chapter allows us to select different news horizons for different shocks based on the data driven criteria.

in terms of the log marginal data density. The exceptions are Australian and the US news shocks to wage markup. All specifications with wage-markup news shocks are outperformed by no news specification. Thus, the news shocks on wage markup are not included in the estimated model. As a result of the news horizon search, the best-fitting individual news structures have been selected in the case of Australia as follows: $h = \{1,5\}$ for the technology shock, $h = \{3,9\}$ for the preference (consumption) shock, $h = \{1,4\}$ for the labour disutility shock, $h = 2$ for the monetary policy shock, $h = 11$ for the country risk premium shock and $h = 1$ for the price markup shocks in the domestic and import firms. For the US economy, $h = 9$ for the technology shock, $h = \{6,8\}$ for the preference (consumption) shock, $h = 2$ for both labour disutility shock and monetary policy shock, and $h = 10$ for the price markup shock are chosen as the best-fitting horizon structure. The choice of $h = 2$ for the US monetary policy shock is also obtained by Gomes et al. (2013).

Joint inclusion of news shocks at the selected horizons is used to produce all results such as posterior estimates, impulse responses, variance decomposition and historical decomposition. Whether the joint inclusion of the news shocks improves the overall fit of the model is formally investigated in Section 3.3.6.

3.3.5 Posterior estimates of the parameters

The last panel in Table 3.1 reports the posterior estimates of the model parameters. The data are informative about the estimated parameters, and the estimates are fairly consistent with those of previous papers (e.g., Justiniano and Preston (2010a), Robinson (2013) for Australia, and Smets and Wouters (2007), Galí et al. (2011) for the US). For this reason and given the focus of this chapter on the impact of news shocks on labour market and macroeconomic fluctuations, only the selected parameters are discussed. The estimates of parameters, θ_ω and θ_ω^*, indicate that wages in both Australia and the US are re-optimized approximately every two quarters, while δ_ω and δ_ω^* imply the relatively low level of backward indexation in both countries. As found by Theodorides and Zanetti (2014), the wage rigidities would help to replicate the empirical results regarding responses of unemployment and wages to a productivity news shock. The estimated labour supply elasticity in Australia is lower than it is in the US. The inverse of the Frisch labour supply elasticity is 5.61 in Australia and 4.98 in the US. According to the finding obtained by Grabek and Kłos (2013), the low labour supply elasticity in both countries may result in the strong response of real wages and the weak response of unemployment to an unanticipated monetary policy shock. However, the estimated steady-state wage markup in Australia (32 per cent) is higher than it is in the US (25 per cent). The steady-state wage markups are generally consistent with an average unemployment rate of 6.5 per cent and 6.0 per cent over the period 1993:Q1-2013:Q4 in Australia and the US, respectively.

The posterior mean of the parameters, ϑ_z and ϑ_z^*, controlling the short-run wealth effects on labour supply, are estimated as 0.06 and 0.11, respectively. The lower values imply that the preference in both Australia and the US is closer to a preference used by Greenwood et al. (1988), and therefore would help to generate (i) the co-movement of output and labour force (and employment) in response to news shocks about future productivity as originally argued by Jaimovich and Rebelo (2008, 2009), and (ii) the pro-cyclical movement of both employment and labour force in response to unanticipated technology and monetary policy shocks as discussed by Christiano et al. (2010b) and Galí et al. (2011). In both Australia and the US, monetary policy is inertial, with parameters, ρ_R and ρ_R^*, of around 0.9, and is implemented as anti-inflationary policy, with parameters, χ_π and χ_π^*, of more than two. Badarinza and Margaritov (2011) have shown that the interest rate smoothing and inflation targeting behaviour amplify the effects of the monetary policy news shock.

The data contains significant information about the parameters of the shock processes as the small size of the posterior standard deviation is measured compared to the prior standard deviation. The exception is the unanticipated component of consumption preference shock, where the standard deviation of the posterior is larger than the standard deviation of the prior. The estimated standard deviations of news and unanticipated components imply that a substantial part of the variances of the shocks is anticipated in Australia. News components account for 73.5 per cent[78] of σ_a^2, 87.8 per cent of σ_{rp}^2, 52.5 per cent of σ_n^2, 38.9 per cent of σ_g^2, 37.7 per cent of σ_i^2, 26.1 per cent of $\sigma_{cp^H}^2$ and 19.0 per cent of $\sigma_{cp^F}^2$. Instead, in the case of the US, the shocks are less anticipated. For instance, 17.5 per cent of $\sigma_{a^*}^2$, 4.7 per cent of $\sigma_{g^*}^2$, 49.5 per cent of $\sigma_{n^*}^2$, 53.9 per cent of $\sigma_{i^*}^2$ and 42.4 per cent of $\sigma_{cp^*}^2$ are anticipated. The result, showing that the news component

[78] From Table 3.1, the unanticipated component ($\sigma_{a,0}$) is 0.34 and news components ($\sigma_{a,0}$ and $\sigma_{a,1}$) are 0.46 and 0.33, respectively. From the variance formula, $\sigma_z^2 = \sum_{h=0}^{H} \sigma_{z,h}^2$, the proportion of anticipated components is $0.735 = (0.46^2 + 0.33^2)/(0.46^2 + 0.33^2 + 0.34^2)$.

accounts for over 50 per cent of the variance of monetary policy shocks, is entirely consistent with results found by Milani and Treadwell (2012) and Gomes et al. (2012).

3.3.6 The model fit and comparison

Figure 3.B.1 in Appendix 3.B shows the data and the model's one-sided predicted values (one-step ahead prediction) of the observed variables. The in-sample fit for most of the variables is reasonably good. The exceptions are wage inflations in Australia and the US. These variables are quite volatile at quarterly frequency and difficult to predict as discussed by Jääskelä and Nimark (2011) for Australia and by Justiniano et al. (2013) for the US. However, the estimated model explains the general movement of the wage inflations. In order to investigate how the presence of the news shocks improves the overall fit of the estimated model, Table 3.2 presents the log marginal data densities of alternative models along with the corresponding Bayes factors, calculated by considering $\mathcal{M}_0$ is as the null hypothesis.

Table 3.2 Model comparison: News vs. No News

Models ($\mathcal{M}$)	Log marginal data densities ($ln\ p(Y^T \mid \mathcal{M})$)	Bayes factor ($\mathcal{BF}$)
$\mathcal{M}_0$: Model with both domestic and foreign news shocks	-1290.28	$\mathcal{BF}_{0,0\|Y^T} = 1$
$\mathcal{M}_1$: Model with only domestic news shocks	-1299.84	$\mathcal{BF}_{0,1\|Y^T} = 14185.9$
$\mathcal{M}_2$: Model with no news shocks	-1302.99	$\mathcal{BF}_{0,2\|Y^T} = 331041.8$

Notes: The table reports Bayes factor comparing the model $\mathcal{M}_0$ to $\mathcal{M}_1$(or $\mathcal{M}_2$). The log marginal data densities reported here are computed from the posterior draws using the Laplace approximation.

According to the last row in Table 3.2, the log marginal data density of the model without news shocks ($\mathcal{M}_2$) is -1302.99. The first and second rows show that the model fit improves when news shocks are introduced. In particular, the Bayes factor between the model with only Australian news shocks ($\mathcal{M}_1$) and the model without news shocks ($\mathcal{BF}_{1,2|Y^T}$) is slightly above 23, implying 'strong' evidence in favour of $\mathcal{M}_1$ model with news shocks originating in Australia, according to Kass and Raftery (1995)[79].

In order to assess the significance of the US news shocks in the estimated model, $\mathcal{M}_0$ model is compared with $\mathcal{M}_1$ model. The Bayes factor, $\mathcal{BF}_{0,1|Y^T} = 14185.9$ suggests

[79] According to their scale of evidence, a Bayes factor between 1 and 3 is 'not worth more than a bare mention', between 3 and 20 suggests a 'positive' evidence, between 20 and 150 suggests a 'strong' evidence, and larger than 150 'very strong' evidence in favour of one of the two models.

'very strong' evidence in favour of $\mathcal{M}_0$ model, implying that the inclusion of the US news shocks helps to improve the overall fit of the model. The Bayes factor between $\mathcal{M}_0$ model and $\mathcal{M}_2$ model, $\mathcal{BF}_{0,2|Y^T} = 331041.8$ also offers 'very strong' evidence for the importance of news shocks originated in both Australian and the US. It is also important to note that the log marginal data density of $\mathcal{M}_0$ model is higher than all log marginal data densities of the models with news shocks shown in Table 3.B.1 of Appendix 3.B. Therefore, the Bayesian model comparison shows that the presence of news shocks (i.e., combination among different types of shocks in domestic and foreign economies) has the potential to improve the overall fit of the estimated small open economy DSGE model.

Table 3.3 reports the estimated model's unconditional predictions of second moments such as standard deviations and serial correlations of the observed variables.

Table 3.3 Data and model-implied moments

	Data		Model	
	SD	Auto-correlation	SD	Auto-correlation
Inflation (π)	0.4	0.23	1.1	0.82
Changes in real exchange rate (Δq)	4.2	0.18	4.2	0.43
Interest rate (i)	1.2	0.90	4.9	0.94
Output (y)	1.8	0.92	3.7	0.93
Changes in terms of trade (Δs)	3.0	0.46	3.1	0.73
Wage inflation (π^w)	0.8	-0.004	1.1	0.73
Unemployment rate (u)	0.9	0.91	1.6	0.82
Employment (n)	1.1	0.91	2.3	0.89
US inflation (π^*)	0.21	0.53	0.29	0.78
US output (y^*)	4.8	0.97	4.1	0.94
US interest rate (i^*)	2.2	0.97	1.9	0.93
US wage inflation (π^{w^*})	0.96	-0.24	0.72	0.26
US unemployment rate (u^*)	1.4	0.95	1.1	0.79
US employment (n^*)	3.9	0.96	2.6	0.93

Notes: The table presents the mean of the posterior distribution of the statistics implied by the estimated model.

For comparison, the table also presents the corresponding empirical second moments calculated over the sample 1993:Q2 to 2013:Q4. The empirical second moments are well matched by the estimated model. For instance, the model reasonably replicates the observed levels of volatility in all six variables of the US economy, and changes in real exchange rate, changes in terms of trade and wage inflation for Australia. However, the model overpredicts the standard deviations of inflation, output, cash rate, unemployment and employment in Australia. A possible explanation for the overprediction is the fact that variances of the shocks are estimated in high values in order to match with high standard deviation of changes in real exchange rate and changes in terms of trade. The model does a good job in replicating the autocorrelations with exceptions of wage inflations in Australia and the US.

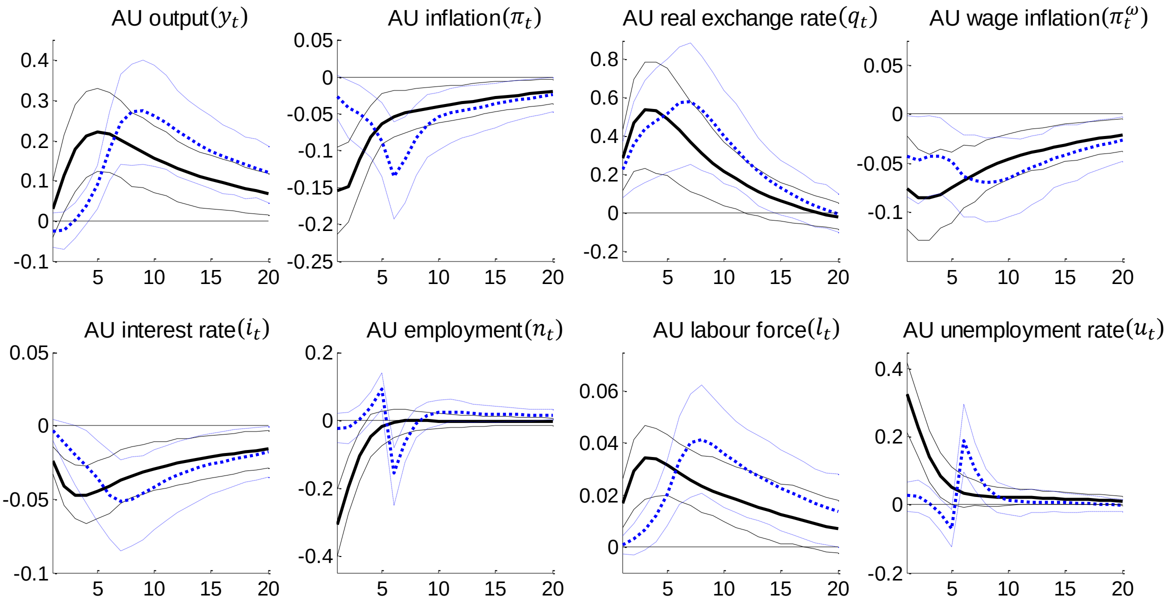
3.4. The importance of news shocks

3.4.1 Impulse responses: what are the effects of news shocks?

3.4.1.1 Technology shocks

The effect of technology news shock in the estimated model is firstly interested because the news-driven business cycle literature heavily focuses on the shock. Figure 3.1 compares the estimated impulse responses of Australian variables to the unanticipated domestic technology shock and to the five-period-ahead news about domestic technology.

Figure 3.1 Impulse responses to a positive AU technology shocks



Notes: Impulse responses of eight domestic observed variables to one-standard-deviation unanticipated shock (solid lines) and 5-period-ahead news shock (dashed lines). The lines represent posterior means and 90 per cent posterior probability interval.

In the context of the estimated model, employment decreases, and output, labour force and unemployment increase in responding to the positive unanticipated technology shock. The result implies that the model cannot reproduce the pro-cyclical employment in response to the unanticipated technology shock.

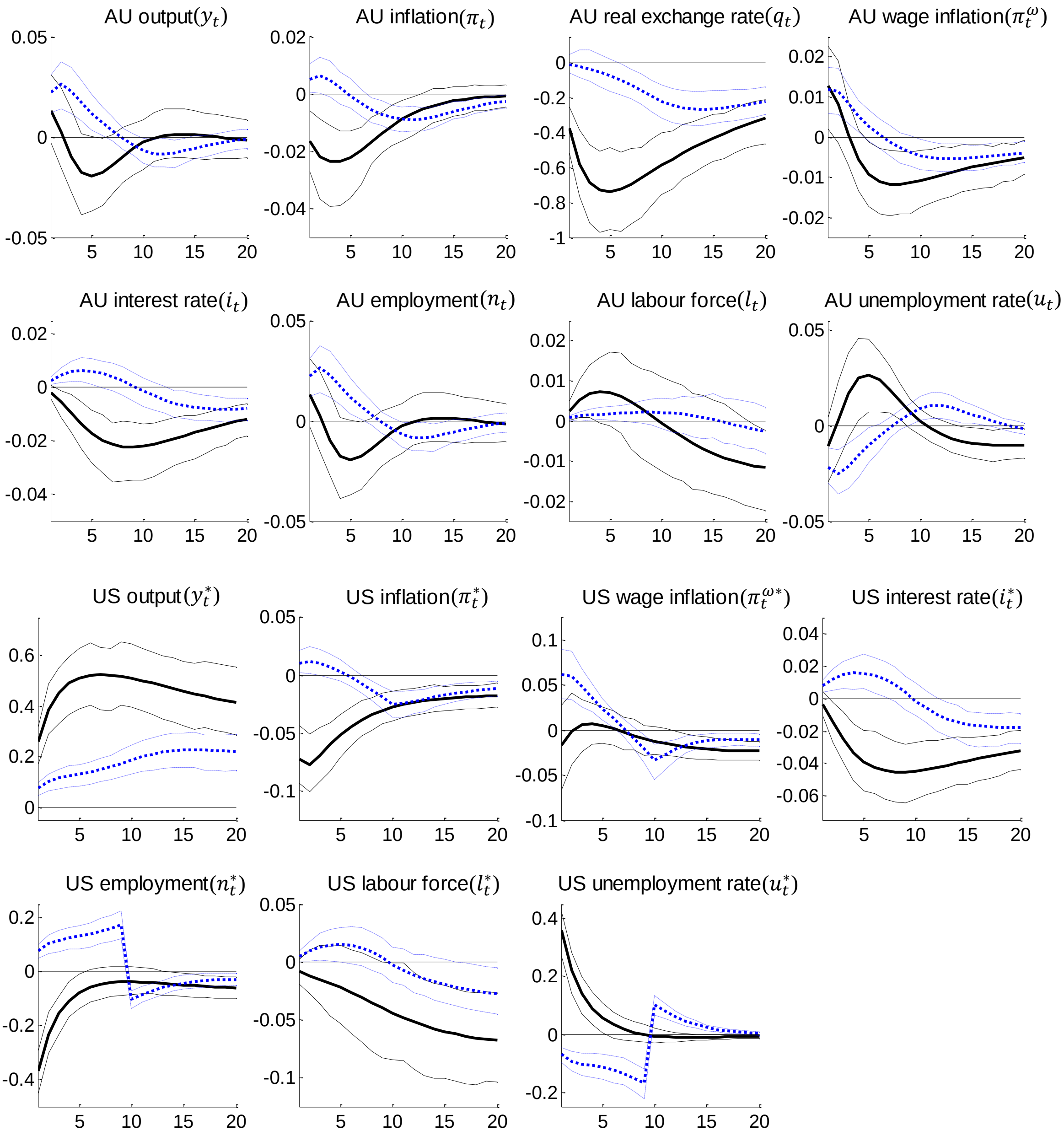
However, good news about domestic future technology initially generates pro-cyclical employment and labour force in Australia. The impact responses of output, employment and labour force are ambiguous. After the impact period, as predicted in the news-driven business cycle literature, those variables jointly increase and unemployment decreases in response to the 5-period-ahead news shock. Therefore, the estimated model with the endogenous preference shifter and nominal rigidities has the potential to replicate the VAR-based results in small open economies (Australia, Canada, New Zealand and United Kingdom) obtained by Kamber et al. (2014).

The responses of nominal variables are in line with the result found by Adalid and Detken (2007) and Chiristiano et al. (2010a) in the sense that the inflation in the booming period is below its steady state value. The monetary policy rule with high weight to inflation therefore induces the fall in interest rate. The news shock leads to a deprecation of real exchange rate in the hump-shaped manner. Therefore, the estimated responses of the exchange rates are entirely consistent with those found by Matsumoto et al. (2008) using a calibrated small open economy DSGE model, and are in line with results obtained by Jaimovich and Rebelo (2008) and Kamber et al. (2014), showing that positive productivity news shocks are associated with counter-cyclical current accounts. However, actual realization of the 5-period-ahead news shock leads to higher unemployment in Australia.

In order to explore the answer to the question, what is the role of technology news shocks in explaining domestic and international business cycle? the effects of the US technology shocks are also interested. Figure 3.2 compares the impulse responses of both Australian and the US variables to the unanticipated shock and to the 9-period-ahead news shock about the US technology.

The responses of the US variables are consistent with those found in previous studies (e.g., Beaudry and Pertier 2006, Galí 2011c, Galí et al. 2011, Fujiwara et al. 2011 and Badarinza and Margaritov 2011). The US unanticipated technology shock does not generate the pro-cyclical employment as found by Galí (1999, 2011c), whereas good news about future technology in the US economy set off a boom today. For instance, the 9-period ahead technology news shock is associated with initial increases in output, employment, labour force, inflation, wage inflation, interest rate, and a decrease in unemployment rate in the US. However, after the realization of the shock, the boom is followed by a rise in unemployment and declines in inflation and interest rate. The estimated model also qualitatively replicates the VAR-based results shown by Theodorides and Zanetti (2014), indicating that unemployment falls, whereas wages increase in response to a good technology news shock.

Figure 3.2 Impulse responses to a positive US technology shocks



Notes: Impulse responses of observed variables to one standard deviation unanticipated shock (solid lines) and 9-period-ahead technology news shock (dashed lines). The lines represent posterior means and 90 per cent posterior probability interval.

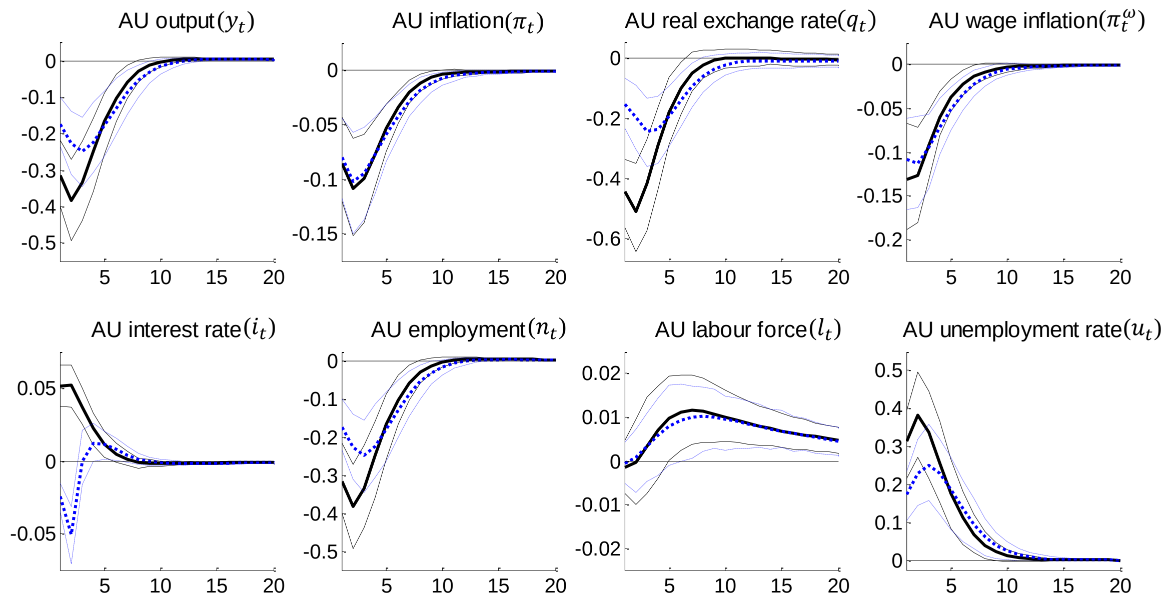
The most important result here is that the positive technology news in the US also leads to business cycle co-movement in Australia, supporting the news view of international business cycles. The estimated model reproduces results of the VAR analysis shown by Kosaka (2013) for a small open economy (i.e., Canada) in the sense that the US news shock drives joint business cycle co-movements across countries (i.e., the US and

Australia). In addition, initial responses of the most nominal variables to the US news shock are shown to be the mirror (but asymmetric) image of the responses to the unanticipated shock.

3.4.1.2 Monetary policy shocks

Figure 3.3 shows impulse responses of macroeconomic variables to the unanticipated shock and to the two-period-ahead news about the tightening of Australian monetary policy.

Figure 3.3 Impulse responses to a tightening AU monetary policy shocks



Notes: Impulse responses of eight domestic observed variables to one standard deviation unanticipated MP shocks (solid lines) and 2-period-ahead monetary policy news shock (dashed lines). The lines represent posterior means and 90 per cent posterior probability interval.

The impulse responses to the unanticipated monetary policy shock are matched with findings typically obtained in previous studies (e.g., Nimark 2009 and Jääskelä and Nimark 2011). The qualitative characteristic of the impulse responses to the unanticipated and the news shocks are quite similar, except for the response of the nominal interest rate. Both unanticipated and news shocks induce a fall in output and employment. The fall in labour demand increases the wage markup through increasing the marginal product of labour. The higher wage markup explains the impact decline in wage inflation, and thereby the impact fall in inflation. The unanticipated monetary policy shock leads to the hump-shaped response of the real exchange rate. Owing to the lower estimate of ϑ_z, employment and labour force move together in the first couple of periods in response to both unanticipated and news shocks, whereas unemployment increases in a hump-shaped manner. An interesting result is that an announcement about future tightening of monetary policy lowers the current interest rate by reducing current inflation and output growth. The actual materialization of the monetary policy news shock leads to a slight overshooting of the nominal interest rate.

Figure 3.B.6 in Appendix 3.B displays the impulse responses of both Australian and the US variables to the unanticipated and the two-period-ahead news shocks on US monetary policy. All impulse responses of the US variables to both shocks replicate the results typically found in the literature (e.g., Badarinza and Margaritov 2011, Milani and Treadwell 2012 and Gomez et al. 2013). The unanticipated tightening of US monetary policy leads to a decline in real economy activity. The weak economic activity leads to a fall in wage inflation, inflation and a rise in unemployment through the same channel explained in the case of Australia.

For all US variables, the news shock has more persistent effect compared to the unanticipated shock, though there are no qualitative differences in the dynamic responses of labour market and macroeconomic variables. However, both shocks in the US monetary policy lead to a rise in real economic activity in Australia, mainly driven by the depreciation of the Australian dollar. When both central banks in Australia and the US simultaneously announce current or future changes in their stance towards monetary policy (e.g., let us assume same amount of changes in their interest rates), there is no significant change in the nominal exchange rate of the Australian dollar. Therefore, the impacts of US monetary policy on the Australian economy will be negligible compared to those of Australian monetary policy.

3.4.1.3 Other shocks

As a novelty in the literature, the estimated model allows us to study the effects of other types of news shocks such as country risk premium, preference, labour disutility and price markup shocks originating in both Australia and the US. The impulse responses to those news shocks are shown in Figure 3.B.2-3.B.8 of Appendix 3.B. An important result here is that the consumption preference news shock leads to business cycle in Australia, and same news shock originating in the US induces international the business cycles across Australia and the US. For the preference shock, the unanticipated and the news shocks have different initial effects. As shown in the literature, the unanticipated positive demand shock directly increases the real economic activity. However, in both Australia and the

US, the news about future surges in the consumption initially drives the real economic activity into a recession. The news about future rise in consumption initially leads to more savings and reduces current consumption. The fall in current consumption declines the current domestic demand for output, and thereby demand for labour. The lower demand for labour and output induces fall in the employment, wage and price inflations and a rise in unemployment. In responding to the situation, the interest rate declines through easing monetary policy. Prior to materialization of the news shock, real exchange rate and labour force in Australia do not respond significantly to the news shock originating both in Australia and the US. After the realization of the shock, demands for output and employment increase, and therefore inflation rises. As a result, real exchange rate starts to appreciate and unemployment falls.

Country risk premium shocks also lead to business cycles in Australia. The unanticipated positive risk premium shock boosts real economic activity. News about future increase in the risk premium initially drives Australian economy into a stagflation, and the economy moves into a recovery position after the realization of the news shock. The different responses to the unanticipated and the news shocks are related to two effects, which work in opposite directions. First, current unanticipated changes in the risk premium or the news about future changes in the risk premium increase the holding of foreign assets, which decreases current consumption. Lower domestic demand leads to a fall in output, and thereby decreases demand for employment. Because of the weak wealth effect, the fall in consumption does not significantly increase the labour force. As a result, wage inflation declines and unemployment increases prior to the materialization of the news shock. Second, the holding of foreign assets leads to the depreciation of the domestic nominal exchange rate. The depreciation of the exchange rate supports higher foreign demand for domestic goods, and thus output increases. The depreciation of the nominal exchange rate also drives an inflation pressure. In responding to the rise in inflation, the interest rate rises gradually. This news shock initially leads to the recession as the effect of the first channel initially dominates those in the second channel. The economy starts to recover over time as the effect of the second channel dominates those in the first channel. When the news shock is materialized in period 11, the economy formally moves into a boom, mainly driven by high depreciation of the real exchange rate.

For labour supply and price markup shocks, originating in Australia and the US, there are no qualitative changes between impulse responses to the unanticipated shock and to news shock. A slight difference in the shape of the responses is that unfavourable news about future labour supply leads to the rise in today’s unemployment rate. The impulse responses to unanticipated wage markup shocks originating in Australia and the US are consistent with those found by Galí et al. (2011).

3.4.2 Variance decomposition: What has driven business cycle fluctuations?

In order to assess the importance of news shocks in Australian and the US macroeconomic fluctuations, the variance decomposition is examined. Figure 3.B.9 in Appendix 3.B presents the contribution of unanticipated and news shocks to the forecast error variance of observables. The result suggests that the news shocks are important sources of macroeconomic fluctuations in both economies. In particular, the Australian economy is more news driven than the US economy. For instance, the news shocks account for over 50 per cent of the 20-quarter ahead forecasting error variance of Australian output, inflation and interest rate. However, the news shocks originating in the US account for less than 35 per cent of the variance of the US macro variables. Moreover, the contribution of news shocks in explaining the forecast error variance of Australian observables rises when forecast horizon increases. The results imply that macroeconomic fluctuations are mainly driven by unanticipated shocks in the short-run, whereas the fluctuations in the medium-to-long run are mainly attributable to news shocks in Australia. Another interesting finding here is that wage inflation and unemployment rate in the US are respectively less and more anticipated than those in Australia. The fractions of variances in the US labour market variables explained by news shocks are totally consistent with the VAR-based result shown by Theodoridis and Zaneti (2014).

To explore what type of news shock is more important in business cycle fluctuations, Table 3.4 presents an unconditional variance decomposition of fourteen observables into the twenty eight shocks (i.e., sources of uncertainty) in the estimated model. In the perspective of the estimated model, contributions of news shocks in explaining variances of five Australian observables (output, employment, inflation, wage inflation and interest rate) dominate those of unanticipated shocks. For the remaining three Australian observables (unemployment, changes in real exchange rate and changes in terms of trade), the news shocks account for one-third of their unconditional variances. For the US, the unanticipated shocks dominate in variances of all six observables.

Table 3.4 Variance decomposition

	Australia							
	y	π	i	Δq	Δs	π^{ω}	u	n
	Technology shock ($\epsilon_{a,t}$)							
$\epsilon^{a,0}$	15.4	7.8	3.9	1.3	1.1	6.7	2.7	1.6
$\epsilon^{a,1}$	33.9	16.9	8.7	2.4	2.4	14.7	4.2	2.6
$\epsilon^{a,5}$	16.4	8.0	4.4	0.6	0.8	7.0	1.7	1.1
	Preference shock ($\epsilon_{g,t}$)							
$\epsilon^{g,0}$	3.1	0.5	1.0	2.1	1.4	1.7	9.3	8.5
$\epsilon^{g,3}$	0.4	0.03	0.05	0.04	0.06	0.1	1.5	1.0
$\epsilon^{g,9}$	0.3	0.04	0.04	0.04	0.04	0.1	1.0	0.7
	Labour disutility shock ($\epsilon_{n,t}$)							
$\epsilon^{n,0}$	1.9	0.9	0.3	0.2	0.2	1.1	2.5	5.3
$\epsilon^{n,1}$	0.9	0.4	0.1	0.08	0.09	0.5	0.7	2.4
$\epsilon^{n,4}$	0.8	0.4	0.1	0.06	0.07	0.4	0.4	2.2
	Monetary policy shock ($\epsilon_{i,t}$)							
$\epsilon^{i,0}$	1.5	1.1	0.3	0.7	0.0	1.2	7.5	4.0
$\epsilon^{i,2}$	0.9	1.1	0.1	0.1	0.0	1.2	4.5	2.4
	Risk premium shock ($\epsilon_{rp,t}$)							
$\epsilon^{rp,0}$	6.0	12.7	24.1	50.2	20.6	8.2	18.4	16.5
$\epsilon^{rp,11}$	12.2	25.3	50.9	27.9	31.0	28.4	15.3	33.9
	Price markup shock ($\epsilon_{cp,t}$)							
$\epsilon^{cp,0\#}$	2.7	14.0	1.6	6.3	29.5	3.6	10.0	7.4
$\epsilon^{cp,1\#}$	1.2	4.7	0.6	2.2	9.4	1.9	4.3	3.4
	Wage markup shock ($\epsilon_{\omega,t}$)							
$\epsilon^{\omega,0}$	1.8	3.7	0.3	0.6	0.8	21.6	11.8	5.1
	Foreign shocks ($\epsilon_{f,t}$)							
$\epsilon^{f,0\#\#}$	0.5	1.8	2.8	4.2	2.0	1.1	3.0	1.5
$\epsilon^{f,h\#\#}$	0.2	0.7	0.7	1.0	0.6	0.4	1.2	0.5

	The United States (US)					
	y^*	π^*	i^*	π^{w^*}	u^*	n^*
	Technology shock ($\epsilon_{a^*,t}$)					
$\epsilon^{a^*,0}$	53.7	15.4	11.2	1.7	4.1	7.9
$\epsilon^{a^*,9}$	11.4	3.1	2.5	2.9	8.8	3.6
	Preference shock ($\epsilon_{g^*,t}$)					
$\epsilon^{g^*,0}$	28.1	30.5	60.3	10.5	29.0	71.2
$\epsilon^{g^*,6}$	1.5	0.9	1.6	1.7	8.3	3.7
$\epsilon^{g^*,8}$	1.2	0.5	1.2	1.0	7.0	3.1
	Labour disutility shock ($\epsilon_{n^*,t}$)					
$\epsilon^{n^*,0}$	0.6	1.2	1.1	0.7	3.3	1.5
$\epsilon^{n^*,2}$	0.8	1.5	1.5	0.6	3.1	2.1
	Monetary policy shock ($\epsilon_{i^*,t}$)					
$\epsilon^{i^*,0}$	0.6	3.2	5.1	2.2	7.8	1.5
$\epsilon^{i^*,2}$	0.7	5.2	3.2	3.1	8.6	1.7
	Price markup shock ($\epsilon_{cp^*,t}$)					
$\epsilon^{cp^*,0}$	0.1	11.1	1.2	0.1	0.4	0.2
$\epsilon^{cp^*,10}$	1.2	24.0	9.4	4.5	5.3	3.1
	Wage markup shock ($\epsilon_{\omega^*,t}$)					
$\epsilon^{\omega^*,0}$	0.2	3.5	1.6	71.2	14.3	0.5

Notes: Figures in per cent and correspond to the mean of the posterior distribution of the variance decomposition. The columns labeled y/y^*, π/π^*, i/i^*, , π^w/π^{w^*}, u/u^* and n/n^* refer, respectively, to output, inflation, interest rate, wage inflation, unemployment rate and employment in Australia/the US. In addition, Δq, Δs respectively refer to changes in real exchange rate and to changes in terms of trade in Australia. #Figures in the column are the sum of contributions of domestic price markup shock and import price markup shock; ## Figures in the column are the sum of contributions of all foreign shocks.

Consistent with the RBC literature, the technology (i.e., productivity) shock is the most important source of output fluctuations in both Australia and the US. For instance, the technology shock explains about two-thirds of the variance of outputs in Australia and the US. In contrast to the literature, over half of the variance of Australian output is attributable to the news component of the technology shock. This result is in line with the VAR-based results for small open economies (i.e., Australia, Canada, New Zealand and UK) obtained by Kamber et al. (2013). In addition, movements in the remaining Australian observables explained by the technology shock are mainly attributable to their news components. For example, the news about Australian future technology explains about 25 per cent of the variance of inflation and wage inflation. However, news about the US future technology accounts for less than 12 per cent of the variance of the US observables. The relatively small contribution of the US technology news shock is consistent with the results found by Fujiwara et al. (2011), Khan and Tsoukalas (2011) and Schmitt-Grohé and Uribe (2012).

The country risk premium shock is another important source of the Australian business cycle. The risk premium shocks explain 86, 78, 50 and 18 per cent of the unconditional variance of Australian interest rate, real exchange rate, employment and output, respectively. The most interesting finding here is that the news component of the risk premium shock accounts for two-thirds of total movements in most of the observables due to the shocks. The present results are in line with the existing literature, highlighting the relevance of the risk premium shock in Australian interest rate and exchange rate fluctuations. For instance, the sign-restricted VAR result reported by Liu (2010) shows that above 46 per cent of the 4-quarter ahead forecasting error variance of interest rate is attributed to the risk premium shock, and Leu (2011) finds that the shock explains 86 per cent of the 4-quarter ahead forecasting error variance of interest rate. Nimark (2009) shows that over half of the unconditional variance of the exchange rate is attributable to the risk premium shock.

There is a significant difference between Australia and the US regarding the importance of consumption preference shocks in driving business cycle fluctuations. As found in a number of studies (e.g., Justiniano et al. 2010, Schmitt-Grohé and Uribe 2012, and Christiano et al. 2014), the preference shocks play a vital role in explaining the variance of output in the US. The preference shocks account for one-third of the variance of output and three-fourths of the variance of employment in the US. Instead, fluctuations in most Australian observables are less driven by preference shocks. Over 10 per cent of the variances of unemployment and employment are attributed to the shock. A reasonable explanation for this is that the open economy dimension may dampen the effects of demand shocks, and amplify effects of supply shocks on real quantities as found by Christiano et al. (2011). However, a common observation in both countries is that news component of the preference shock plays a minor role in generating macroeconomic fluctuations.

Labour market shocks have a minor role in explaining movements in non-labour market indicators of aggregate activity. The similar result is also shown by Christiano et al. (2011), demonstrating the insignificance of labour market shocks in explaining Swedish output. Wage markup shocks play a minor role in the US output and employment fluctuations, and demand shocks are the important sources of unemployment movements as found by Galí et al. (2011). Unemployment fluctuations in Australia are equally driven by country risk premium, supply and demand shocks. Country risk premium, wage markup and supply shocks respectively account for around one-third of the variance in Australian wage inflation. In the US economy, 19 and 71 per cent of the variance of wage inflation is attributable to demand and wage markup shocks, respectively.

Monetary policy shocks account for only a very limited portion of fluctuations in most of the observables. An exception is the importance of the shocks in explaining unemployment rate movements as the shocks account for 16.4 and 12 per cent of the unemployment rate variance in the US and Australia, respectively. As shown by Milani and Treadwell (2012) and Gomes et al. (2013), the news shock on the US monetary policy is generally more important than unanticipated monetary policy shock in explaining the US business cycle. However, this is not the case in Australia.

The price markup shocks explain a substantial part of inflation variance in both economies. For instance, 21 and 40 per cent of Australian inflation and changes in terms of trade are attributed to price markup shocks. The result is consistent with those reported by Nimark (2009) and Liu (2010). The price markup shocks are equally important as the preference and labour disutility shocks in explaining Australian output fluctuations. Furthermore, the shocks account for around 15 per cent of the variation in Australian employment and unemployment rate. The news component of the shocks account for one-third of movements in Australian observables driven by the shocks. Among the US news shocks, 10-quarter-ahead news about the price markup is most significant in explaining the variations in the US inflation, interest rate and wage inflation. Studies (e.g., Justiniano et al. 2010 and Galí et al. 2011) have shown that about 30 per cent of the US inflation variance is explained by the price markup shock. Results presented in Table 3.4 suggest that the US price markup shock explains 35 and 11 per cent of movements in the US inflation and interest rate, respectively. In particular, movements in the US observables explained by the price markup shock are mainly attributable to the news component of the shock.

As discussed by Justiniano and Preston (2010b), the specification of the estimated model, abstracted from international financial linkages and cross-country linkages at multiple stages of production, fails to account for the influence of foreign shocks. The US shocks explain 5 per cent or less of variations in Australian observables. A novel result here is that the US news shocks are less relevant in accounting for the variations in Australian observables compared to the US unanticipated shocks.

3.4.3 Historical decomposition: Do news shocks drive the economy over time?

It is important to use the estimated model to analyse historical decomposition, which describes the variation of key variables in the model over time in terms of the structural shocks. Figure 3.B.10 in Appendix 3.B displays historical decompositions that exhibit the contribution of news shocks to movements in each observable over the period 1993:Q2-2013:Q4. A number of results stand out. First, news shocks have played a vital role in driving fluctuations in Australian output, employment and interest rate over the sample period. An interesting finding is that the fall in cash rate, output growth and employment during the GFC is basically explained by news shocks. The contribution of news shocks to the cash rate was positive and high over periods 2004-2008, and the actual cash rate was relatively low during the same period. Second, for most of the sample period, news shocks have played a minor role in explaining movements in Australian unemployment rate and wage inflation, whereas their relevance increases over the periods 2008-2011 as they contribute to the bulk of movements in these variables. Third, news shocks have a certain impact on Australian inflation, changes in real exchange rate and changes in terms of trade. However the strong movements in these variables are mostly triggered by the unanticipated shocks. Fourth, though news shocks have played a moderate role in fluctuations of most of the US observables, the contributions explained by news shocks entirely move together with the actual observables. In addition, news shocks contribute to the bulk of movements in US inflation over the periods 1996-2000 and early 2012 onwards. Finally, news shocks have not been a major source of the US recession during the GFC. As noted by Theodorides and Zanetti (2014), news shocks play a minimal role in movements of the US wage inflation.

3.5 Conclusion

This chapter has assessed the importance of news shocks as sources of labour market and macroeconomic fluctuations using an estimated small open economy DSGE model. In doing so, the model developed in Chapter 2 is further extended to include the theory of involuntary unemployment proposed by Galí 2011(a,b), and the endogenous preference shifter employed by Galí et al. (2011), which allows for controlling the short-run wealth effects on labour supply. The model is also driven by both unanticipated and news shocks, and estimated using Bayesian methods based on Australian and US data over the period 1993:Q1-2013:Q4.

The analysis delivers a number of key results. First, the Bayesian model comparison confirms that the presence of joint news shocks (i.e., a combination among different types of shocks in Australia and the US) has the potential to improve the overall fit of an estimated small open economy model. Second, the estimated model with the endogenous preference shifter and nominal rigidities has the ability to qualitatively replicate results of the VAR analyses (e.g., Kosaka 2013 and Kamber et al. 2014), supporting the view of news-driven domestic and international business cycles in open economies[80]. News about future technology and consumption preference could lead to business cycles in both Australia and the US, and the news about future country risk premium can drive macroeconomic fluctuations in Australia. Third, the estimated responses of labour market variables to technology news shocks are in line with the VAR-based results (e.g., Theodoridis and Zanetti 2014) in the sense that a positive technology news shock causes a counter-cyclical unemployment rate and rise in wages. News shocks account for 35 and 41 per cent of unemployment fluctuations in Australia and the US, respectively. Fourth, news shocks play a major role in the Australian business cycle over the inflation-targeting period. Over half of the variances in Australian most observables are explained by news shocks. In addition, news shocks were a main source of the Australian recession during

[80] The news about future domestic technology does lead to positive co-movement among output, employment and labour force in both Australia and the US. In addition, the US news shocks on technology and preference do propagate to Australia, generating international business cycles.

the GFC. Fifth, the news about future country risk premium is an important source of the business cycle in Australia. For example, the risk premium news shock accounts for over one-fourth of the unconditional variances in most Australian observables. Finally, the real exchange rate plays a vital role in the propagation of news shocks. Positive news shocks on technology and country risk premium are associated with the depreciation of the real exchange rate. About one-third of the variance in the real exchange rate is attributable to news shocks, particularly to news about future country risk premium. The results showing the importance of country risk premium shock in the business cycle and role of flexible exchange rate in the propagation of shocks are entirely consistent with existing literature on the Australian business cycle (e.g., Nimark 2009, Liu 2010, Jääskelä and Nimark 2011 and Leu 2011).

Further augmentations of the present model may include (i) allowing for propagation of shocks passing through investment and financial intermediation, and (ii) introducing investment and financial shocks, recently identified as important drivers of business cycles (e.g., Justiniano et al. 2010 and Christiano et al. 2011, 2014). It is left for the next chapter to assess the impact of financial shocks on business cycles in a small open economy.

3.6 References

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Appendix 3.A Equations of the log-linearized model

The steady state of the model is characterized by zero inflation and balanced trade. All variables are in log-deviation from their respective steady state values ($x_t = log(X_t/X)$)[81].

3.A.1 Domestic Economy

Euler equation: $c_t - hc_{t-1} = E_t(c_{t+1} - hc_t) - \sigma^{-1}(1-h)(i_t - E_t\pi_{t+1}) + \sigma^{-1}(1-h)(\varepsilon_{g,t} - \varepsilon_{g,t+1})$ (3.A.1)

where i_t and π_t respectively denotes nominal interest rate and overall CPI inflation.

Goods market clearing:

$$y_t = (1-\alpha)c_t + \alpha\eta(2-\alpha)s_t + \alpha\eta\psi_{F,t} + \alpha y_t^* \quad (3.A.2)$$

where α is the share of foreign goods in the aggregate consumption bundle; η is the elasticity of substitution between domestic and foreign goods; y_t and y_t^* are domestic and foreign output, respectively; $\psi_{F,t} = (e_t + p_t^*) - p_{F,t}$ and $s_t = p_{F,t} - p_{H,t}$ respectively denote the law of one price gap, so-called by Monacelli (2005) and the terms of trade.

Time-differences in the terms of trade:

$$\Delta s_t = \pi_{F,t} - \pi_{H,t} \quad (3.A.3)$$

where $\pi_{F,t} = p_{F,t} - p_{F,t-1}$ and $\pi_{H,t} = p_{H,t} - p_{H,t-1}$ respectively denote inflation of imported goods and inflation of domestically produced goods.

Real exchange rate: $q_t = e_t + p_t^* - p_t = \psi_{F,t} + (1-\alpha)s_t$ (3.A.4)

Real exchange rate therefore depends on deviations from the law of one price and terms of trade.

Domestic firms' inflation equation extended with the cost channel:

$$\pi_{H,t} - \delta_H\pi_{H,t-1} = \beta E_t(\pi_{H,t+1} - \delta_H\pi_{H,t}) + k_H mc_t + \varepsilon_{cp^H,t} \quad (3.A.5)$$

with $k_H = \frac{(1-\theta_H)(1-\theta_H\beta)}{\theta_H}$, where θ_H and δ_H respectively denote the domestic Calvo price stickness and the domestic price indexation parameters; $\varepsilon_{cp^H,t}$ is a price markup shock that captures inefficient variations in the domestic firm's price markup[82]; and

Real marginal costs: $mc_t = \omega_t + \alpha s_t + \upsilon_H i_t - \varepsilon_{a,t}$, where υ_H denotes a friction of domestic firms' wage bill that must be financed in advance, and $\omega_t = w_t - p_t$ is the real wage, where w_t and p_t respectively denote nominal wage and price.

[81] Exceptions are: the nominal and real exchange rate are defined as $e_t = \log(\tilde{e}_t/\tilde{e})$, $q_t = \log(\tilde{q}_t/\tilde{q})$; interest rates are specified as $i_t = \tilde{\iota}_t - \tilde{\iota}$, the net foreign asset is denoted as $a_t = A_t - A$ and the shocks are described as $\varepsilon_{x,t} = \log(\tilde{\varepsilon}_{x,t}/\tilde{\varepsilon}_x)$, $\varepsilon_{rp,t} = \tilde{\varepsilon}_{rp,t} - \tilde{\varepsilon}_{rp}$.

[82] It is assumed that $\varepsilon_{cp^H,t} = k_H\mu_{H,t}^p$ and $\varepsilon_{cp^F,t} = k_F\mu_{F,t}^p$, where $\mu_{H,t}^p$and $\mu_{F,t}^p$ are price markup shocks in domestic and retail sectors, as discussed by Smets and Wouters (2003, 2007).

Retailers' inflation equation, extended with the cost channel:

$$\pi_{F,t} - \delta_F \pi_{F,t-1} = \beta E_t(\pi_{F,t+1} - \delta_F \pi_{F,t}) + k_F(\psi_{F,t} + \upsilon_F i_t^*) + \varepsilon_{cp^F,t} \quad (3.A.6)$$

where $k_F = \frac{(1-\theta_F)(1-\theta_F\beta)}{\theta_F}$, υ_F corresponds to a friction of retail firms' inputs with foreign currency that must be financed in advance, i_t^* is the foreign nominal interest rate, and $\varepsilon_{cp^F,t}$ captures variations in the retailers' price mark-up.

Consumer price index (CPI) inflation:

$$\pi_t = \pi_{H,t} + \alpha\Delta s_t \quad (3.A.7)$$

The CPI inflation is equal to the sum of domestic goods price inflation and terms of trade, weighted by the importance of imported goods in the CPI basket.

Real wage: $$\omega_t = \omega_{t-1} + \pi_t^\omega - \pi_t \quad (3.A.8)$$

Wage inflation: $$\pi_t^\omega - \delta_\omega \pi_{t-1} = \beta E_t(\pi_{t+1}^\omega - \delta_\omega \pi_t) - \varrho_\omega(\mu_{\omega,t} - \mu_{\omega,t}^n) \quad (3.A.9)$$

with $\varrho_\omega \equiv \frac{(1-\theta_\omega)(1-\beta\theta_\omega)}{\theta_\omega(1+\varphi\zeta_\omega)}$, $\mu_{\omega,t}^n = 100 \cdot \varepsilon_{\omega,t}$ and

Average wage markups and unemployment:

$$\mu_{\omega,t} = \omega_t - (z_t + \varphi n_t + \varepsilon_{n,t}) = \varphi u_t \quad (3.A.10)$$

Equation (3.A.10) allows us to correctly identify both wage markup shock and labour supply shock.

Endogenous reference shifter:

$$z_t = (1-\vartheta_z)\, z_{t-1} + \vartheta_z\left(-\varepsilon_{g,t} + (\sigma/(1-h))(c_t - hc_{t-1})\right) \quad (3.A.11)$$

Employment and labour force:

$$n_t = y_t - \varepsilon_{a,t} \quad (3.A.12)$$

$$l_t = n_t + u_t \quad (3.A.13)$$

Modified UIP condition:

$$i_t - i_t^* = (1-\phi_e)E_t\Delta e_{t+1} - \phi_e\Delta e_t - \phi_a a_t + \varepsilon_{rp,t} \quad (3.A.14)$$

where ϕ_e governs how much the expected depreciation is allowed to affect the risk premium in the UIP condition; $\Delta e_t = \pi_t - \pi_t^* + \Delta q_t$ and a_t respectively denote the change in the nominal exchange rate and net foreign asset; and $\varepsilon_{rp,t}$ represents the risk premium shock. The modified UIP condition ($\phi_e > 0$) helps the model to reproduce the empirical evidence on delayed real exchange rate overshooting as the modification allows 'mechanical' sources of endogenous persistence for the nominal exchange rate.

Net foreign assets:

$$a_t = \frac{1}{\beta}a_{t-1} - \alpha(s_t + \psi_{F,t}) + y_t - c_t \quad (3.A.15)$$

Domestic monetary policy rule:

$$i_t = \rho_R i_{t-1} + (1-\rho_R)(\chi_\pi \pi_t + \chi_y y_t + \chi_{\Delta y}\Delta y_t) + \varepsilon_{i,t} \quad (3.A.16)$$

where $\varepsilon_{i,t}$ is a domestic monetary policy shock.

3.A.2 Foreign economy

When applying $\alpha^* = 0$ condition and $P_t^* = P_{F,t}^*$[83] assumptions into (3.A.1)-(3.A.16) equations, equations describing the foreign economy can be found as described in (3.A.17-3.A.25). Foreign variables and parameters are denoted with superscript "*".

IS curve:

$$y_t^* - h^* y_{t-1}^* = E_t(y_{t+1}^* - h^* y_t^*) - \sigma^{*-1}(1 - h^*)(i_t^* - E_t \pi_{t+1}^*)$$
$$+\sigma^{*-1}(1 - h^*)(\varepsilon_{g^*,t} - \varepsilon_{g^*,t+1}) \qquad (3.A.17)$$

Phillips curve:

$$\pi_t^* - \delta^* \pi_{t-1}^* = \beta^* E_t(\pi_{t+1}^* - \delta^* \pi_t^*) + k^* mc_t^* + \varepsilon_{cp^*,t} \qquad (3.A.18)$$

where $k^* = \frac{(1-\theta^*)(1-\theta^*\beta^*)}{\theta^*}$; $\varepsilon_{cp^*,t}$ is a foreign price markup shock, and

Real marginal cost: $mc_t^* = \omega_t^* + \nu^* i_t^* - \varepsilon_{a^*,t}$

Real wage:

$$\omega_t^* = \omega_{t-1}^* + \pi_t^{\omega*} - \pi_t^* \qquad (3.A.19)$$

Wage inflation:

$$\pi_t^{w*} - \delta_\omega^* \pi_{t-1}^* = \beta^* E_t\left(\pi_{t+1}^{\omega^*} - \delta_\omega^* \pi_t^*\right) - \varrho_\omega^*\left(\mu_{\omega,t}^* - \mu_{\omega,t}^{n^*}\right) \qquad (3.A.20)$$

with $\varrho_\omega^* \equiv \frac{(1-\theta_\omega^*)(1-\beta^*\theta_\omega^*)}{\theta_\omega^*(1+\varphi^*\zeta_\omega^*)}$, $\mu_{\omega,t}^{n^*} = 100 \cdot \varepsilon_{\omega^*,t}$ and

Average and natural wage markups and unemployment:

$$\mu_{\omega,t}^* = \omega_t^* - \left(z_t^* + \varphi^* n_t^* + \varepsilon_{n^*,t}\right) = \varphi^* u_t^* \qquad (3.A.21)$$

Endogenous reference shifter:

$$z_t^* = (1 - \vartheta_z^*)\, z_{t-1}^*$$
$$+\vartheta_z^*\left(-\varepsilon_{g^*,t} + (\sigma^*/(1-h^*))(y_t^* - h^* y_{t-1}^*)\right) \qquad (3.A.22)$$

Employment and labour force:

$$n_t^* = y_t^* - \varepsilon_{a^*,t} \qquad (3.A.23)$$

$$l_t^* = n_t^* + u_t^* \qquad (3.A.24)$$

Foreign monetary policy rule:

$$i_t^* = \rho_R^* i_{t-1}^* + (1 - \rho_R^*)\left(\chi_\pi^* \pi_t^* + \chi_y^* y_t^* + \chi_{\Delta y}^* \Delta y_t^*\right) + \varepsilon_{i^*,t} \qquad (3.A.25)$$

where $\varepsilon_{i^*,t}$ is a foreign monetary policy shock.

[83] Since the foreign economy is very large, trade flows to and from the domestic economy are negligible compared to total foreign economic activity. This means that α^* tends to zero. As a result, foreign consumption is given by $C_t^* = C_{F,t}^*$, which implies that the foreign CPI is entirely determined by foreign goods price, $P_t^* = P_{F,t}^*$.

Appendix 3.B Data definitions, tables and figures

3.B.1 Data definitions

3.B.1.1 Australia

Output: real non-farm GDP, chain volume, seasonally adjusted; Australian Bureau of Statistics (ABS) Cat No 5206.0: A2302589X

Inflation: quarterly inflation, excluding interest payments (prior to the September quarter 1998) and tax changes of 1999-2000, seasonally adjusted; Reserve Bank of Australia (RBA) Statistical Table G1 Consumer Price Inflation

Interest rates: cash rate, quarterly average; RBA Statistical Table F13 International Official Interest Rates

Wage inflation: quarterly percentage changes in average non-farm (current prices) compensation per employee, seasonally adjusted; ABS Cat No 5206.0: A2302622R

Unemployment rate: unemployment rate, at the end of quarter, seasonally adjusted; ABS Cat No 6202.0: A181525X

Employment: Employed persons, at the end of quarter, seasonally adjusted; ABS Cat No 6202.0: A181515V

Real exchange rate: real trade-weighted index; RBA Statistical Table F15 Real Exchange Rate Measures

Terms of trade: terms of trade index, seasonally adjusted; ABS Cat No 5206.0: A2304200A

3.B.1.2 The United States (US)

Output: non-farm business output, seasonally adjusted; U.S. Bureau of Labor Statistics (BLS): PRS85006043

Inflation: quarterly percentage changes in chain-type price index of GDP, seasonally adjusted; Federal Reserve Bank of St. Louis, FRED database: GDPCTPI

Interest rates: Federal funds rate, quarterly average; RBA Statistical Table F13 International Official Interest Rates

Wage inflation: quarterly changes in non-farm compensation per employee, computed as non-farm compensation of employees, seasonally adjusted (BLS: PRS85006063), divided by non-farm employment, seasonally adjusted (BLS: PRS85006013)

Unemployment rate: unemployment rate, at the end of quarter[30], seasonally adjusted; BLS: LNS14000000

Employment: non-farm employment, seasonally adjusted; BLS: PRS8500601

Table 3.B.1 Best-fitting news horizon selection: Comparing log marginal data densities of alternative models

News horizon	Domestic shocks								Foreign shocks					
	$\epsilon_{t-h}^{a,h}$	$\epsilon_{t-h}^{g,h}$	$\epsilon_{t-h}^{n,h}$	$\epsilon_{t-h}^{i,h}$	$\epsilon_{t-h}^{rp,h}$	$\epsilon_{t-h}^{cp^H,h}$	$\epsilon_{t-h}^{cp^F,h}$	$\epsilon_{t-h}^{\omega,h}$	$\epsilon_{t-h}^{a^*,h}$	$\epsilon_{t-h}^{g^*,h}$	$\epsilon_{t-h}^{n^*,h}$	$\epsilon_{t-h}^{i^*,h}$	$\epsilon_{t-h}^{cp^*,h}$	$\epsilon_{t-h}^{\omega^*,h}$
No news	-1303.0	-1303.0	-1303.0	-1303.0	-1303.0	-1303.0	-1303.0	**-1303.0**	-1303.0	-1303.0	-1303.0	-1303.0	-1303.0	**-1303.0**
$h = 1$	-1300.0	-1307.5	-1302.6	-1299.0	-1298.5	**-1300.2**	**-1301.4**	-1309.7	-1304.4	-1301.0	-1300.0	-1304.3	-1304.1	-1310.3
$h = 2$	-1302.3	-1307.8	-1304.3	**-1296.8**	-1299.8	-1304.3	-1302.7	-1312.1	-1305.0	-1302.2	**-1299.2**	**-1291.6**	-1305.5	-1310.9
$h = 3$	-1301.8	-1302.7	-1304.5	-1304.5	-1305.7	-1304.8	-1302.7	-1318.9	-1305.1	-1302.1	-1299.6	-1301.7	-1300.0	-1311.6
$h = 4$	-1302.4	-1306.8	-1302.0	-1303.9	-1306.1	-1304.5	-1303.5	-1305.4	-1304.2	-1302.2	-1301.1	-1299.6	-1298.2	-1312.3
$h = 5$	-1301.6	-1307.2	-1304.6	-1302.5	-1305.4	-1304.5	-1303.9	-1308.8	-1304.9	-1299.5	-1301.2	-1298.7	-1297.0	-1312.3
$h = 6$	-1302.4	-1307.0	-1304.2	-1303.7	-1304.0	-1304.5	-1303.1	-1308.6	-1304.4	-1298.4	-1301.3	-1297.8	-1293.9	-1312.4
$h = 7$	-1303.3	-1307.4	-1304.3	-1312.0	-1304.2	-1304.3	-1303.3	-1308.3	-1303.2	-1298.9	-1302.0	-1300.4	-1295.0	-1311.8
$h = 8$	-1302.4	-1306.7	-1304.0	-1304.8	-1304.0	-1304.2	-1303.6	-1305.4	-1303.2	-1295.6	-1302.1	-1297.9	-1293.9	-1313.1
$h = 9$	-1303.2	-1302.7	-1304.2	-1303.2	-1302.4	-1304.3	-1303.3	-1308.6	**-1298.0**	-1297.2	-1303.2	-1298.1	-1293.6	-1312.4
$h = 10$	-1302.7	-1306.7	-1304.2	-1303.5	-1301.0	-1304.1	-1303.3	-1308.4	-1301.7	-1297.7	-1303.7	-1299.8	**-1292.8**	-1312.5
$h = 11$	-1302.3	-1306.8	-1304.3	-1303.1	**-1298.1**	-1304.2	-1303.1	-1308.2	-1301.1	-1299.0	-1303.7	-1298.5	-1292.9	-1312.0
$h = 12$	-1302.5	-1307.3	-1304.3	-1303.7	-1300.9	-1304.2	-1303.3	-1308.2	-1300.9	-1296.6	-1303.2	-1298.5	-1293.3	-1313.0
$h = 1,5$	**-1299.0**													
$h = 1,3,5$	-1300.4													
$h = 3,9$		**-1301.9**												
$h = 1,4$			**-1299.7**											
$h = 1,2$				-1298.3	-1299.6		-1302.5							
$h = 1,11$					-1301.2									
$h = 9,12$									-1301.76					
$h = 6,8$										**-1291.9**				
$h = 2,3$											-1299.5			
$h = 2,6$												-1292.6		
$h = 6,10$													-1294.91	

Notes: The table shows the log marginal data density calculated using the Laplace approximation for alternative news horizons. The log marginal data density with respect to the best-fitting news horizon for each shock is shown in bold.

Figure 3.B.1 Data and one-sided predicted values

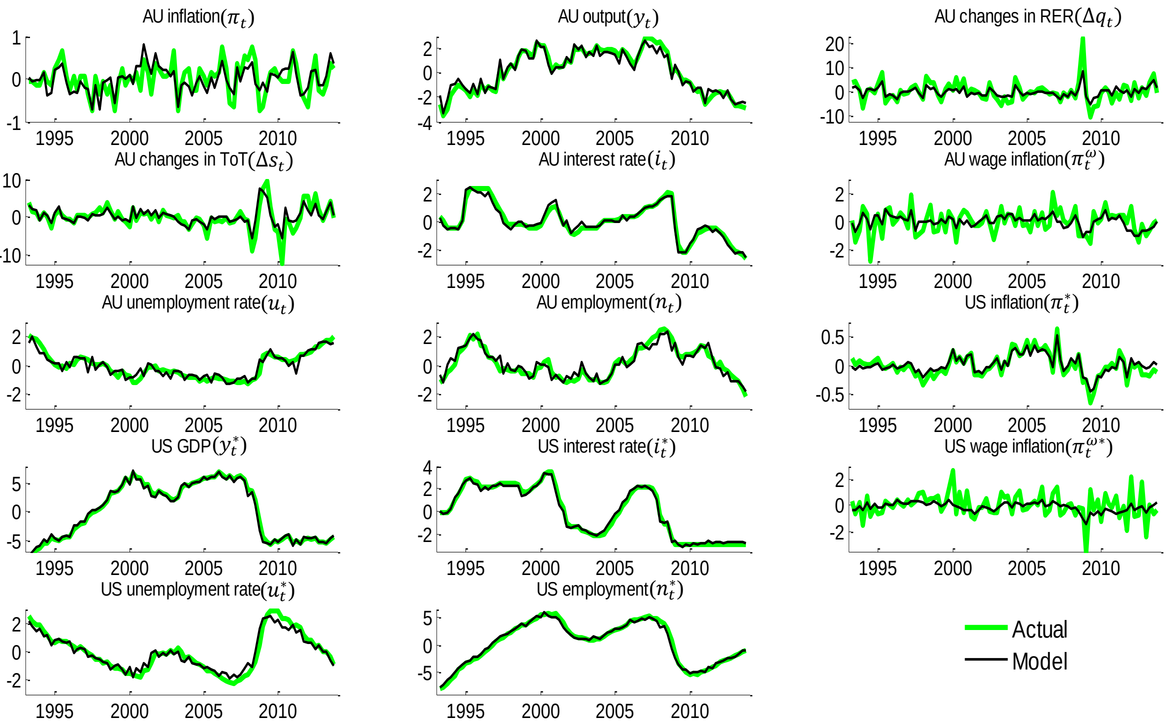
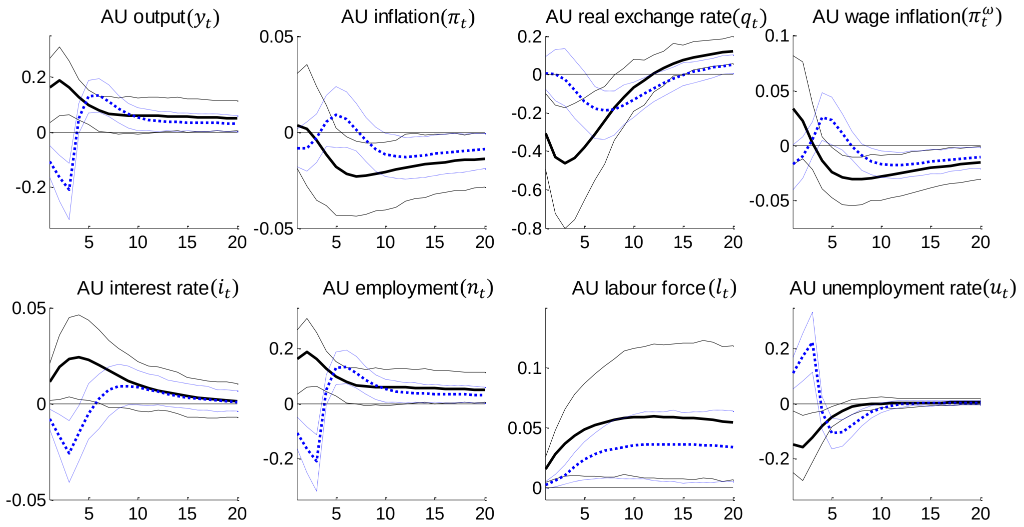
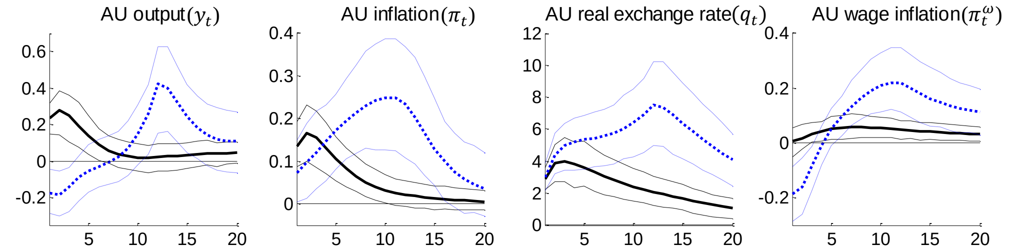


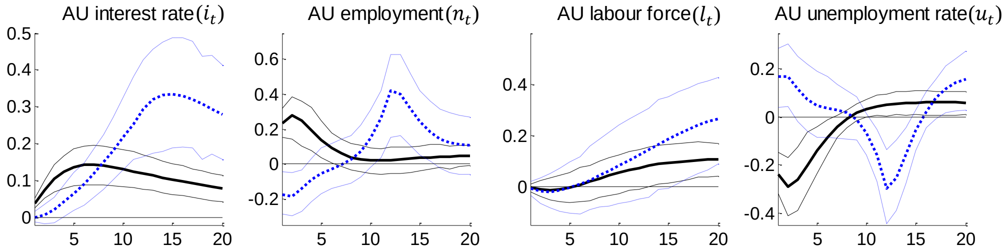
Figure 3.B.2 Impulse responses to positive AU consumption preference shocks



Notes: Impulse responses of eight domestic observed variables to one standard deviation unanticipated consumption preference shock (solid lines) and 3-period-ahead consumption preference news shock (dashed lines). The lines represent posterior means and 90 per cent posterior probability.

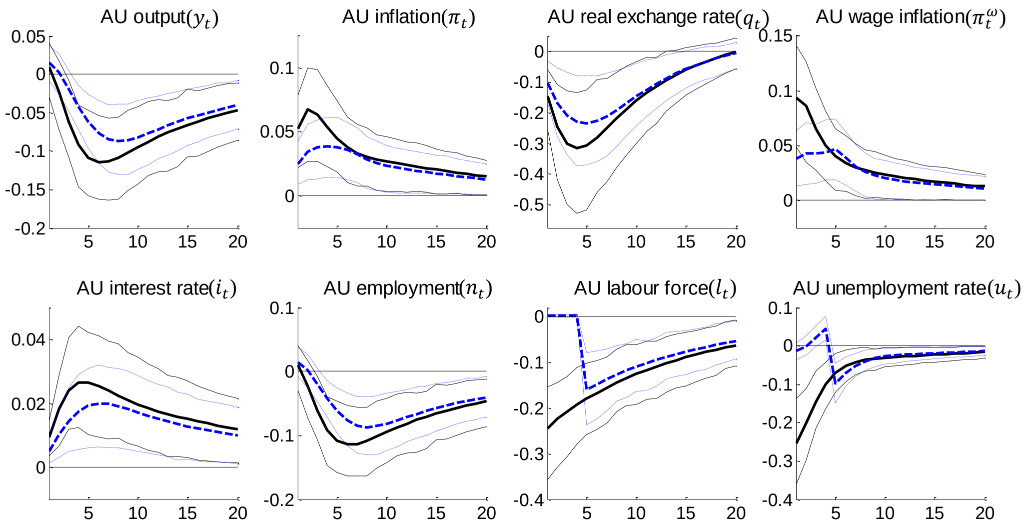
Figure 3.B.3 Impulse responses to positive AU risk premium shocks





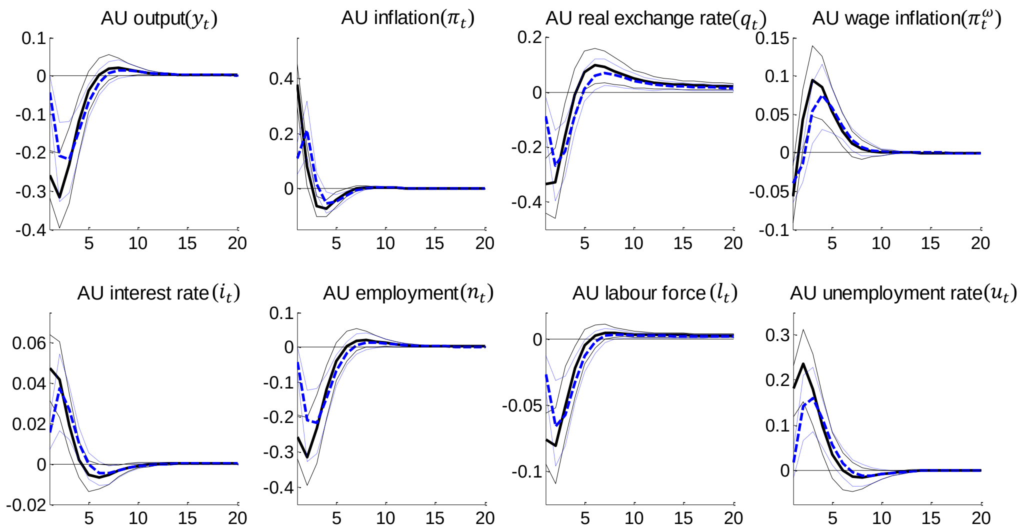
Notes: Impulse responses of eight domestic observed variables to one standard deviation unanticipated risk premium shock (solid lines) and 11-period-ahead risk premium news shock (dashed lines). The lines represent posterior means and 90 per cent posterior probability.

Figure 3.B.4 Impulse responses to positive AU labour supply shocks



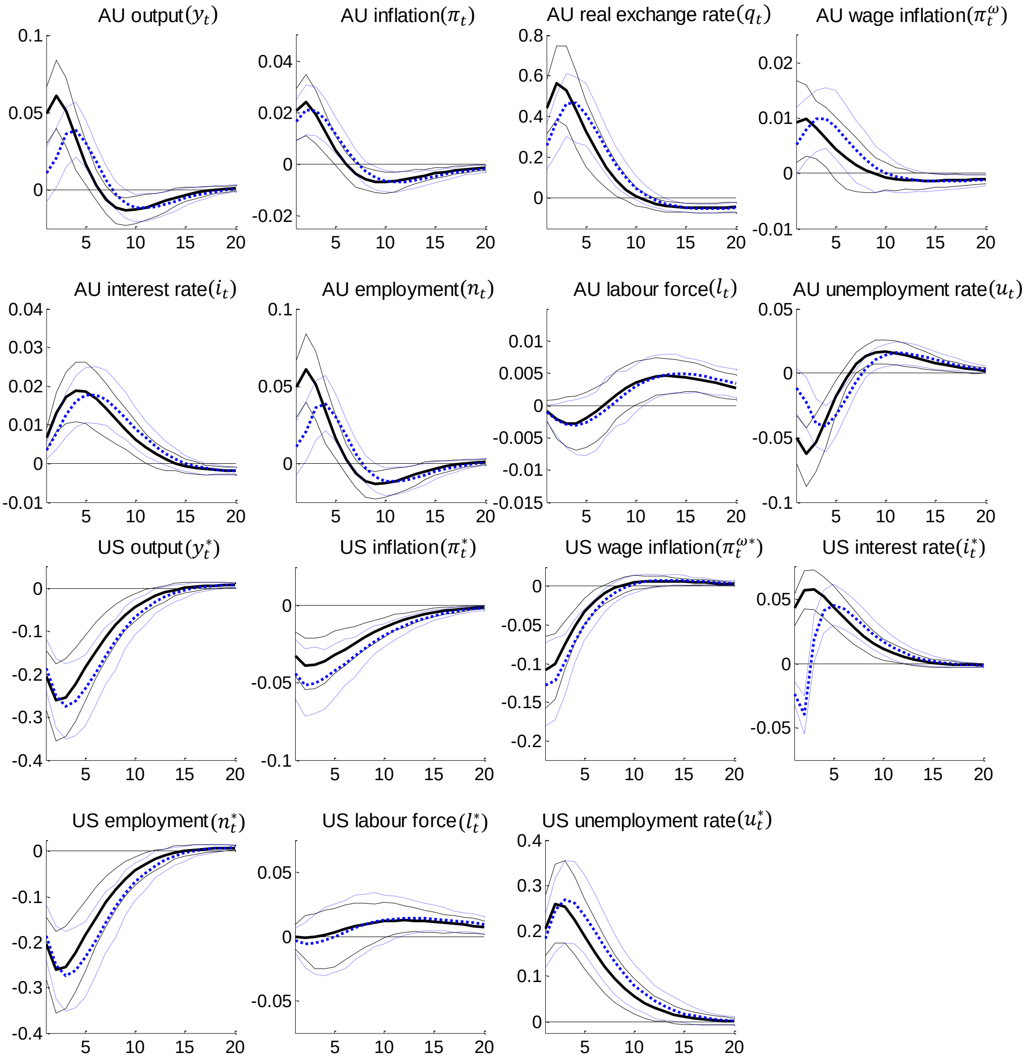
Notes: Impulse responses of eight domestic observed variables to one standard deviation unanticipated labour disutility shock (solid lines) and 4-period-ahead labour disutility news shock (dashed lines). The lines represent posterior means and 90 per cent posterior probability.

Figure 3.B.5 Impulse responses to positive AU price markup shocks



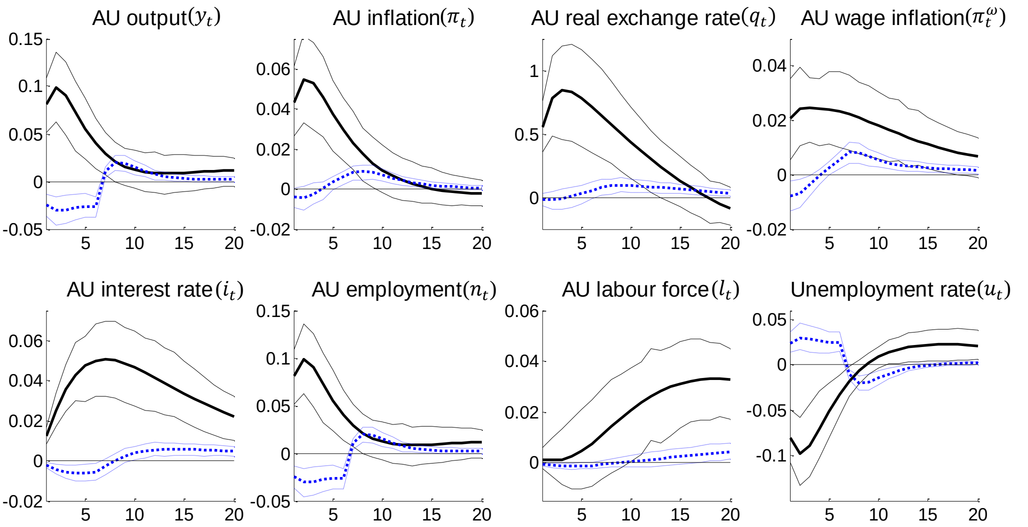
Notes: Impulse responses of eight domestic observed variables to one standard deviation unanticipated price markup shock in domestic firms (solid lines) and 1-period-ahead price markup news shock in domestic firms (dashed lines). The lines represent posterior means and 90 per cent posterior probability.

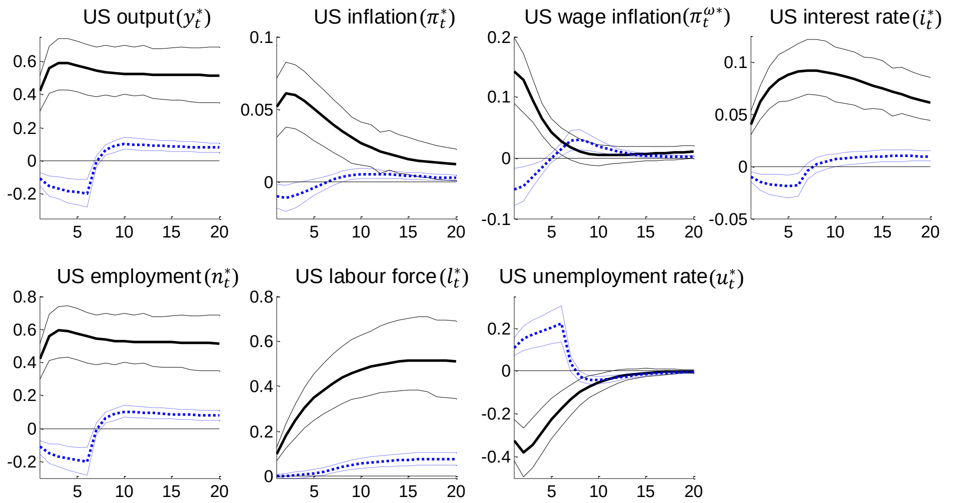
Figure 3.B.6 Impulse responses to tightening US monetary policy shocks



Notes: Impulse responses of observed variables to one standard deviation unanticipated MP shock (solid lines) and 2-period-ahead MP news shock (dashed lines). The lines represent posterior means and 90 per cent posterior probability interval.

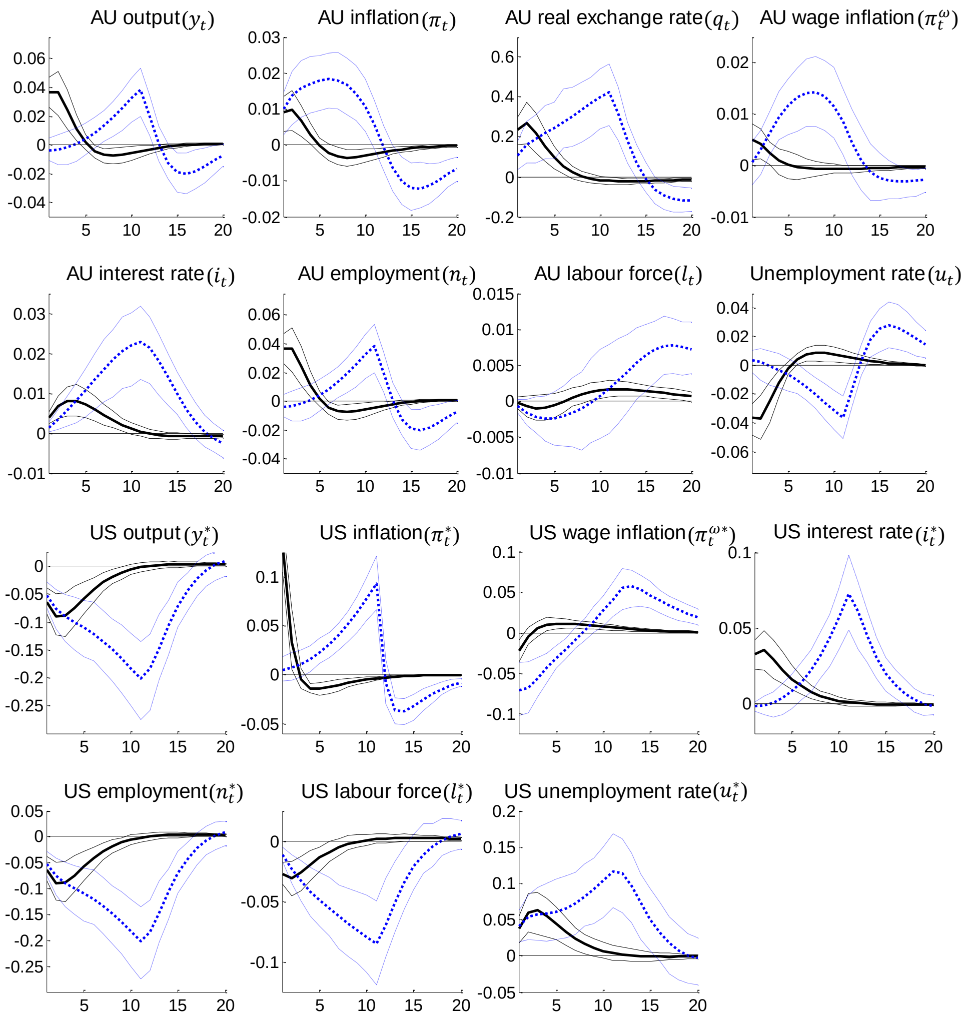
Figure 3.B.7 Impulse responses to positive US consumption preference shocks





Notes: Impulse responses of observed variables to one standard deviation unanticipated price markup shock (solid lines) and 6-period-ahead price markup news shock (dashed lines). The lines represent posterior means and 90 per cent posterior probability.

Figure 3.B.8 Impulse responses to positive US price markup shocks



Notes: Impulse responses of observed variables to one standard deviation unanticipated price markup shock (solid lines) and 10-period-ahead price markup news shock (dashed lines). The lines represent posterior means and 90 per cent posterior probability.

Figure 3.B.9 Forecast error variance decomposition

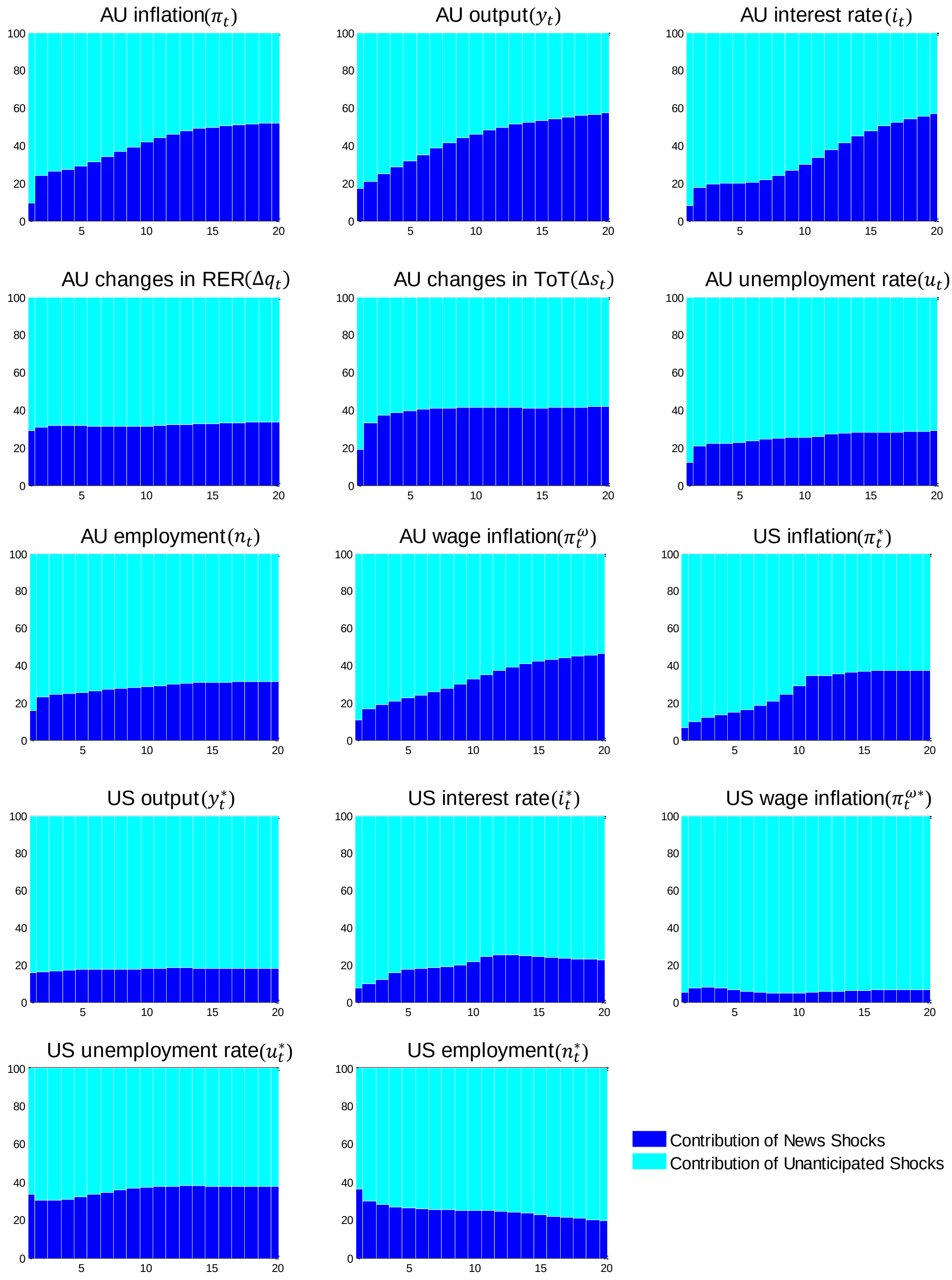
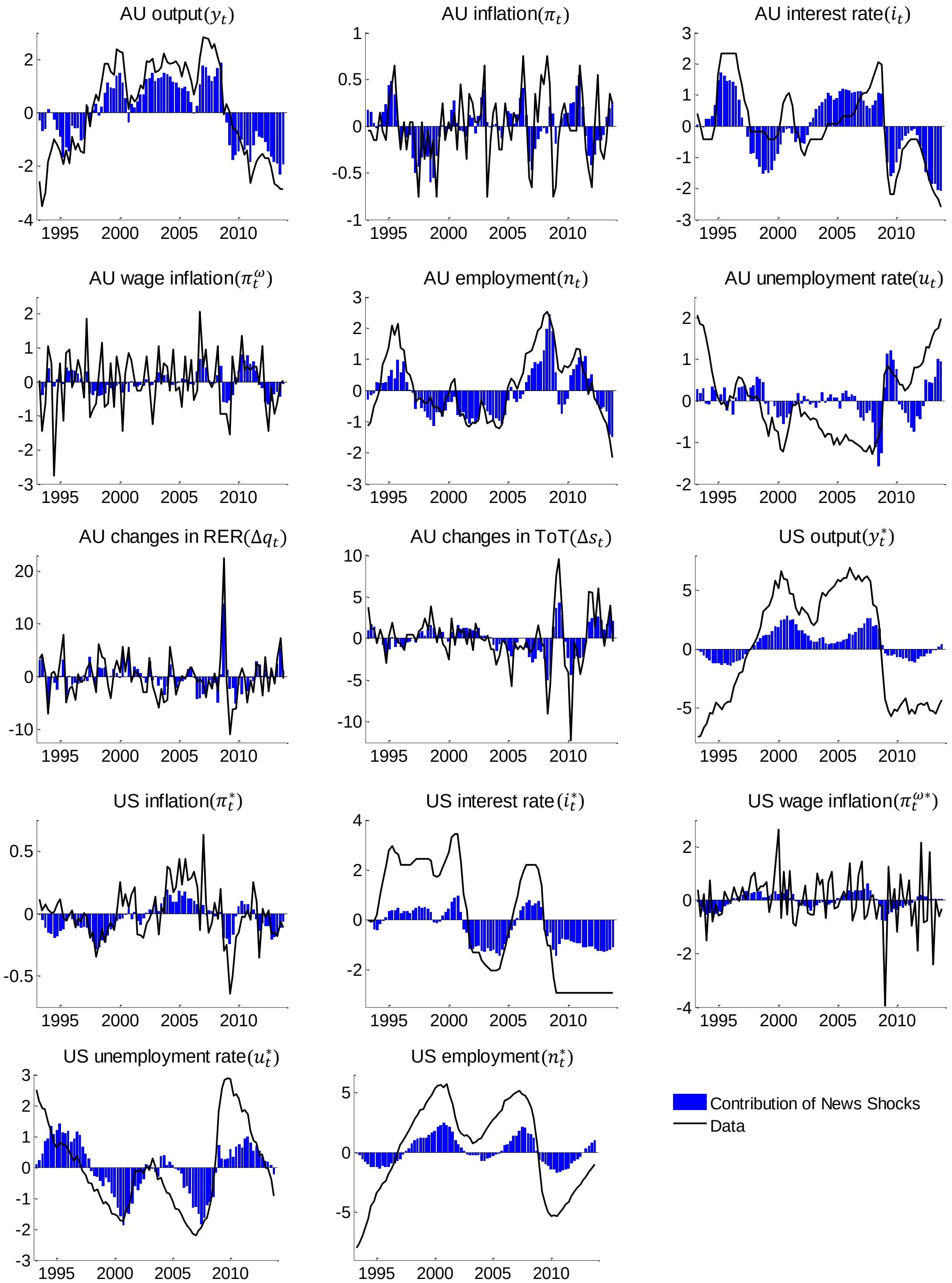


Figure 3.B.10 Actual data and contribution of news shocks



Appendix 3.C Derivation of key equations

3.C.1 Optimal wage setting decision of workers unions

Worker unions choose W'_t in order to maximize their expected perspective households' utility (3.8) subject to labour demand constraint (3.7). The optimization problem can be solved using stochastic Lagrangian multiplier approach, and Lagrangian function is

$$\mathcal{L}_t = \sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau E_t\left\{\Lambda_{t+\tau}W'_t\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega}N_{t+\tau|t} - \Theta_{t+\tau}\tilde{\varepsilon}_{n,t+\tau}\frac{N_{t+\tau|t}^{1+\varphi}}{1+\varphi} - \lambda_t^w\left(N_{t+\tau|t} - \left(\frac{W'_t}{W_{t+\tau}}\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega}\right)^{-\zeta_{\omega,t+\tau}}N_{t+\tau}\right)\right\}$$

First order conditions are found to be

$$\frac{\partial\mathcal{L}_t}{\partial W'_t} = \sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau E_t\left\{\begin{matrix}\Lambda_{t+\tau}\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega}N_{t+\tau|t} - \\ \lambda_t^w\zeta_{\omega,t}\left(\frac{1}{W_{t+\tau}}\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega}\right)^{-\zeta_{\omega,t+\tau}}{W'_t}^{-\zeta_{\omega,t+\tau}-1}N_{t+\tau}\end{matrix}\right\} = 0 \quad (3.C.1)$$

$$\frac{\partial\mathcal{L}_t}{\partial N_{t+\tau|t}} = \sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau E_t\left\{\Lambda_{t+\tau}W'_t\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega} - \Theta_{t+\tau}\tilde{\varepsilon}_{n,t+\tau}N_{t+\tau|t}^{\varphi} - \lambda_t^w\right\} = 0 \quad \Longrightarrow$$

$$\lambda_t^w = \sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau E_t\left\{\Lambda_{t+\tau}W'_t\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega} - \Theta_{t+\tau}\tilde{\varepsilon}_{n,t+\tau}N_{t+\tau|t}^{\varphi}\right\} \quad (3.C.2)$$

$$\frac{\partial\mathcal{L}_t}{\partial\lambda_t^w} = \left(\frac{W'_t}{W_{t+\tau}}\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega}\right)^{-\zeta_{\omega,t+\tau}}N_{t+\tau} - N_{t+\tau|t} = 0 \Longrightarrow$$

$$\left(\frac{1}{W_{t+\tau}}\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega}\right)^{-\zeta_{\omega,t+\tau}}{W'_t}^{-\zeta_{\omega,t+\tau}-1}N_{t+\tau} = N_{t+\tau|t}/W'_t \quad (3.C.3)$$

Substituting (3.C.2) and (3.C.3) into (3.C.1) yields

$$\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau E_t\left\{\Lambda_{t+\tau}\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega}N_{t+\tau|t} - \zeta_{\omega,t+\tau}\left[\Lambda_{t+\tau}W'_t\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega} - \Theta_{t+\tau}\tilde{\varepsilon}_{n,t+\tau}N_{t+\tau|t}^{\varphi}\right]\left(N_{t+\tau|t}/W'_t\right)\right\} = 0 \Longrightarrow$$

$$\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau E_t\left\{\Lambda_{t+\tau}N_{t+\tau|t}\left(\begin{matrix}(1-\zeta_{\omega,t+\tau})W'_t\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega} + \\ \zeta_{\omega,t+\tau}\frac{\Theta_{t+\tau}\tilde{\varepsilon}_{l,t+\tau}N_{t+\tau|t}^{\varphi}}{\Lambda_{t+\tau}}\end{matrix}\right)\right\} = 0 \quad (3.C.4)$$

From $MRS_{t+\tau|t} \equiv -\frac{U_{n,t+\tau|t}}{U_{c,t+\tau}}$ and $\Lambda_{t+\tau|t} = U_{c,t+\tau}/P_{t+\tau}$, the following relationship is obtained

$$P_{t+\tau}MRS_{t+\tau|t} = -\frac{U_{n,t+\tau|t}}{\Lambda_{t+\tau}} = \frac{\Theta_{t+\tau}\tilde{\varepsilon}_{n,t+\tau}N_{t+\tau|t}^{\varphi}}{\Lambda_{t+\tau}} \quad (3.C.5)$$

Substituting (3.C.5) into (3.C.4) results

$$\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau E_t\left\{\Lambda_{t+\tau}N_{t+\tau|t}\left(W'_t\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\delta_\omega} - \mathcal{M}_{\omega,t+\tau}^n P_{t+\tau}\,MRS_{t+\tau|t}\right)\right\} = 0 \quad (3.C.6)$$

where $\mathcal{M}_{\omega,t+\tau}^n \equiv \zeta_{\omega,t+\tau}/(\zeta_{\omega,t+\tau}-1)$ and $MRS_{t+\tau|t} = \frac{\Theta_{t+\tau}\tilde{\varepsilon}_{l,t+\tau}N_{t+\tau|t}^{\varphi}}{(\Theta_{t+\tau}/Z_{t+\tau})} = \tilde{\varepsilon}_{l,t+\tau}Z_{t+\tau}N_{t+\tau|t}^{\varphi}$[84]. Equation (3.C.6) is the combined condition of the first order conditions shown in equation (3.9) of the text.

[84] The notation of the endogenous preference shifter ($\Theta_t \equiv Z_t U_{c,t}$) is used here.

3.C.2 Log-linear approximation to equilibrium conditions[85]

Optimal wage setting: taking a log-linear approximation to equations (3.6) and (3.9) yields wage inflation equation. Log-linearization of the aggregate wage index (3.6) around the zero inflation steady state in which $W = W'$ is

$$W(1 + w_t) = W(1 + (1 - \theta_\omega)w'_t + \theta_\omega w_{t-1} + \theta_\omega \delta_\omega p_{t-1} - \theta_\omega \delta_\omega p_{t-2}) \Rightarrow$$

$$w_t = (1 - \theta_\omega)w'_t + \theta_\omega w_{t-1} + \theta_\omega \delta_\omega \pi^p_{t-1} \quad (3.C.7)$$

Subtracting w_{t-1} from both sides of equation (3.C.7) returns

$$w'_t - w_{t-1} = \frac{1}{1-\theta_\omega}\pi^w_t - \frac{\theta_\omega \delta_\omega}{1-\theta_\omega}\pi^p_{t-1} \quad (3.C.8)$$

where $\pi^w_t = w_t - w_{t-1}$ and $\pi^p_t = p_t - p_{t-1}$.

Note that in a perfect foresight zero inflation steady state, the following condition is satisfied:

$$\frac{W'}{P} = \frac{W}{P} = \mathcal{M}^n_\omega \, MRS$$

A log-linear approximation to equation (3.9) around above steady state is

$$W(1 + w'_t) = W + W(1 - \beta\theta_\omega)E_t\left[\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau\left(\mu^n_{\omega,t+\tau} + p_{t+\tau} + mrs_{t+\tau|t} - \delta_\omega p_{t+\tau-1}\right)\right] + W\delta_\omega p_{t-1} \Rightarrow$$

$$w'_t = (1 - \beta\theta_\omega)E_t\left[\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau\left(\mu^n_{\omega,t+\tau} + p_{t+\tau} + mrs_{t+\tau|t} - \delta_\omega p_{t+\tau-1}\right)\right] + \delta_\omega p_{t-1} \quad (3.C.9)$$

In order to replace $mrs_{t+\tau|t}$ in equation (3.C.9), a log-linear approximation to $MRS_{t+\tau|t} = Z_{t+\tau}\tilde{\varepsilon}_{l,t+\tau}N^\varphi_{t+\tau|t}$ has to be conducted as

$$MRS\left(1 + mrs_{t+\tau|t}\right) = MRS + MRS\varepsilon_{l,t+\tau} + MRSz_{t+\tau} + MRS\varphi n_{t+\tau|t} \Rightarrow$$

$$mrs_{t+\tau|t} = \varepsilon_{l,t+\tau} + z_{t+\tau} + \varphi n_{t+\tau|t}, \text{ where } \varepsilon_{l,t+\tau} = \log(\tilde{\varepsilon}_{l,t+\tau}/\tilde{\varepsilon}_l).$$

Using $mrs_{t+\tau} \equiv \varepsilon_{l,t+\tau} + z_{t+\tau} + \varphi n_{t+\tau}$ (see Galí 2008, 2011 for detail), the following equation can be obtained:

$$mrs_{t+\tau|t} = mrs_{t+\tau} + \varphi\left(n_{t+\tau|t} - n_{t+\tau}\right) \quad (3.C.10)$$

Linearizing the labour demand (3.7) yields

$$n_{t+\tau|t} - n_{t+\tau} = -\zeta_\omega\left(w'_t - w_{t+\tau} + \delta_\omega(p_{t+\tau-1} - p_{\tau-1})\right) \quad (3.C.11)$$

Combining equation (3.C.10) with equation (3.C.11) yields

$$mrs_{t+\tau|t} = mrs_{t+\tau} - \varphi\zeta_\omega\left(w'_t - w_{t+\tau} + \delta_\omega(p_{t+\tau-1} - p_{\tau-1})\right) \quad (3.C.12)$$

Using equation (3.C.12), (3.C.9) can be rewritten as

$$(1 + \varphi\varepsilon_\omega)w'_t = (1 - \beta\theta_\omega)E_t\left[\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau\begin{pmatrix}(1 + \varphi\zeta_\omega)w_{t+\tau} + \mu^n_{\omega,t+\tau} - \mu_{\omega,t+\tau} - \\ \delta_\omega(1 + \varphi\zeta_\omega)p_{t+\tau-1} + \delta_\omega\varphi\zeta_\omega p_{\tau-1}\end{pmatrix}\right] + \delta_\omega p_{t-1} \Rightarrow$$

$$w'_t = (1 - \beta\theta_\omega)E_t\left[\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau\left(w_{t+\tau} - (1 + \varphi\zeta_\omega)^{-1}\left(\mu_{\omega,t+\tau} - \mu^n_{\omega,t+\tau}\right) - \delta_\omega p_{t+\tau-1}\right)\right]$$

[85] The log-linear approximation is used to transform the equilibrium conditions into a linear form. The log-linearization transforms the domain with a log function, and then approximates with a linear function. By definition of the log-linearization, if $\mathbb{R} \rightarrow \mathbb{R}$ is differentiable, and x^* is some point in $\mathbb{R}$, then the log-linearization $\hat{f}$ of f around x^* is $\hat{f}(x) = f(X^*) + X^* f'(X^*)x$, where $x = \log X - \log X^*$.

$$+\delta_\omega p_{t-1} \tag{3.C.13}$$

where $\mu_{\omega,t} \equiv (w_t - p_t) - mrs_t$ denotes the economy's average wage markup.

Rewritten equation (3.C.13) in the period $t+1$

$$w'_{t+1} = (1-\beta\theta_\omega)E_t\left[\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau\left(w_{t+1+\tau} - (1+\varphi\zeta_\omega)^{-1}\left(\mu_{\omega,t+1+\tau} - \mu^n_{\omega,t+1+\tau}\right) - \delta_\omega p_{t+\tau}\right)\right] + \delta_\omega p_t \tag{3.C.14}$$

The right hand side of equation (3.C.13) can be rewritten in terms of two parts (when $\tau = 0$ and $\tau > 0$) as

$$w'_t = (1-\beta\theta_\omega)\Big[\left(w_t - (1+\varphi\zeta_\omega)^{-1}\left(\mu_{\omega,t} - \mu^n_{\omega,t}\right) - \delta_\omega p_{t-1}\right) + (\beta\theta_\omega)E_t\left[\sum_{\tau=0}^{\infty}(\beta\theta_\omega)^\tau\left(w_{t+1+\tau} - (1+\varphi\zeta_\omega)^{-1}\left(\mu_{\omega,t+1+\tau} - \mu^n_{\omega,t+1+\tau}\right) - \delta_\omega p_{t+\tau}\right)\right]\Big] + \delta_\omega p_{t-1} \tag{3.C.15}$$

Inserting equation (3.C.14) into equation (3.C.15) yields

$$w'_t = (1-\beta\theta_\omega)\left(\left(w_t - (1+\varphi\zeta_\omega)^{-1}\left(\mu_{\omega,t} - \mu^n_{\omega,t}\right) - \delta_\omega p_{t-1}\right)\right) + (\beta\theta_\omega)E_t[w'_{t+1} - \delta_\omega p_t] + \delta_\omega p_{t-1}$$

Subtracting w_{t-1} from both sides of above equation yields the following first order difference equation:

$$w'_t - w_{t-1} = (\beta\theta_\omega)E_t[w'_{t+1} - w_t] - (1-\beta\theta_\omega)(1+\varphi\zeta_\omega)^{-1}\left(\mu_{\omega,t} - \mu^n_{\omega,t}\right) + \pi^w_t - \delta_\omega\theta_\omega\beta\pi^p_t \tag{3.C.16}$$

Combining equation (3.C.16) with equation (3.C.8), the wage inflation equation shown in equation (3.10) can be found as

$$\pi^w_t - \delta_\omega\pi^p_{t-1} = \beta E_t\left(\pi^w_{t+1} - \delta_\omega\pi^p_t\right) - \varrho_\omega\left(\mu_{\omega,t} - \mu^n_{\omega,t}\right) \tag{3.C.17}$$

where $\varrho_\omega \equiv \frac{(1-\theta_\omega)(1-\beta\theta_\omega)}{\theta_\omega(1+\varphi\zeta_\omega)}$.

Labour supply curve: taking a log-linear approximation to equation (3.12) yields labour supply equation (3.13). Log-linearization of equation (3.12) around the steady state ($\frac{W}{P} = ZL(k)^\varphi$) is

$$\frac{W_t(k)}{P_t} = \tilde{\varepsilon}_{l,t}Z_tL_t(k)^\varphi \Rightarrow \frac{W}{P}(1 + w_t(k) - p_t) = ZL(k)^\varphi\left(1 + \varepsilon_{l,t} + z_t + \varphi l_t(k)\right)$$

$$w_t(k) - p_t = \varepsilon_{l,t} + z_t + \varphi l_t(k) \tag{3.C.18}$$

Endogenous reference shifter: A log-linear approximation to endogenous reference shifter, given by $Z_t = Z_{t-1}^{1-\vartheta_z}\tilde{\varepsilon}_{g,t}{}^{-\vartheta_z}(C_t - hC_{t-1})^{\sigma\vartheta_z}$, around the steady state is

$$Z(1+z_t) = Z + Z(1-\vartheta_z)\, z_{t-1} - Z\vartheta_z\varepsilon_{g,t} + Z\frac{\sigma\vartheta_z}{1-h}(c_t - hc_{t-1}) \Rightarrow$$

$$z_t = (1-\vartheta_z)\, z_{t-1} + \vartheta_z\left(-\varepsilon_{g,t} + \frac{\sigma}{1-h}(c_t - hc_{t-1})\right) \tag{3.C.19}$$

Chapter 4

Financial frictions and financial shocks in an estimated small open economy DSGE model

Abstract

This chapter examines the importance of financial frictions and financial shocks in a small open economy DSGE model for explaining macroeconomic fluctuations. In doing so, a small open economy DSGE model with involuntary unemployment, financial frictions and financial shocks is developed. To quantify effects, the model is estimated using Bayesian methods on Australian and the US data. The main results are (i) the presence of financial accelerator and foreign debt improves the model fit, and (ii) financial shocks (i.e., credit supply and financial wealth shocks) are important for explaining investment and output fluctuations, (iii) including financial data in the analysis changes the model dynamics and influences the significance of the financial and marginal efficiency of investment (MEI) shocks, and (iv) the financial and country risk premium shocks have contributed significantly to Australian investment downturns in 2001-2002 and 2008-2009.

Keywords: Financial frictions, Financial shocks, Open economy macroeconomics, New Keynesian DSGE model, Bayesian estimation.

JEL classification: C11, E22, E32, E44, F41

4.1 Introduction

A long-standing tradition in macroeconomics, beginning with Fisher's (1933) debt-deflation interpretation of the Great Depression, gives a central role to financial factors in driving business cycle fluctuations[86]. The global financial crisis (GFC) of 2008-2009 has shown that the real-financial linkage is essential in explaining macroeconomic fluctuations and should not be abstracted from business cycle models for designing appropriate stabilization policy. On the other hand, the Modigliani-Miller (1958) theorem asserts that financial structure (i.e., corporation finances itself by debt or equity) is both intermediate and irrelevant to real economic outcomes. However, the canonical macroeconomic models, adopting the assumption of frictionless financial markets articulated by Modigliani-Miller (1958), have failed to account for the severity of the interaction between financial conditions and the real economy during the GFC. Consequently, there has been a surge of interest in assessing the importance of financial factors in business cycle fluctuations using dynamic stochastic general equilibrium (DSGE) models featuring financial frictions and shocks.

The present chapter investigates whether financial frictions and financial shocks are important in an estimated small open economy DSGE model[87] for explaining macroeconomic fluctuations. The present chapter contributes to the existing literature by examining the following questions: (i) are financial frictions and foreign debt empirically relevant in an estimated small open economy model? (ii) do financial frictions play an important role in the transmission of non-financial shocks? and (iii) what are the quantitative effects of financial shocks on business cycle dynamics in Australia and the US?

From the modelling point of view, the departure point is the model built in Chapter 3, which reformulates the Justiniano and Preston (2010a,b; henceforth J-P) model to allow for involuntary unemployment as suggested by Galí (2011) and Galí et al. (2011). In order to address the research questions, the model is further extended in three dimensions. First, the capital is incorporated into the model as a preliminary requirement for incorporating financial frictions. Second, financial frictions are incorporated into the model based on

[86] Drawing on Fisher (1933), it can be argued that deteriorating credit market conditions (e.g., rising debt burdens and falling asset prices) are not a passive reflection of a weakening real economy, but are themselves a key source of economic contractions.

[87] The model consists of a small open economy (Australia) and a large economy (the US). However, the model is asymmetric in structure, implying that there is an only one way effect from the US to Australia.

the financial accelerator framework developed by Bernanke et al. (1999) (henceforth, BGG) that is in turn built on Bernanke and Gertler (1989)[88], Bernanke et al. (1996) and Carlstrom and Fuerst (1997). In particular, the modelling of financial frictions assumes that domestic is entrepreneurs holds both domestic and foreign (or foreign currency denominated) debts and follows the framework used by Gertler et al. (2007), Christensen and Dib (2008), Gilchrist et al. (2009) and Christiano et al. (2008, 2010, 2014)[89]. Third, two financial shocks, directly affecting the financial sector (i.e., the credit spread or borrowers' external financing cost), are introduced. Specifically, credit supply shock and financial wealth shock are included following the recent literature (e.g., Dib et al. 2008, Gilchrist et al. 2009 and Christiano et al. 2010).

Three versions of the model are estimated using Bayesian methods for Australian and the US data over the period 1993:Q1-2013:Q4, covering the inflation-targeting period in Australia and the GFC. The main findings can be summarized as follows. First, the presence of financial frictions in the model substantially changes the model dynamics and improves the model fit in terms of the Bayes factor, suggesting that financial frictions are empirically relevant. Second, financial shocks (i.e., changes in the credit supply and/or in the equity market index) play a significant role in driving investment and output fluctuations in both countries. In the case of Australia, the financial shocks account for around 40 per cent of the variation in investment, a quarter of GDP and more than 90 per cent of the spread on the external finance and equity market index. Third, when the model with financial frictions is estimated to match financial data, shocks to demand of the capital market (i.e., financial shocks) is more important in explaining macroeconomic fluctuations compared to shocks to the supply of the market (i.e., the MEI shock). Fourth, the estimated model implies that the vast bulk of Australian investment downturns in 2001-2002 are mainly explained by the country risk premium shock, while the sharp downturn in investment during the GFC is attributable to both financial and country risk premium shocks.

The remainder of the chapter is structured as follows. Section 4.2 describes a small open economy model with financial frictions and shocks. Section 4.3 presents the model

[88] Bernanke and Gertler (1989) originally formulated ideas of the credit-view (i.e., financial frictions) in a general equilibrium framework by assuming the costly state verification problem proposed by Townsend (1979) in which lenders must pay some monitoring cost to observe borrowers' true payoff.

[89] Earlier papers incorporating financial frictions in general equilibrium models include, for example, those published by Kiyotaki and Moore (1997), Christiano et al. (2003), Céspedes et al. (2004), Elekdag et al. (2006) and Meier and Müller (2006).

solution and estimation, consisting of the data and priors for parameters of the model. Section 4.4 discusses the importance of financial frictions and shocks in the model for explaining macroeconomic fluctuations. Finally, section 4.5 concludes that financial frictions and shocks play a pivotal role in explaining real economic activity, particularly, investment and output by looking through the empirical findings.

4.2 The model

4.2.1 The basic structure of the model

The basic structure of the model is the model built in Chapter 3 that is, in turn, based on the J-P model[90]. The basic structure deviates from the J-P model in the following ways. First, the J-P model is reformulated to allow some imperfections in the labour market (i.e., introducing involuntary unemployment and wage setting process) following the papers published by Galí (2011) and Galí et al. (2011). Second, the foreign economy is specified as the closed economy version of the open economy model as assumed by Monacelli (2005). Third, as suggested by Adolfson et al. (2008) and Adolfson et al. (2013), the UIP condition is modified by allowing for a negative correlation between the country risk premium and the expected depreciation in the nominal exchange rate. Fourth, the cost channel of monetary policy (i.e., working capital channel) is incorporated as discussed by Christiano et al. (2011) assuming that the domestic firms must borrow working capital loans to pay for inputs (i.e., a friction of wage bills), whereas the retail firms borrow their imported goods loans from a foreign seller at the foreign currency interest rate. As assumed by Christiano et al. (2010), the working capital loans are frictionless, implying that there is no asymmetric information between borrower and lender, and no risk to lenders.

The model assumes that only the accumulation and management of physical capital involves frictions. To this end, it is necessary to modify the setting of the above environment by incorporating the capital (produced by capital producers) as another factor input, and introducing entrepreneurs who purchase new, installed physical capital

[90] The J-P model technically represents a semi-small open economy, where domestic producers have some market power. The specification of the model allows for incomplete asset markets, habit formation and indexation of prices to past inflation in a small open economy model, proposed by Monacelli (2005) and Galí and Monacelli (2005). The Justiniano and Preston (2010a) model assumes fully flexible wages and perfect competition in labour markets. However, Justiniano and Preston (2010b) incorporate staggered wage setting following Erceg et al. (2000) into Justiniano and Preston’s (2010a) model.

and rent out capital services to domestic producers. Consequently, the model consists of households, labour unions, firms (domestic producers and retailers), capital producers, entrepreneurs and policy makers (a monetary authority and a fiscal authority). Behaviours of households, labour unions, retail firms and a monetary authority are not affected by introducing financial frictions into the model. Thus, in what follows, the characteristics of capital producers, domestic goods producers, entrepreneurs and a fiscal authority are discussed, and the general equilibrium is defined.

4.2.2 Introducing capital into the model

4.2.2.1 Capital producers

There is a continuum of perfectly competitive capital producers. At the end of period t, they purchase investment goods and install physical capital that has been used in period t from entrepreneurs. Capital producers use these inputs to produce new installed capital that can be used in period $t+1$, and sell the new capital to entrepreneurs.

As discussed by Christiano et al. (2003, 2008), consistent with profit maximization and market clearing on the capital market, the total amount of capital purchased by capital producers must be equal to total undepreciated capital stock in the economy. Thus the economy-wide capital available for production evolves over time according to

$$K_{t+1} = (1-\delta)K_t + \tilde{\varepsilon}_{i,t}\left(1-\chi\left(\frac{I_t}{I_{t-1}}\right)\right)I_t \tag{4.1}$$

where I_t denotes gross investment. As used by Christiano et al. (2005), the investment adjustment cost function $\chi(\cdot)$ is an increasing and convex function with the following properties in steady state: $\chi(1) = \chi'(1) = 0$, and $\chi''(1) = 1/\kappa > 0$. And $\tilde{\varepsilon}_{i,t}$ denotes the marginal efficiency of investment (MEI) shock that affects how investment is transformed into capital. Justiniano et al. (2010, 2011) have emphasized the importance of the MEI shock in explaining business cycles. The optimization problem of a representative capital producer is to maximize the present discount value of future profits

$$\underset{\{I_{t+\tau}\}}{\text{Max}}\, E_t \sum_{\tau=0}^{\infty} \beta^{\tau}\, \Lambda_{t+\tau}\, \Pi_{t+\tau}^{k} \tag{4.2}$$

where the capital producer's profits in period t is given by

$$\Pi_t^k = Q_t P_t\left((1-\delta)K_t + \tilde{\varepsilon}_{i,t}\left(1-\chi\left(\frac{I_t}{I_{t-1}}\right)\right)I_t - K_t\right) - P_t I_t,$$

E_t is the expectation conditional on the time-t information set including all time-t shocks, P_t and Q_t respectively denotes the consumer price index and the real price of (both new and used) installed capital (Tobin's Q), and $\Lambda_{t+\tau}$ denotes marginal utility of income[91]. The first-order condition to this problem yields the investment demand equation given by

$$\left(1-\chi\left(\frac{I_t}{I_{t-1}}\right)-\chi'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right)\tilde{\varepsilon}_{I,t}Q_t$$

$$+\beta E_t\left\{Q_{t+1}\tilde{\varepsilon}_{i,t+1}\frac{\Lambda_{C,t+1}}{\Lambda_{C,t}}\chi'\left(\frac{I_{t+1}}{I_{t+1}}\right)\left(\frac{I_{t+1}^2}{I_t^2}\right)\right\}=1 \qquad (4.3)$$

4.2.2.2 Domestic good producers

Aggregate domestic output is determined by the following Dixit-Stiglitz aggregate:

$$Y_t=\left(\int_0^1 Y_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right)^{\frac{\varepsilon}{\varepsilon-1}} \qquad (4.4)$$

where $\varepsilon>1$ denotes the elasticity of substitution between types of differentiated domestic goods. The differentiated goods are produced by monopolistically competitive domestic firms, indexed by $i\in[0,1]$. Each firm i produces a differentiated good using the following production technology:

$$Y_{H,t}(i)=\tilde{\varepsilon}_{a,t}K_t^s(i)^{\Omega}N_t(i)^{1-\Omega} \qquad (4.5)$$

where $\tilde{\varepsilon}_{a,t}$ represents technology shock, Ω determines the share of capital services in production, $K_t^s(i)$ represents the capital service (i.e., effective utilization of the capital stock) given by $K_t^s(i)=U_tK_t$, U_t implies the degree of capital utilization, and $N_t(i)$ denotes the labour service.

Firms are competitive in factor markets where they confront a nominal rental rate, $P_tR_t^k$, on capital services and a nominal wage rate, W_t, on labour services. As assumed by Christiano et al. (2010), each firm must finance a constant fraction, υ_k, of its rental cost of capital, $P_tR_t^kK_t^s(i)$, and a constant fraction, υ_n, of its wage bill, $W_tN_t(i)$, in advance of production at a (one-period) nominal interest rate, R_t. Then, the cost minimization problem of a representative domestic producer implies

[91] Households have the same marginal utility of income, $\Lambda_{t+\tau}=\Lambda_{C,t+\tau}/P_{t+\tau}$, where $\Lambda_{C,t+\tau}$ denotes the marginal utility of consumption (see, Woodford 2003, Chapter 3). This is derived from the household optimization.

$$R_t^k = \frac{\Omega}{1-\Omega}\left(\frac{N_t}{K_t^s}\right)\left(\frac{W_t}{P_t}[1+\upsilon_n R_t]\right)(1+\upsilon_k R_t)^{-1} \quad (4.6)$$

The firm's real marginal cost of producing one unit of output, $Y_{H,t}(i)$, is given by

$$MC_t = \Omega^{-\Omega}(1-\Omega)^{-(1-\Omega)}\left(\frac{W_t}{P_t}[1+\upsilon_n R_t]\right)^{1-\Omega}\left(R_t^k[1+\upsilon_k R_t]\right)^{\Omega}\left(\tilde{\varepsilon}_{a,t}\right)^{-1}\left(\frac{P_t}{P_{H,t}}\right) \quad (4.7)$$

Remaining behaviours of the domestic producer are same as described in the J-P model.

4.2.3 Introducing financial frictions and financial shocks

The behaviour of entrepreneurs is modelled in the form of a BGG financial accelerator mechanism. Specifically, this section closely follows the modelling framework of Gertler et al. (2007), Christensen and Dib (2008) and Gilchrist et al. (2009)[92]. In the framework, the financial frictions reflect the condition in which borrowers and lenders are different agents who have different information. Therefore, the model includes 'entrepreneurs' who own and manage the capital stock, financed both by internal and external (i.e., borrowed) funds.

There is a large number of entrepreneurs in the economy. At the end of period t, each entrepreneur has a level of real net worth, NW_{t+1}. The entrepreneurs combine their net worths with a nominal debt (e.g., taking bank loan or issuing bond), B_{t+1}, to purchase new, installed physical capital, K_{t+1}, from the capital producer. The real loan for this purpose is

$$\frac{B_{t+1}}{P_t} = Q_t K_{t+1} - NW_{t+1} \quad (4.8)$$

In the model, foreign-denominated debt is also considered regarding the literature on introducing BGG-type financial frictions into an open economy model (e.g., Céspedes et al. 2004, Elekdag et al. 2006, Gertler et al. 2007 and Dib et al. 2008). In particular, the model incorporates the co-existence of foreign and domestic currency debt in a small open economy as modelled by Anand et al. (2010) and Freystätter (2011). The presence of the foreign currency debt helps the model to capture the effects of exchange rate depreciation triggered by external shocks on the economy passing through the balance sheets of entrepreneurs.

[92] Other papers employed the framework include, for example, Céspedes et al. (2004), Elekdag et al. (2006), Dib (2008, 2010a,b), Anand et al. (2010) and Freystätter (2010, 2011).

The constant fraction, ϖ^d, of the borrowing, B^d_{t+1}, is raised domestically (or in domestic currency), and $(1-\varpi^d)$ friction of the borrowing, B^f_{t+1}, is raised from abroad (or in foreign currency). Therefore, the domestic currency and foreign currency denominated debts are respectively given by

$$B^d_{t+1} = \varpi^d (Q_t K_{t+1} - NW_{t+1}) P_t \quad (4.9)$$

$$B^f_{t+1} = (1-\varpi^d)(Q_t K_{t+1} - NW_{t+1}) P_t \quad (4.10)$$

After observing the period $t+1$ aggregate rates of capital return and prices, each entrepreneur determines the utilization rate of its effective capital, U_{t+1}, and then rents out capital services, $U_{t+1}K_{t+1}$, in a competitive market. The nominal rental rate of capital services is denoted by $R^k_{t+1}P_{t+1}$. In choosing the capital utilization rate, each entrepreneur takes into account the 'user cost' function, $a(U_{t+1})K_{t+1}P_{t+1}$, $a', a'' > 0$[93]. Thus the entrepreneur chooses U_{t+1} to maximize the rental profits

$$\max_{\{u_{t+1}\}} [U_{t+1}R^k_{t+1} - a(U_{t+1})]\, K_{t+1}P_{t+1}$$

The first-order condition of the maximization gives

$$R^k_{t+1} = a'(U_{t+1}) \quad (4.11)$$

Equation (4.11) implies that as the rental rate increases, it becomes more profitable to use capital more intensively up to the point where extra gains match the extra output costs[94].

The entrepreneur's demand for capital depends on the expected marginal return and the expected marginal financing cost. The expected marginal return to capital purchased in period t (i.e., expected gross return to holding a unit of capital from t to $t+1$), $E_t\left(1+R^{e,k}_{t+1}\right)$, can be written[95] as

$$E_t\left(1+R^{e,k}_{t+1}\right) = \frac{E_t\left[U_{t+1}R^k_{t+1} - a(U_{t+1}) + (1-\delta)Q_{t+1}\right]}{Q_t} \quad (4.12)$$

[93] Operating one unit of physical capital at rate U_{t+1} requires $a(U_{t+1})$ of investment goods for maintenance costs. The increasing and convex function $a(\cdot)$ captures the idea that the capital utilization is costly.
[94] As discussed by Christiano (2010), the following steady-state conditions are assumed: $U = 1$, $a(1) = 0$, $a''(U)/a'(U) = \sigma_a \geq 0$ is a parameter that controls the degree of convexity of the cost function.
[95] After determining the utilization rate of capital and earning rent (net of utilization costs), the entrepreneur sells the undepreciated fraction of its capital, $(1-\delta)K_{t+1}$, at the real price, Q_{t+1} to capital producers. In this way, the total pay-off in period $t+1$ received by the entrepreneur, expressed in real term is $[U_{t+1}R^k_{t+1} - a(U_{t+1}) + (1-\delta)Q_{t+1}]K_{t+1}$. This can be also expressed as $\left(1+R^{e,k}_{t+1}\right)Q_tK_{t+1}$ to measure gross return to capital purchased in period t (the amount of K_{t+1} at Q_t price).

The marginal cost of external funds to the entrepreneur depends on financial conditions. As assumed by BGG, there exists an agency problem (i.e., a costly state verification problem proposed by Townsend 1979). The lender must pay a monitoring cost to observe the borrower's true payoff (i.e., the realized return on capital). Under this problem, a financial contract itself is an instrument that can be used to overcome the asymmetric information between lenders and borrowers. Therefore, the entrepreneur and the lender negotiate a financial contract that simultaneously satisfies (i) the requirement that the lender receive an expected return at the end of the contract equal to the opportunity cost of his or her fund; and (ii) maximization of the end-of-contract level of net worth for the entrepreneur. The expression and derivation of the optimal contract between entrepreneurs and lenders under asymmetric information triggered by the agency problem is well detailed in various papers (see BGG, Gertler et al. 2003 and Chiristiano et al. 2010, 2014). The optimal contract under the agency problem suggests that external finance is more expensive than internal finance (using internally generated cash flows), owing to the costs of evaluating borrower's prospects and monitoring their actions. Since the lender must receive a competitive return, it charges the borrower a premium to cover the monitoring cost (i.e., interpretable as a bankruptcy cost). The premium is the so-called external finance premium (EFP) that a borrower must pay.

The financial contract overcomes the asymmetric information by making the terms of the debt dependent on the borrower's financial position. Specifically, solving the optimal contract, BGG show that the EFP (or credit spread), $S_t(\cdot)$, can be an increasing function of the borrower's leverage ratio, $Q_t K_{t+1}/NW_{t+1}$. Following recent papers (see Dib et al. 2008, 2010a,b, Gilchrist et al. 2009 and Freystätter 2010, 2011), a shock to the EFP is also introduced. Thus the EFP is assumed to have the following functional form:

$$S_t(\cdot) = \left(\frac{Q_t K_{t+1}}{NW_{t+1}}\right)^{\psi} \tilde{\varepsilon}_{cs,t} \tag{4.13}$$

where the parameter, $\psi > 0$, measures the elasticity of the EFP with respect to the leverage. Changes in the credit spread may also reflect shifts in the effective supply of funds offered by financial intermediaries in the presence of financial market frictions (Gilchrist and Zakrajšek 2012). Thus, as assumed by Gilchrist et al. (2009), the credit supply shock, $\tilde{\varepsilon}_{cs,t}$ ($\tilde{\varepsilon}_{cs} = 1$ in the steady state), affects the EFP. The shock to the supply of credit, $\tilde{\varepsilon}_{cs,t}$, captures changes in the efficiency of the financial intermediation process or changes in the financial sector that raise or lower the EFP beyond the level warranted by current economic conditions (e.g., a deterioration in the capital position of financial intermediaries, leading to a reduction in the credit supply)[96].

By definition, the entrepreneur's overall expected marginal cost of funds is the product of the EFP, $S_t(\cdot)$, and the gross real opportunity cost of funds that is the cost of raising funds in the absence of capital market frictions, $E_t f_{t+1}$. According to equations (4.9) and (4.10), the expected gross real opportunity cost of funds, $E_t f_{t+1}$, is the weighted average of the expected costs for domestic currency debt, $E_t f_{t+1}^d$, and for foreign currency denominated debt, $E_t f_{t+1}^f$:

$$E_t f_{t+1} = \varpi^d E_t f_{t+1}^d + (1-\varpi^d) E_t f_{t+1}^f \tag{4.14}$$

where $E_t f_{t+1}^d = (1+R_t)\frac{P_t}{P_{t+1}}$ and $E_t f_{t+1}^f = (1+R_t^*)\Phi_{t+1}\frac{\tilde{e}_{t+1}}{\tilde{e}_t}\frac{P_t}{P_{t+1}}$. Here, $\tilde{e}_t$ denotes the nominal exchange rate, R_t^* denotes the foreign risk-free nominal interest rate, Φ_{t+1} represents the country risk premium, and P_t^* indicates the foreign overall price index. In the equilibrium, the uncovered interest rate parity condition, $(1+R_t) = (1+R_t^*)\Phi_{t+1}(\tilde{e}_{t+1}/\tilde{e}_t)$, ensures that $E_t f_{t+1}^d$ equals $E_t f_{t+1}^f$. Consequently, the entrepreneur's demand for capital satisfies the optimality condition[97]

$$E_t\left(1+R_{t+1}^{e,k}\right) = E_t\left[S_t(\cdot)\left(\varpi^d(1+R_t)\frac{P_t}{P_{t+1}} + (1-\varpi^d)(1+R_t^*)\Phi_{t+1}\frac{RER_{t+1}}{RER_t}\frac{P_t^*}{P_{t+1}^*}\right)\right] \tag{4.15}$$

where $RER_t = \tilde{e}_t P_t^*/P_t$ denotes the real exchange rate and the right-hand side of equation (4.15) shows the expected marginal financing cost. Equation (4.15) provides the foundation for the financial accelerator, in which endogenous changes in the credit market work to propagate and amplify shocks to the macroeconomy. This links the entrepreneur's financial position to the marginal cost of funds and, hence, to the demand for capital. For example, changes in the price of capital, Q_t, may have significant effects on the leverage ratio, $Q_t K_{t+1}/NW_{t+1}$. In this way, the model also captures the relation

[96] The reverse relationship between the EFP and the borrower's net worth arises since, when the borrower can finance the greater share of capital by self-finance or finance with collateralized debt, lender's risk (i.e., the expected bankruptcy costs for lenders) will be lower and hence, borrowers in good financial condition generally pay a lower EFP for external finance. Because borrowers' net worth is pro-cyclical (e.g., due to the pro-cyclicity of profits and assets prices), the EFP will be countercyclical, promoting the swings in borrowing, and hence in investment, spending and production.

[97] For an entrepreneur who is not fully self-financed, it would be optimal when the expected return to capital in equilibrium equals the expected marginal financing cost. Let us assume, for example, that at margin, the entrepreneur considers acquiring a unit of capital financed by debt. However, the additional debt increases the leverage ratio, raising the EFP and the overall marginal cost of finance. Consequently, compared to the perfect capital markets, the demand for capital is lower.

between asset price movements and collateral in the theory of the credit cycle stressed by Kiyotaki and Moore (1997).

After entrepreneurs have settled their debt to the lender in period $t+1$, and the capital has been re-sold to capital producers, entrepreneurs' net worth in period $t+1$ is determined. At this point, entrepreneurs exit the economy with probability, $1-\gamma_{t+1}$, and survive to continue another period of activity with probability, γ_{t+1}. Each period new entrepreneurs enter in sufficient numbers so that the population of entrepreneurs remains constant. New entrepreneurs entering in period $t+1$ receive a 'start-up' transfer of net worth, W^e. Since W^e is relatively small, this exit and entry process helps to ensure that entrepreneurs do not accumulate enough net worth to escape the financial frictions. Let V_t be aggregate entrepreneurial equity (i.e., wealth/profits accumulated by entrepreneurs). Then the law of motion for aggregate net worth, NW_{t+1}, is

$$NW_{t+1} = \gamma_t V_t + W^e \tag{4.16}$$

with

$$V_t = \left(1+R_t^{e,k}\right)Q_{t-1}K_t - \left[S_{t-1}(\cdot)\left(\varpi^d(1+R_{t-1})\frac{P_{t-1}}{P_t} + (1-\varpi^d)(1+R_{t-1}^*)\Phi_t\frac{RER_t}{RER_{t-1}}\frac{P_{t-1}^*}{P_t^*}\right)\right]\frac{B_t}{P_t-1} \tag{4.17}$$

where $\gamma_t V_t$ denotes the equity held by entrepreneurs at period $t-1$ who are still in business at period t. The aggregate entrepreneurial equity, V_t, equals gross earnings of entrepreneurs who are active in period t minus their total payments to lenders. In this expression, $\left(1+R_t^{e,k}\right)$ denotes the ex-post real return on capital, and the object in square brackets in equation (4.17) represents the ex-post cost of borrowing.

According to equation (4.17), changes in net worth are propagated through three channels, each of which is economically distinctive. On the asset side, there is a genuine 'accelerator' channel that alters net worth by changes in the flows of entrepreneurial earnings and by capital gains and losses on entrepreneurial assets. As discussed by Gertler et al. (2007), equations (4.16) and (4.17) suggest unpredictable variations in the asset price, Q_t, play a key role in the financial accelerator since the variations provide the principle source of fluctuations in $\left(1+R_t^{e,k}\right)$ given by equation (4.12). For example, decline in asset prices (for example, due to negative demand shocks) deteriorates the borrowers' balance sheet (i.e., decreases in net worth) leading to an increase in the EFP, and hence raise external financing cost. The increase in external financing cost, in turn, reduces the demand for capital and leads to further cuts in investment and output. The resulting slowdown in economic activity causes asset prices to fall further and deepens the economic downturn. This is the financial accelerator channel highlighted by BGG, and it tends to amplify the economic effects of any shock that has a pro-cyclical impact on economic activity. On the liability side, changes in net worth are propagated through the 'Fisher deflation channel' highlighted by Fisher (1933) and the 'foreign-currency denominated debt channel' stressed by Aghion et al. (2000) and Céspedes et al. (2004). The 'Fisher deflation' channel implies that in the case of nominal debt contracts, negative surprises to the price level can alter the ex-post real burden of the debt that the borrower will have to bear when the contract will eventually mature. Therefore, unexpected deflation reduces entrepreneurial net worth. The 'foreign-currency denominated debt channel' implies that if debt is denominated in foreign currency units, the depreciation of the exchange rate trigged by external shocks decreases entrepreneurial net worth, thus enhancing the financial accelerator mechanism. As shown by Christiano et al. (2003, 2010), 'Fisher deflation' and 'accelerator' channels reinforce each other when shocks move the price level and output in the same direction, but also tend to cancel each other in the case of shock, which moves the price level and output in opposite directions. Gertler et al. (2007) and Freystätter (2011) have shown that the 'foreign currency denominated debt channel' supports the 'accelerator' channel in the case of a country risk premium shock.

According to equations (4.16) and (4.17), the value of entrepreneurs' net worth at the end of period t is hit by two financial shocks (i.e., two different sources of shock to the EFP) with different time structures. First, a shock to the survival probability (i.e., variations in the rate of destruction of total financial wealth of the economy), referred to as a financial wealth shock, $\tilde{\varepsilon}_{fw,t}$ (i.e., $\tilde{\varepsilon}_{fw} = 1$ in the steady state), is introduced by assuming $\gamma_t = \gamma\tilde{\varepsilon}_{fw,t}$ as suggested by Christiano et al. (2003, 2008, 2010). This shock was originally introduced by Gilchrist and Leahy (2002) and captures changes in the entrepreneurial net wealth that are not linked to movements in fundamentals (e.g., driven by 'irrational exuberance' or asset price bubbles). Nolan and Thoenissen (2009) refer to the shock as a shock to the efficiency of contractual relations between borrowers and lenders. The financial wealth shock, $\tilde{\varepsilon}_{fw,t}$, is realized at time t and has a contemporaneous impact on net worth in period t, N_{t+1}, and therefore affects directly the creditworthiness of borrowers. Second, the credit supply shock, $\tilde{\varepsilon}_{cs,t-1}$, raising directly the EFP at the period $t-1$, reduces entrepreneurial net worth at the end of period t, N_{t+1}, by increasing payments to lenders, per unit of currency borrowed. The exogenous changes in the EFP and entrepreneur net worth affect the economy passing through the financial accelerator mechanism (i.e., acting through entrepreneur's balance sheets). Therefore, the financial shocks can be a source of macroeconomic fluctuations.

Entrepreneurs who close business at period t consume their remaining resources. Thus, the amount of the consumption composite consumed by exiting entrepreneurs, C_t^e, is given by

$$C_t^e = (1-\gamma)V_t \tag{4.18}$$

In this expression, $(1-\gamma_t)V_t$ denotes the total amount of equity that exiting entrepreneurs remove from the market.

4.2.4 Resource constraint

The aggregate resource constraint is given by

$$C_{H,t} + C_{H,t}^* + C_t^e + G_t + I_t + a(U_t)K_{t-1} = Y_t \tag{4.19}$$

where $C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t$ and $C_{H,t}^* = \varsigma\left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\eta^*} Y_t^*$ respectively denote the domestic and foreign demands for domestically produced goods as discussed in the J-P model. The third term corresponds to the consumption of the $1-\gamma_t$ entrepreneurs who exit the economy in period t. Government consumption, G_t, is determined exogenously and a government spending shock follows a stochastic process as modelled by Smets and Wouters (2003, 2007)[98]. The fifth term is the amount of final goods used in producing I_t investment goods. The last term on the left of equation (4.19) captures capital utilization costs. Note that modification in the aggregate resource constraint also changes the linearized dynamics of the net foreign asset in the J-P model. The modified equation of the net foreign asset is shown in Appendix 4.C.4.

4.2.5 The foreign economy

All foreign variables and parameters are denoted by superscript "*" in the log-linearized model. As assumed by Monacelli (2005) and Justiniano and Preston (2010b), the foreign economy is modelled as a closed version of the model in the open economy by assuming that the foreign economy is very large, and trade flows to and from the domestic economy

[98] Fiscal policy is fully Ricardian. The government finances its budget deficit by issuing short-term bonds.

are negligible compared to total foreign economic activity. The fraction of the borrowing raised domestically, ϖ^{d*}, is equal to one in the foreign economy, and the remaining setting is the same as for the domestic economy.

4.2.6 The log-linearized model and shock processes

Key steady-state relations used to estimate the model are shown in Appendix 4.A.1. The log-linearized equations of the model are summarized in Appendix 4.A.2. The remaining equations, not discussed in sections 4.2.2-4.2.5, are similar to those discussed in the basic structure of the model. The domestic block is described by 26 equations in the unknowns $\{y_t, n_t, c_t, i_t, q_t, k_t^s, k_t, u_t, r_t^k, tot_t, rer_t, \pi_t, \pi_{H,t}, mc_t, \pi_{F,t}, \pi_t^{\omega}, \omega_t, un_t, l_t, \psi_{F,t}, a_t, r_t, r_t^{e,k}, s_t, nw_t, c_t^e\}$, and the foreign block is given by 20 equations in the unknowns $\{y_t^*, n_t^*, c_t^*, i_t^*, q_t^*, k_t^{s*}, k_t^*, u_t^*, r_t^{k*}, \pi_t^*, mc_t^*, \omega_t^*, \pi_t^{\omega*}, un_t^*, l_t^*, r_t^*, r_t^{e,k*}, s_t^*, nw_t^*, c_t^{e*}\}$. When combined with processes for the exogenous disturbances and the definitions $\Delta s_t = s_t - s_{t-1}$ and $\Delta q_t = q_t - q_{t-1}$, these relations constitute a linear rational expectations model driven by 22 disturbances, $\{\varepsilon_{g,t}, \varepsilon_{a,t}, \varepsilon_{c,t}, \varepsilon_{i,t}, \varepsilon_{pm^h,t}, \varepsilon_{pm^f,t}, \varepsilon_{n,t}, \varepsilon_{\omega,t}, \varepsilon_{rp,t}, \varepsilon_{r,t}, \varepsilon_{cs,t}, \varepsilon_{fw,t}, \varepsilon_{g^*,t}, \varepsilon_{a^*,t}, \varepsilon_{c^*,t}, \varepsilon_{i^*,t}, \varepsilon_{pm^*,t}, \varepsilon_{n^*,t}, \varepsilon_{\omega^*,t}, \varepsilon_{r^*,t}, \varepsilon_{cs^*,t}, \varepsilon_{fw^*,t}\}$[99]. Stochastic representation of structural disturbances is assumed in line with those in the model estimated by Smets and Wouters (2007) and Gilchrist et al. (2009). For instance, the exogenous spending $(\varepsilon_{g,t}, \varepsilon_{g^*,t})$ follows an AR(1) process and is also affected by the productivity shock $(\varepsilon_{a,t}, \varepsilon_{a^*,t})$[100]:

$$\varepsilon_{g,t} = \rho_g \varepsilon_{g,t-1} + \epsilon_{g,t} + \rho_{ga}\epsilon_{a,t} \tag{4.20}$$

$$\varepsilon_{g^*,t} = \rho_{g^*} \varepsilon_{g^*,t-1} + \epsilon_{g^*,t} + \rho_{ga^*}\epsilon_{a^*,t} \tag{4.21}$$

The price mark-up and wage mark-up disturbances ($\varepsilon_{x,t}$, $x = \{pm^h, pm^f, \omega, pm^*, \omega^*\}$) are assumed to follow an ARMA(1,1) process[101]:

$$\varepsilon_{x,t} = \rho_x \varepsilon_{x,t-1} + \epsilon_{x,t} - \mu_x \epsilon_{x,t-1}, \tag{4.22}$$

The remaining structural disturbances ($\varepsilon_{y,t}$, $= \{a, c, i, n, rp, r, cs, fw, a^*, c^*, i^*, n^*, r^*, cs^*, fw^*\}$) are assumed to follow an independent AR(1) process

[99] All $\tilde{\varepsilon}_x$ shocks, except $\tilde{\varepsilon}_{rp}$ have unit means, while all ε_x disturbances have zero means.

[100] The inclusion of the productivity shock is motivated by the fact that, in the estimation, exogenous spending also includes net exports, which may be affected by domestic productivity developments.

[101] The presence of the moving average (MA) term is designed to capture the high-frequency fluctuations in inflation and wage inflation.

$$\varepsilon_{y,t} = \rho_y \varepsilon_{y,t-1} + \epsilon_{y,t} \tag{4.23}$$

where $\epsilon_{k,t} = \{\epsilon_{g,t}, \epsilon_{g^*,t}, \epsilon_{x,t}, \epsilon_{y,t}\}$ denotes a vector of mutually-uncorrelated *i.i.d.* shocks with $\sigma_k^2 = E[\epsilon_{k,t}\epsilon'_{k,t}]$.

4.3 The model solution, data and estimation

4.3.1 The model solution

The model consists of log-linear equations and exogenous-driven forces. Using standard methods for solving the linear rational expectations model (e.g., Blanchard and Khan (1980) and Sims 2002), the model can be written in the following state-space form[102]

$$\xi_t = F(\theta)\xi_{t-1} + G(\theta)\epsilon_t, \quad \epsilon_t \sim NID(0, I) \tag{4.25}$$

$$Y_t = H(\theta)\xi_t \tag{4.26}$$

where ξ_t denotes the vector of state variables, including the model endogenous variables, $\{y_t, n_t, c_t, i_t, q_t, k_t^s, k_t, u_t, r_t^k, tot_t, rer_t, \pi_t, \pi_{H,t}, mc_t, \pi_{F,t}, \pi_t^\omega, \omega_t, un_t, l_t, \psi_{F,t}, a_t, r_t, r_t^{e,k},$ $s_t, nw_t, c_t^e, y_t^*, n_t^*, c_t^*, i_t^*, q_t^*, k_t^{s*}, k_t^*, u_t^*, r_t^{k*}, \pi_t^*, mc_t^*, \omega_t^*, \pi_t^{\omega^*}, un_t^*, l_t^*, r_t^*, r_t^{e,k*}, s_t^*, nw_t^*, c_t^{e*}\}$, expectations at period t $\{c_{t+1,} i_{t+1,} q_{t+1}, \pi_{t+1}, \pi_{H,t+1}, \pi_{F,t+1}, \pi_{t+1}^\omega, rer_{t+1}, r_{t+1}^k, r_{t+1}^{e,k}, k_{t+1},$ $nw_{t+1}, c_{t+1}^*, i_{t+1}^*, q_{t+1}^* \pi_{t+1}^*, \pi_{t+1}^{\omega*}, r_{t+1}^{k*}, r_{t+1}^{e,k*}, k_{t+1}^*, nw_{t+1}^*\}$, and the all disturbances that are not *i.i.d.* $(\varepsilon_{g,t}, \varepsilon_{g^*,t}, \varepsilon_{x,t}, \varepsilon_{y,t})$; ϵ_t is the vector of structural *i.i.d.* innovations distributed $(0, I)$ $\{\epsilon_{g,t}, \epsilon_{g^*,t}, \epsilon_{x,t}, \epsilon_{y,t},\}$; and Y_t denotes the vector of control variables (observables). The matrices $F(\theta)$, $G(\theta)$ and $H(\theta)$ denote complicated nonlinear functions of the structural parameters of the model, implied by the vector θ.

For model evaluation purposes, three variants of the model are estimated. The model detailed in Sections 4.2.1-4.2.4 and estimated using all financial variables (AFV) is called the 'baseline model with AFV'. The same model, but estimated by dropping all financial variables (DAFV)[103], is called the 'baseline model with DAFV'. Those are richer models in the sense that they have similar features to the model estimated by Christiano et al. (2011) and Galí et al. (2011), but with the addition of financial frictions and financial shocks in an open economy setting. Following Christiano et al. (2010, 2014), a simpler version of the model, called the 'simple model', is also estimated. This model is obtained

[102] Here the parameter space, providing unique stable solution, is only considered.
[103] The dropped variables are the spread on external finance and real net worth in Australia and the US.

from the baseline specification by assuming that there are no financial frictions and shocks. It is derived by assuming (i) no feedback from financial conditions to the real economy and no financial shocks, implied by (i) $S_t(\cdot) = 1$ because of $\psi = 0$ and the absence of shocks to $\tilde{\varepsilon}_{cs,t}$, and (ii) dropping equations (4.8)-(4.10) and (4.16)-(4.18). Accordingly, equation (4.15) implies that all real interest rates in the economy with no financial frictions are equal to risk-free real interest rates and changes to $(1 + R_{t+1})\, P_t/P_{t+1} = \left(1 + R^{e,k}_{t+1}\right)$[104]. The specification of the simple model is therefore closer to the standard medium-scale New Keynesian DSGE models (e.g., Smets and Wouters 2003, 2007, Christiano et al. 2005, Adolfson et al. 2008).

4.3.2 Data

The model is estimated using the US (foreign economy) and Australian (domestic economy) data over the period 1993:Q1-2013:Q4. The estimation period covers the inflation-targeting period in Australia and includes the recent GFC. The details of the observed data are given in Appendix 4.B.1. The US observables include eight variables that are standard in the empirical analysis of aggregate data: real non-farm GDP, real consumption, real investment, employment, the federal funds rate, unemployment rate, inflation (computed as quarterly percentage changes in the GDP implicit price deflator), and wage inflation (measured as quarterly percentage changes in non-farm compensation per employee). In addition, to quantify the strength of financial frictions and to properly identify financial shocks, two US financial variables are also observed. As used by Christiano et al. (2014), real entrepreneurial net worth in period t, NW^*_{t+1} is approximated by the ratio of the Dow Jones Wilshire 5000 index to the GDP implicit price deflator. The EFP is measured by the spread between the yield on seasoned BAA-rated long-term corporate bonds and the yield on the constant maturity ten-year Treasury notes[105].

Australian data includes 10 standard variables: real non-farm GDP, real consumption, real investment, employment, quarterly inflation[106], cash rate, unemployment rate and, terms of trade, G7 GDP-weighted real exchange rate and wage inflation calculated as

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[104] The modification changes the real return on capital defined in (4.12) into the standard equality condition commonly used in the literature: $E_t[(1 + R_{t+1})\, P_t/P_{t+1}] = E_t[U_{t+1}R^k_{t+1} - a(U_{t+1}) + (1-\delta)Q_{t+1}]/Q_t$. In addition, the aggregate resource constraint is changed as $C_{H,t} + C^*_{H,t} + G_t + I_t + a(U_t)K_{t-1} = Y_t$.

[105] Christiano et al. (2014) note that replacing the BAA corporate bond spread by the spread measure constructed by Gilchrist and Zakrajšek (2012) gives similar results.

[106] As there is no reliable data for non-farm inflation, seasonally adjusted inflation based on consumer price index-all groups excluding interest and tax changes of 1999–2000 is used. As interest rate effect is excluded, the measure helps to appropriately estimate the cost channel effects.

quarterly percentage changes in average non-farm compensation per employee. Moreover, Australian two-financial variables are observed. The All Ordinaries Index[107] divided by the GDP implicit price deflator is used as a proxy for real entrepreneurial net worth in period t, NW_{t+1}. Following Christiano et al. (2010), the EFP is measured as the weighted average of the non-financial corporate ten-year BBB-rated bond yield spread and the spread between the large business lending rate and the cash rate[108]. Prior to empirical analysis, the data is transformed as follows[109]: logarithm is taken from all real variables and employment, and then the resulting variables are linearly de-trended. Real exchange rate and terms of trade are first log-differenced (scaled by 100) and then demeaned. The unemployment rate is de-trended, and all remaining series are demeaned separately. The de-trending and de-meaning ensure that the resulting variables used in the estimation are stationary as they represent the business cycle-related part of the original variable. The data used in empirical analysis is detailed in Figure 4.B.1 in Appendix 4.B.

4.3.3 Bayesian inference and priors

Structural parameters of the model, θ, are estimated using Bayesian methods. The advantage of Bayesian methods to estimate and evaluate DSGE models has been discussed in several papers (e.g., Lubik and Schorfheide 2006, An and Schorfheide 2007, and Del Negro and Schorfheide 2011). Nowadays, it is accepted that Bayesian estimation is well-suited to dealing with the problem of potential model misspecification and lack of identification. Another advantage of Bayesian estimation over its alternatives (Maximum likelihood or GMM) is that the posterior distribution of the parameters incorporates all of the uncertainty surrounding the model's parameters and the model specification[110]. In Bayesian inference, a prior distribution, $p(\theta)$, is updated by sample information contained in the likelihood function, $L(Y|\theta)$, to form a posterior distribution of parameters given the data, $\mathcal{L}(\theta|Y)$. Specifically, the posterior likelihood function, $\mathcal{L}(\theta|Y)$, is proportional to the product, $L(Y|\theta)\ p(\theta)$. This formulation supplies the basis

[107] The All Ordinaries Index is Australia's premier market indicator. The index represents the 500 largest companies listed on the Australian Stock Exchange (ASX).
[108] From 2005 onwards, the EFP is computed as the weighted average of the spreads, and the series is backcasted by the large business lending rate spread. Construction of the bond yield spread data is detailed by Arsov et al. (2013).
[109] The officially published real exchange rate and the terms of trade are the inverse of same variables in the model, so the observables are converted into the model definition. Interest rates are expressed in quarterly terms.
[110] There is also a clear advantage when it comes to model comparisons since the models are not required to be nested and numerical methods for the computation of the marginal likelihood permit constructing posterior model probabilities.

of Bayesian estimation. The state-space solutions of the model, presented in equations (4.25) and (4.26), are used to evaluate the likelihood function ($L(Y|\theta)$) performed by the Kalman filter. Techniques used in the Bayesian estimation such as Random Walk Metropolis (RWM) and Kalman filter algorithms are detailed by An and Shorfheide (2007) and Guerrón-Quintana and Nason (2012).

The Bayes factor is employed to evaluate the relative fit of the models. Let $\mathcal{M}_i$ be a given model, with $\mathcal{M}_i \in M$ and $p_i(\theta|\mathcal{M}_i)$ denoting the prior density for model $\mathcal{M}_i$. The marginal likelihood for a given model $\mathcal{M}_i$ and data Y is

$$L(Y|\mathcal{M}_i) = \int_\theta L(Y|\theta, \mathcal{M}_i) p_i(\theta|\mathcal{M}_i) d\theta$$

where $L(Y|\mathcal{M}_i)$ and $L(Y|\theta, \mathcal{M}_i)$ respectively denote the marginal data density and the likelihood function for the data Y conditional on the parameter and the model. Then the Bayes factor of model $\mathcal{M}_i$ versus model $\mathcal{M}_j$ is computed as

$$\mathcal{BF}_{i,j|Y} = L(Y|\mathcal{M}_i) / L\left(Y\middle|\mathcal{M}_j\right) \tag{4.27}$$

Christopher Sims's 'csminwel' optimization routine is used to obtain the posterior mode and to compute the Hessian matrix at the mode. To test the presence of the identification problem, over 50 optimization runs are launched, and the different optimization routine always converges to the same mode value. Since a unique mode for the model is obtained, the Hessian from the optimization routine is used as a proposal density, properly scaled (i.e., using $\mathrm{c} = 0.15$) to attain an acceptance rate between 20-30 per cent. For the RWM results, two independent chains of 500,000 draws are generated, where the initial 200,000 draws are discarded. Convergence of the chains is monitored using both the univariate and the multivariate convergence diagnostics variants of Brooks and Gelman (1998).

In what follows, the specifications of priors are discussed. Priors for the model parameters consist of two sets. The first set includes a small number of parameters that are fixed by commonly used values in the literature. Australian and US discount factors, β and β^*, are respectively set to equal to 0.9938 and 0.9973, which are consistent with the average of real interest rates over the estimation sample. The parameter governing openness, α, is set at 0.2, consistent with average share of imports in consumption basket (Jääskelä and Nimark 2011) and share of imports in GDP (Kuttner and Robinson 2010). The spending-GDP ratio for the US, g_{y^*}, is fixed at 0.18 following Smets and Wouters (2007) and Fornarim amd Quadrini (2012). The spending-GDP ratio for Australia, g_y, is set at 0.225

per cent, which corresponds to the average value of the ratio of general government expenditure (i.e., sum of final consumption expenditure and public gross fixed capital formation) to GDP in the sample period. Capital depreciation rate for both countries, δ and δ^*, is assigned to the commonly used value of 0.025 (on a quarterly basis). Following Bernanke at al. (1999), Chistensen and Dib (2008) and Christiano et al. (2011), the entrepreneurial survival probabilities, γ and γ^*, are set to 0.9728, implying an expected working life for entrepreneurs of 36 years. Finally, the entrepreneurs' share of consumption for both countries, c_y^e and c_y^{e*}, is set at 0.01 as calibrated by Gilchrist et al. (2009).

The second set of parameters (55 Australian and 44 US economy parameters) to be estimated and their prior assumptions are listed in the first panel of Table 4.1. Priors for both Australia and the US parameters, unrelated to the financial frictions are selected fairly consistent with those used in previous papers (e.g., Smets and Wouters 2007, Justiniano and Preston 2010a,b, Robinson 2013 and Galí et al. 2011). Priors for the parameters governing financial frictions are selected as follows: Following Dib et al. (2008) and Gilchrist et al. (2009), the prior for the elasticity of the EFP with respect to the leverage ratio, ψ and ψ^*, is described by a Beta distribution with mean 0.05 and standard error 0.0125. As used by Elekdag et al. (2006), the prior for the steady-state ratio of capital to net worth for both countries (K/NW and K^*/NW^*) is set by a Gamma distribution with mean 2 and standard error 0.3, consistent with the calibrated values by Christensen and Dib (2008) (2.0) and Gilchrist et al. (2009) (1.7). The prior for the share of the domestic debt in the total debt of entrepreneurs, ϖ^d, is chosen as a Beta distribution with mean 0.6[111] and standard error 0.1. For all standard deviations of innovations, inverse-gamma distributions are used. Prior variances of the shocks are chosen as fairly diffuse.

[111] The mean value is consistent with the share of gross external debt in private sector in the total private debt (as of 2014), which is computed using the table on overview of Australian debts shown by Soos and Egan (2014).

Table 4.1 Prior densities and posterior estimates

	Parameters	Australia								
		Prior Distribution			Posterior Distribution					
		D	M	SD	Baseline model with AFV		Baseline model with DAFV		Simple model	
					M	[5, 95] prob	M	[5, 95] prob	M	[5, 95] prob
Structural parameters										
Ω	Capital share in production	N	0.3	0.02	0.26	[0.24, 0.29]	0.28	[0.25, 0.31]	0.26	[0.23, 0.28]
χ''	Investment adjustment cost	N	4.0	1.0	3.45	[2.10, 4.87]	3.38	[1.98, 4.81]	3.15	[1.76, 4.47]
κ	Capital utilization	B	0.5	0.15	0.72	[0.57, 0.88]	0.70	[0.52, 0.87]	0.71	[0.54, 0.89]
h	Degree of external habit	B	0.7	0.1	0.88	[0.79, 0.95]	0.88	[0.79, 0.95]	0.85	[0.78, 0.93]
σ	Intertemporal ES	G	1.2	0.2	1.33	[1.01, 1.66]	1.33	[0.99, 1.69]	1.31	[0.96, 1.63]
η	Elasticity H-F goods	G	1.5	0.1	1.38	[1.23, 1.54]	1.36	[1.22, 1.50]	1.40	[1.24, 1.56]
φ	Inverse of Frisch elasticity	N	2.0	1.0	5.87	[4.87, 6.94]	5.89	[4.90, 6.91]	5.99	[4.84, 7.00]
θ_H	Calvo domestic prices	B	0.6	0.15	0.47	[0.38, 0.56]	0.44	[0.34, 0.53]	0.44	[0.35, 0.52]
δ_H	Indexation domestic	B	0.5	0.2	0.61	[0.37, 0.87]	0.57	[0.30, 0.86]	0.58	[0.32, 0.88]
υ_k	Cost channel-capital	B	0.5	0.25	0.48	[0.08, 0.88]	0.49	[0.08, 0.89]	0.49	[0.10, 0.89]
υ_n	Cost channel-labour	B	0.5	0.25	0.31	[0.003, 0.63]	0.31	[0.004, 0.61]	0.32	[0.006, 0.62]
θ_F	Calvo import prices	B	0.6	0.15	0.71	[0.63, 0.78]	0.70	[0.63, 0.78]	0.73	[0.66, 0.80]
δ_F	Indexation foreign	B	0.5	0.2	0.52	[0.28, 0.78]	0.49	[0.23, 0.72]	0.47	[0.20, 0.72]
υ_F	Cost channel-import	B	0.5	0.25	0.52	[0.12, 0.93]	0.52	[0.11, 0.92]	0.51	[0.10, 0.91]
ϕ_a	Interest debt elasticity	IG	0.01	1.0	0.007	[0.003, 0.01]	0.007	[0.003, 0.01]	0.006	[0.003, 0.01]
ϕ_e	UIP modification	B	0.5	0.1	0.31	[0.19, 0.42]	0.27	[0.19, 0.36]	0.29	[0.22, 0.38]
θ_ω	Calvo wages	B	0.6	0.15	0.52	[0.41, 0.63]	0.51	[0.42, 0.60]	0.48	[0.36, 0.58]
δ_ω	Indexation wages	B	0.5	0.2	0.24	[0.14, 0.34]	0.29	[0.17, 0.40]	0.30	[0.19, 0.41]
$\mathcal{M}_\omega$	Steady state wage-markup	N	1.25	0.25	1.42	[1.11, 1.69]	1.44	[1.15, 1.73]	1.39	[1.12, 1.64]
ϑ_z	Reference shifter	B	0.05	0.025	0.035	[0.005, 0.07]	0.036	[0.007, 0.06]	0.04	[0.006, 0.07]
ρ_R	Taylor rule, smoothing	B	0.5	0.25	0.89	[0.86, 0.92]	0.90	[0.87, 0.93]	0.89	[0.87, 0.92]
χ_π	Taylor rule, inflation	G	1.5	0.25	1.55	[1.23, 1.87]	1.75	[1.36, 2.11]	1.72	[1.39, 2.08]
χ_y	Taylor rule, output	G	0.25	0.13	0.12	[0.05, 0.19]	0.13	[0.04, 0.21]	0.14	[0.05, 0.21]
$\chi_{\Delta y}$	Taylor rule, output growth	G	0.25	0.13	0.18	[0.05, 0.31]	0.17	[0.05, 0.29]	0.20	[0.05, 0.34]
ψ	Elasticity of EFP	B	0.05	0.013	0.01	[0.007, 0.01]	0.037	[0.02, 0.05]	-	-
K/NW	Capital-net worth ratio	G	2.0	0.3	1.85	[1.53, 2.16]	1.46	[1.17, 1.74]	-	-
ϖ^d	Weight of domestic debt	B	0.6	0.1	0.54	[0.39, 0.69]	0.60	[0.44, 0.76]	-	-
Persistence of the exogenous processes										
ρ_g	Spending AR(1)	B	0.8	0.1	0.97	[0.96, 0.98]	0.97	[0.95, 0.98]	0.97	[0.95, 0.98]
ρ_{ga}	Spending-technology	N	0.5	0.2	0.36	[0.15, 0.58]	0.38	[0.15, 0.59]	0.31	[0.07, 0.53]
ρ_a	Technology AR(1)	B	0.8	0.1	0.93	[0.89, 0.97]	0.92	[0.88, 0.96]	0.93	[0.89, 0.97]
ρ_c	Consumption preference AR(1)	B	0.5	0.2	0.47	[0.24, 0.71]	0.46	[0.23, 0.70]	0.47	[0.27, 0.67]
ρ_i	MEI AR(1)	B	0.5	0.2	0.21	[0.07, 0.35]	0.28	[0.07, 0.47]	0.27	[0.12, 0.42]
ρ_{cp^f}	Import price-markup AR(1)	B	0.8	0.1	0.84	[0.67, 0.98]	0.86	[0.75, 0.97]	0.86	[0.76, 0.97]
μ_{cp^f}	Import price-markup MA(1)	B	0.5	0.2	0.69	[0.50, 0.89]	0.68	[0.50, 0.87]	0.68	[0.48, 0.87]
ρ_{cp^h}	Domestic price-markup AR(1)	B	0.8	0.1	0.82	[0.71, 0.94]	0.85	[0.74, 0.96]	0.82	[0.70, 0.95]
μ_{cp^h}	Domestic price-markup MA(1)	B	0.5	0.2	0.52	[0.30, 0.73]	0.48	[0.27, 0.71]	0.47	[0.23, 0.70]
ρ_{rp}	Risk premium AR(1)	B	0.8	0.1	0.75	[0.58, 0.91]	0.80	[0.71, 0.91]	0.79	[0.69, 0.90]
ρ_n	Labour disutility AR(1)	B	0.8	0.1	0.90	[0.86, 0.94]	0.91	[0.86, 0.95]	0.90	[0.85, 0.94]
ρ_w	Wage-markup AR(1)	B	0.5	0.2	0.32	[0.08, 0.54]	0.34	[0.10, 0.58]	0.35	[0.10, 0.59]
μ_w	Wage-markup MA(1)	B	0.5	0.2	0.48	[0.27, 0.79]	0.65	[0.35, 0.91]	0.45	[0.27, 0.65]
ρ_r	Monetary policy AR(1)	B	0.5	0.2	0.29	[0.17, 0.41]	0.34	[0.21, 0.48]	0.32	[0.19, 0.45]
ρ_{cs}	Credit supply AR(1)	B	0.5	0.2	0.80	[0.72, 0.89]	0.47	[0.20, 0.75]	-	-
ρ_{fw}	Financial wealth AR(1)	B	0.5	0.2	0.37	[0.21, 0.52]	0.36	[0.10, 0.60]	-	-
Standard deviations, shock innovations										
σ_g	Sd spending	IG	1.0	1.0	0.88	[0.75, 1.00]	0.87	[0.73, 1.00]	0.91	[0.78, 1.03]
σ_a	Sd technology	IG	1.0	1.0	0.62	[0.54, 0.69]	0.62	[0.54, 0.71]	0.63	[0.55, 0.71]
σ_c	Sd consumption preference	IG	2.0	2.0	7.22	[3.08, 11.0]	6.92	[3.1, 10.94]	5.10	[2.81, 7.22]
σ_i	Sd MEI	IG	2.0	2.0	13.1	[7.48, 18.2]	12.7	[6.72, 18.2]	11.4	[6.46, 16.0]
σ_n	Sd labour disutility,	IG	1.0	1.0	2.20	[1.79, 2.61]	2.20	[1.79, 2.61]	2.24	[1.81, 2.68]
σ_r	Sd monetary policy,	IG	0.25	0.25	0.11	[0.09, 0.12]	0.11	[0.09, 0.12]	0.11	[0.09, 0.12]
σ_{rp}	Sd risk premium	IG	1.0	1.0	0.93	[0.51, 1.36]	0.78	[0.51, 1.02]	0.80	[0.52, 1.08]
σ_{pm^h}	Sd domestic price-markup	IG	1.0	1.0	1.18	[0.86, 1.49]	1.26	[0.86, 1.64]	1.27	[0.89, 1.66]
σ_{pm^f}	Sd import price-markup	IG	1.0	1.0	2.48	[1.91, 3.02]	2.40	[1.86, 3.0]	2.26	[1.71, 2.80]
σ_w	Sd wage-markup	IG	1.0	1.0	0.49	[0.29, 0.68]	0.44	[0.27, 0.59]	0.39	[0.25, 0.53]
σ_{cs}	Sd credit supply	IG	1.0	1.0	0.14	[0.12, 0.16]	0.94	[0.31, 1.62]	-	-
σ_{fw}	Sd financial wealth	IG	2.0	2.0	4.41	[3.71, 5.08]	1.30	[0.64, 1.90]	-	-

Table 4.1 Prior densities and posterior estimates (Continued)

	Parameters	The US economy								
		Prior Distribution			Posterior Distribution					
					Baseline model with AFV		Baseline model with DAFV		Simple model	
		D	M	SD	M	[5, 95] prob	M	[5, 95] prob	M	[5, 95] prob
Structural parameters										
Ω^*	Capital share in production	N	0.3	0.02	0.18	[0.16, 0.20]	0.25	[0.22, 0.28]	0.17	[0.15, 0.19]
$\chi^{*\prime\prime}$	Investment adjustment cost	N	4.0	1.0	2.97	[1.52, 4.29]	2.96	[1.81, 4.07]	3.17	[1.80, 4.50]
κ^*	Capital utilization	B	0.5	0.15	0.79	[0.67, 0.92]	0.75	[0.63, 0.87]	0.75	[0.62, 0.90]
h^*	Degree of external habit	B	0.5	0.1	0.74	[0.64, 0.84]	0.55	[0.44, 0.64]	0.62	[0.53, 0.72]
σ^*	Intertemporal ES	G	1.0	0.4	1.42	[0.80, 2.04]	1.62	[1.13, 2.07]	1.54	[1.02, 2.00]
η^*	Elasticity H-F goods	G	1.5	0.1	1.28	[1.14, 1.42]	1.25	[1.11, 1.39]	1.32	[1.17, 1.45]
θ^*	Calvo prices	B	0.6	0.1	0.84	[0.79, 0.88]	0.78	[0.73, 0.82]	0.82	[0.78, 0.87]
δ_p^*	Indexation prices	B	0.5	0.2	0.32	[0.10, 0.53]	0.16	[0.03, 0.28]	0.19	[0.03, 0.34]
φ^*	Inverse of Frisch elasticity	N	2.0	1.0	4.42	[3.38, 5.43]	4.76	[3.87, 5.65]	4.98	[3.97, 6.00]
v_k^*	Cost channel-capital	B	0.5	0.25	0.50	[0.11, 0.91]	0.53	[0.14, 0.94]	0.49	[0.09, 0.89]
v_n^*	Cost channel-labour	B	0.5	0.25	0.46	[0.04, 0.83]	0.40	[0.02, 0.77]	0.46	[0.06, 0.86]
θ_ω^*	Calvo wages	B	0.5	0.15	0.57	[0.42, 0.71]	0.55	[0.44, 0.66]	0.54	[0.41, 0.66]
δ_ω^*	Indexation wages	B	0.5	0.15	0.10	[0.03, 0.15]	0.15	[0.07, 0.23]	0.13	[0.05, 0.21]
$\mathcal{M}_\omega^*$	Steady state wage-markup	N	1.25	0.25	1.30	[1.04, 1.57]	1.30	[1.09, 1.51]	1.29	[1.06, 1.50]
ϑ_z^*	Reference shifter	B	0.05	0.025	0.06	[0.02, 0.10]	0.1	[0.06, 0.13]	0.08	[0.05, 0.11]
ρ_R^*	Taylor rule, smoothing	B	0.75	0.1	0.87	[0.84, 0.90]	0.85	[0.82, 0.89]	0.85	[0.82, 0.88]
χ_π^*	Taylor rule, inflation	G	1.5	0.25	2.08	[1.68, 2.48]	2.40	[2.03, 2.78]	2.24	[1.82, 2.63]
χ_y^*	Taylor rule, output	G	0.25	0.13	0.02	[0.005, 0.04]	0.04	[0.02, 0.07]	0.03	[0.01, 0.05]
$\chi_{\Delta y}^*$	Taylor rule, output growth	G	0.25	0.13	0.48	[0.31, 0.66]	0.45	[0.29, 0.62]	0.43	[0.28, 0.60]
ψ^*	Elasticity of EFP	B	0.05	0.013	0.011	[0.008, 0.01]	0.042	[0.03, 0.06]	-	-
K^*/NW	Capital-net worth ratio	G	2.0	0.3	1.98	[1.57, 2.38]	1.92	[1.53, 2.33]	-	-
Persistence of the exogenous processes										
ρ_g^*	Spending AR(1)	B	0.5	0.2	0.76	[0.67, 0.86]	0.83	[0.75, 0.91]	0.79	[0.71, 0.87]
ρ_{ga}^*	Spending-Technology	N	0.5	0.25	0.40	[0.32, 0.48]	0.44	[0.36, 0.52]	0.39	[0.31, 0.48]
ρ_a^*	Technology AR(1)	B	0.8	0.1	0.96	[0.93, 0.98]	0.96	[0.94, 0.98]	0.96	[0.94, 0.99]
ρ_c^*	Consumption reference AR(1)	B	0.5	0.2	0.88	[0.76, 0.99]	0.98	[0.98, 0.99]	0.99	[0.98, 0.99]
ρ_i^*	MEI AR(1)	B	0.5	0.2	0.54	[0.31, 0.78]	0.66	[0.35, 0.94]	0.72	[0.63, 0.80]
ρ_{cp}^*	Price-markup AR(1)	B	0.5	0.2	0.88	[0.81, 0.96]	0.94	[0.90, 0.97]	0.90	[0.84, 0.96]
μ_{cp}^*	Price-markup MA(1)	B	0.5	0.2	0.64	[0.48, 0.80]	0.57	[0.40, 0.74]	0.61	[0.44, 0.77]
ρ_n^*	Labour disutility AR(1)	B	0.8	0.1	0.96	[0.92, 0.99]	0.94	[0.90, 0.98]	0.94	[0.91, 0.98]
ρ_w^*	Wage-markup AR(1)	B	0.5	0.2	0.29	[0.04, 0.52]	0.23	[0.05, 0.40]	0.25	[0.05, 0.46]
μ_w^*	Wage-markup MA(1)	B	0.5	0.2	0.41	[0.23, 0.58]	0.79	[0.71, 0.86]	0.42	[0.19, 0.62]
ρ_r^*	Monetary policy AR(1)	B	0.5	0.2	0.44	[0.32, 0.57]	0.45	[0.32, 0.59]	0.47	[0.35, 0.59]
ρ_{cs}^*	Credit supply AR(1)	B	0.8	0.1	0.95	[0.92, 0.98]	0.77	[0.67, 0.87]	-	-
ρ_{fw}^*	Financial wealth AR(1)	B	0.5	0.2	0.26	[0.12, 0.40]	0.40	[0.12, 0.67]	-	-
Standard deviations, shock innovations										
σ_g^*	Sd spending	IG	1.0	1.0	0.28	[0.25, 0.32]	0.28	[0.25, 0.32]	0.30	[0.25, 0.34]
σ_a^*	Sd technology	IG	1.0	1.0	0.67	[0.59, 0.76]	0.68	[0.59, 0.76]	0.67	[0.59, 0.75]
σ_c^*	Sd consumption preference	IG	2.0	2.0	4.60	[2.12, 8.35]	5.28	[3.98, 6.78]	6.28	[3.99, 8.91]
σ_i^*	Sd MEI	IG	2.0	2.0	4.96	[2.09, 7.52]	2.38	[0.81, 4.04]	4.98	[2.99, 6.99]
σ_n^*	Sd labour disutility	IG	1.0	1.0	1.78	[1.37, 2.15]	1.67	[1.34, 2.00]	1.78	[1.42, 2.13]
σ_r^*	Sd monetary policy	IG	0.25	0.25	0.09	[0.08, 0.11]	0.10	[0.09, 0.12]	0.10	[0.08, 0.11]
σ_{pm}^*	Sd cost push	IG	0.25	0.25	0.15	[0.11, 0.18]	0.13	[0.11, 0.17]	0.13	[0.10, 0.16]
σ_w^*	Sd wage-markup	IG	1.0	1.0	0.91	[0.44, 1.39]	0.79	[0.43, 1.11]	0.84	[0.43, 1.28]
σ_{cs}^*	Sd,credit supply	IG	1.0	1.0	0.14	[0.12, 0.16]	0.78	[0.40, 1.19]	-	-
σ_{fw}^*	Sd,financial wealth	IG	2.0	2.0	5.71	[4.82, 6.57]	1.17	[0.65, 1.68]	-	-

Notes: D, M and SD represent density, mean and standard deviation, respectively; G: Gamma distribution, B: Beta distribution, N: Normal distribution, IG: Inverse Gamma distribution. Figures in brackets indicate 90 per cent posterior probability intervals.

4.3.4 Posterior estimates of the parameters

The last three panels in Table 4.1 report the posterior estimates of parameters from the three variants of the model. The panel marked baseline model with AFV reports the mean and the 90 per cent probability interval of the posterior distribution of the baseline model when all financial variables (AFV) is included in the estimation as observables. However, the panel marked baseline model with DAFV reports the posterior parameters of the baseline model when observed financial variables are dropped from the estimation. The panel marked simple model reports the posterior parameters of the simple model discussed in Section 4.3.1. For the simple model, the dataset is same as the data used in the estimation of the baseline model with DAFV.

Most estimated parameters, unrelated to the financial frictions, are quite similar across the three models and are in line with previous estimated DSGE models for the US and Australia. For this reason and given the focus of this chapter, only selected parameters regarding financial frictions and shocks are discussed here. As explained by Del Negro et al. (2015), the model with financial friction and financial data yields higher estimates of the price rigidity and indexation parameters. The elasticity of the EFP, ψ and ψ^*, are estimated away from zero in both baseline models with and without financial data. In the case of the baseline model with DAFV, the estimated parameters, $\psi = 0.037$ and $\psi^* = 0.042$, are closer to the values obtained by Elekdag et al. (2006), Christensen and Dib (2008) and Gilchrist et al. (2009). The results suggest that the financial accelerator is operative in both countries, implying the feedback between the financial and real sectors through entrepreneurial balance sheets. The higher elasticity in the US compared to Australia may imply that the financial accelerator is quantitatively more important in the US. The relatively lower estimates of the EFP in the case of baseline model with AFV, $\psi = 0.01$ and $\psi^* = 0.011$, reflect the nature of observed financial data.

Other interesting estimates are the capital-net worth ratios, K/NW and K^*/NW^*. In Australia, the parameter is very sensitive to whether the financial data is included or not in the estimation. For instance, K/NW is estimated as 1.85 and 1.46 in the model with AFV and the model with DAFV, respectively, implying that 46 per cent and 32 per cent of entrepreneurs' capital expenditure is financed by debts. The parameter, K^*/NW^* is estimated closer to 2, which is the commonly calibrated value in the literature. The parameter, ϖ^d, governing how the aggregate balance sheet of entrepreneurs is vulnerable to changes in exchange rate and foreign variables, is estimated as 0.54, with 10th and 90th percentiles of 0.39 and 0.69, respectively in the baseline model with AFV. The result shows that at least 40 per cent of the total debt of entrepreneurs is vulnerable to the external shocks. In the model with DAFM, the posterior of the parameter does not change from its prior. Those results imply that using the financial data in the estimation is informative for the parameter.

The estimates of $\rho_{cs}$and ρ_{cs}^{*} indicate that credit supply shocks are more persistent in both Australia and the US. In particular, it is the case when financial variables are used in the estimation as observables. However, financial wealth shocks are less persistent compared to all other shocks. The financial wealth shocks measured by σ_{fw} and σ_{fw}^{*} are more volatile, whereas credit supply shocks are less volatile in both countries when the financial data is observed. Two simple measures are analysed to access whether the baseline model properly identifies unobserved financial variables and shocks when financial data is not used in the empirical analysis. First, the estimated mean spread on external finance, S_t, is 1.41 per cent for Australia and 2.77 per cent for the US, respectively implying an annualized premium of 5.6 per cent and 11.1 per cent. The model-implied premiums are quite high compared to the directly observed proxy values. Second, the correlation between the spread generated by the model with DAFV and the observed proxy of it (discussed in Section 4.3.2) over the sample period is 0.19 for Australia and 0.86 for the US. These results suggest that it is difficult to identify financial variables and shocks without observing financial data.

Though most estimates of the remaining parameters are quite robust across the different models, there are a few exceptions. For instance, estimates of the parameters governing the response of monetary policy to the inflation, χ_{π} and χ_{π}^{*}, fall when the financial data is observed in the estimation. For the US economy, the MEI shock, σ_{i}^{*}, is estimated less volatile in the model with DAFV compared to the other models. Moreover, estimates of the consumption preference and MEI shocks in Australia are higher in the model with AFV.

4.3.5 The model fit and comparison

To evaluate how the baseline model with AFV fits the data, a set of statistics implied by the model (i.e., in-sample fit and absolute fit) is compared to those measured in the data. Figure 4.B.1 in Appendix 4.B shows the actual data and the one-sided fit (one step-ahead prediction) of the baseline model with AFV to assess the model's forecasting performance. For most of the observed variables, the in-sample fit is good. The exceptions are inflation in Australia and wage inflations in both countries. These variables are quite volatile at a quarterly frequency and difficult to predict as discussed by Jääskelä and Nimark (2011) for Australia and by Justiniano et al. (2013) for the US. However, the model reasonably explains the general movement of CPI and wage inflations.

To investigate whether the presence of foreign-currency denominated debt and the financial accelerator in the model improves the overall fit of the model, Table 4.2 presents the log marginal data densities of alternative models along with the corresponding Bayes factors.

Table 4.2 Model comparison: Financial frictions vs. No financial frictions

Models ($\mathcal{M}$)	Log marginal data densities ($ln\ L(Y\|\mathcal{M}_i)$)	Bayes factor ($\mathcal{BF}$)
$\mathcal{M}_0$: Baseline model with AFV ($0 < \varpi^d < 1$)	-2547.15	$\mathcal{BF}_{0,0\|Y} = 1$
$\mathcal{M}_1$: Baseline model with AFV and $\varpi^d = 1$	-2551.03	$\mathcal{BF}_{0,1\|Y} = 48.4$
$\mathcal{M}_2$: Baseline model with DAFV ($0 < \varpi^d < 1$)	-1832.90	$\mathcal{BF}_{2,2\|Y} = 1$
$\mathcal{M}_3$: Baseline model with DAFV and $\varpi^d = 1$	-1839.79	$\mathcal{BF}_{2,3\|Y} = 982.4$
$\mathcal{M}_4$: Simple model with no financial friction	-1843.01	$\mathcal{BF}_{2,4\|Y} = 24587.7$

Notes: The table reports Bayes factor comparing $\mathcal{M}_0$ to $\mathcal{M}_1$, and $\mathcal{M}_2$ to $\mathcal{M}_3$ and $\mathcal{M}_4$. The log marginal data densities reported here is computed from the posterior draws using the modified harmonic mean approximation, described in Geweke (1999).

First, the models with and without foreign-currency denominated debt are compared to explore the importance of the foreign-currency denominated debt assumption in the model. In the case of observed financial variables, $\mathcal{M}_0$ is compared with $\mathcal{M}_1$ model, and in the case of dropping financial data, $\mathcal{M}_2$ is compared with $\mathcal{M}_3$. The results in the first four rows of Table 4.2 clearly show that the model fit improves when the foreign-currency denominated debt is introduced in the model. For instance, the Bayes factor between $\mathcal{M}_2$ model and $\mathcal{M}_3$ model ($\mathcal{BF}_{2,3|Y}$) is 928.4, implying 'very strong' evidence in favour of the significance of the foreign-currency denominated debt assumption, according to Kass and Raftery (1995)[112]. When comparing the models with and without financial frictions, the Bayes factor of the baseline model with financial frictions against the simple model is $\mathcal{BF}_{2,4|Y} = 24587.7$, suggesting that financial frictions are empirically relevant. The

[112] According to their scale of evidence, a Bayes factor between 1 and 3 is 'not worth more than a bare mention', between 3 and 20 suggests a 'positive' evidence, between 20 and 150 suggests a 'strong' evidence, and larger than 150 'very strong' evidence in favour of one of the two models.

result extends the findings provided by Christensen and Dib (2008), Queijo von Heideken (2009) and Villa (2013), estimating the model with BGG-type financial friction for the closed economy (the US and the Euro area), in the case of a small open economy model with financial frictions.

Table 4.3 compares selected second moments generated by the models to those measured in the data to assess the conformity between the data and the models.

Table 4.3 Data and model-implied moments

	Data			Baseline model with AFV			Baseline model with DAFV			Simple model		
	SD	AC	CO$^{\#}$	SD	AC	CO$^{\#}$	SD	AC	CO$^{\#}$	SD	AC	CO$^{\#}$
AU inflation	0.4	0.23	0.01	0.9	0.64	-0.14	0.9	0.63	-0.03	0.9	0.54	-0.05
AU ΔRER	4.2	0.18	-0.09	3.8	0.24	0.10	3.7	0.22	0.07	3.8	0.23	0.13
AU interest rate	1.2	0.90	0.20	2.4	0.94	-0.35	2.2	0.93	-0.24	1.8	0.90	-0.37
AU output	1.8	0.92	1.00	3.0	0.90	1.00	2.9	0.89	1.00	2.4	0.87	1.00
AU consumption	2.1	0.96	0.86	5.4	0.96	0.05	5.0	0.97	-0.05	4.1	0.95	0.18
AU investment	5.8	0.79	0.59	15.1	0.95	0.42	13.5	0.93	0.42	10.2	0.93	0.35
AU ΔToT	3.0	0.46	-0.18	2.3	0.56	0.13	2.4	0.52	0.10	2.5	0.51	0.15
AU wage inflation	0.8	0.00	0.13	0.9	0.49	-0.16	1.2	0.28	-0.03	0.9	0.38	-0.07
AU unemployment	0.9	0.91	-0.88	1.8	0.70	-0.44	1.9	0.68	-0.48	1.7	0.67	-0.49
AU employment	1.1	0.91	0.06	2.1	0.78	0.61	2.1	0.76	0.66	1.9	0.75	0.63
AU Spread	1.0	0.97	-0.68	1.6	0.90	-0.33	-	-	-	-	-	-
AU AO Index	16.1	0.92	0.72	35.7	0.96	0.43	-	-	-	-	-	-
US inflation	0.2	0.53	0.39	0.4	0.80	0.04	0.3	0.77	-0.18	0.3	0.74	0.03
US output	4.8	0.97	1.00	3.9	0.95	1.00	4.9	0.96	1.00	5.8	0.96	1.00
US consumption	4.2	0.99	0.96	4.8	0.96	0.72	5.6	0.97	0.93	8.2	0.96	0.93
US investment	13.5	0.97	0.94	19.4	0.96	0.52	14.7	0.96	0.61	12.8	0.93	0.20
US interest rate	2.2	0.97	0.38	2.0	0.95	0.05	1.8	0.95	0.01	1.6	0.93	0.35
US wage inflation	1.0	-0.24	0.24	2.0	-0.07	0.06	0.7	0.21	-0.01	1.0	0.15	0.06
US unemployment	1.4	0.95	-0.87	2.1	0.87	-0.43	1.2	0.81	-0.23	1.6	0.85	-0.25
US employment	3.9	0.96	0.93	2.8	0.93	0.61	3.9	0.96	0.70	6.4	0.96	0.91
US Spread	0.8	0.89	-0.16	2.1	0.93	-0.26	-	-	-	-	-	-
US Wilshire 5000	23.2	0.96	0.74	36.2	0.96	0.26	-	-	-	-	-	-

Notes: The table presents the mean of the posterior distribution of the statistics implied by the estimated model are reported. #in the correlation, AU output is used for Australian observables, whereas US output is used for the US observables.

For the models, the mean of the posterior distribution is reported. The models generally overpredict the volatility of the aggregate variables, which is a common problem in the literature on the estimated DSGE models (e.g., Christensen and Dib 2008 and Queijo von Heideken 2009)[113]. Though all moments are not replicated well by the models, the presence of financial frictions helps in fitting some moments of the variables.

[113] As discussed by Justiniano et al. (2011), a likelihood-based estimator tries to match the entire auto-covariance function of the data and hence must strike a balance between matching all the second moments, and therefore the estimated model does not capture standard deviation and autocorrelation perfectly.

4.4 The importance of financial frictions and financial shocks

4.4.1 Impulse responses

This section aims to answer two questions, namely (i) what are effects of financial shocks on the macroeconomy? and (ii) what is the role of financial frictions in the transmission of non-financial shocks?

4.4.1.1 Responses to financial shocks

Figure 4.1 and Figure 4.2 present impulse responses of the estimated baseline models to adverse credit supply shocks in Australia and the US, respectively. The adverse shock potentially leads a domestic recession in both economies. For instance, the higher spread on the external finance, triggered by the adverse shock, deteriorates the entrepreneurs' balance sheet and accordingly reduces the demand for capital. As a result, the adverse shocks result in a persistent reduction in investment and output in both countries. According to the baseline model with AFV, in the case of Australia, a one-standard deviation credit supply shock leads an increase of about 20 basis points in the spread on external finance, which declines the level of output by 4-10 basis points and the level of investment by about 75 basis points relative to the steady state.

However, in the case of the US economy, a same sized rise in EPF (20 basis points) causes 3 times higher impacts on output and investment than those estimated in Australia, which is in line with findings shown by Gilchrist et al. (2009). The response of both output and investment is hump-shaped, with the peak in the response of investment occurring 4-5 quarters for Australia, and 7-8 quarters for the US after the impact of the shock. The weak domestic demand leads to a reduction in both inflation and interest rate. As explained and shown by Barnett and Thomas (2014) for the United Kingdom, a contraction in credit supply also leads to real exchange rate depreciation in Australia. The exogenous rise in the spread on external finance immediately reduces employment.

Those results, suggesting a contraction in the credit supply have significant adverse consequences for the macroeconomy, are consistent with the VAR-based results shown by Gilchrist and Zakrajšek (2012) for the US and Jacobs and Rayner (2012) for Australia. Moreover, the spillover of the US credit supply shock to Australian economy is immediate and not negligible as emphasized by Haddow and Mileva (2013). Movements in the real exchange rate and terms of trade are key channels for the propagation of the shock to the Australian economy. Another interesting result is that when financial data is included in the analysis, the impulse responses become more hump-shaped and the peak effect of the shock is delayed.

Figure 4.1 Responses to an adverse AU credit supply shock

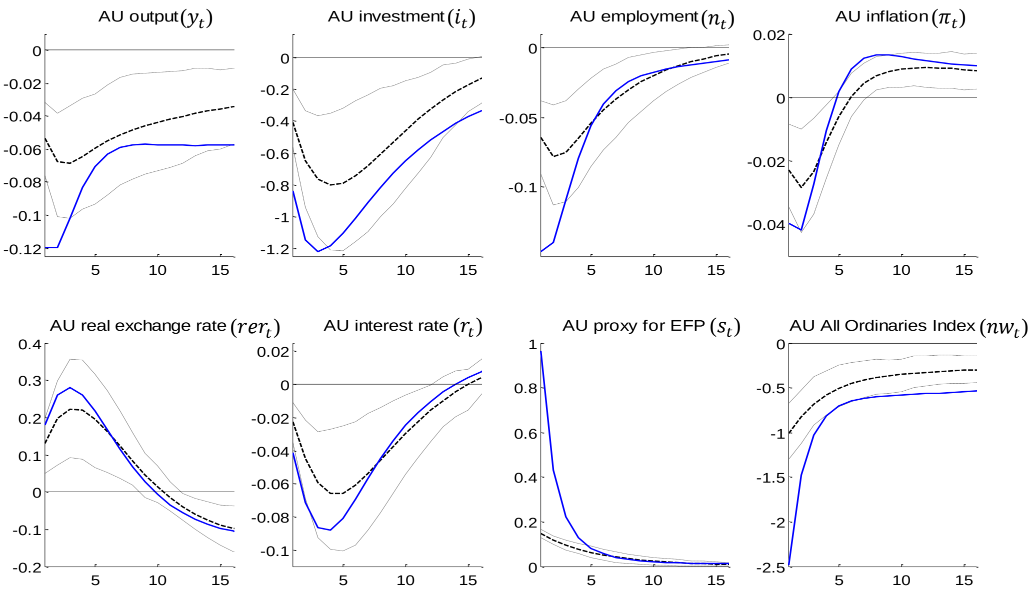
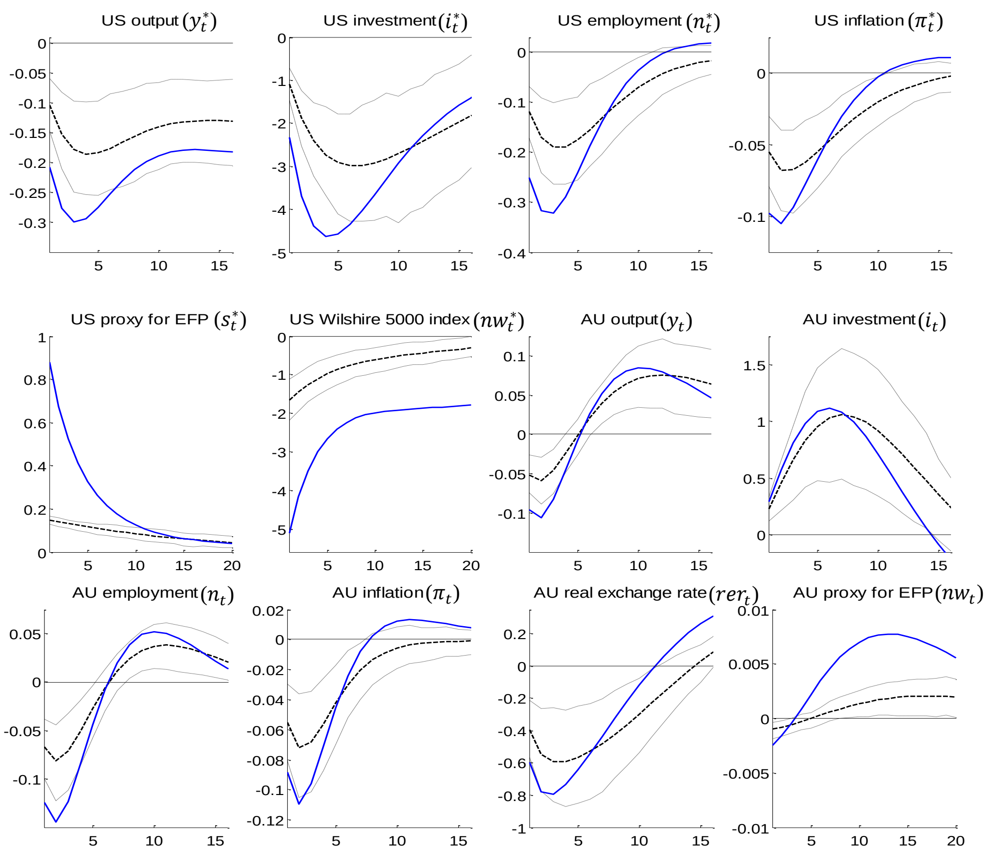


Figure 4.2 Responses to a negative US credit supply shock



Notes: Impulse responses to a one standard deviation shock (not equal among models). Black dashed lines represent the posterior mean and 90% posterior probability interval for responses of the baseline model with AFV. The blue solid line represents the posterior mean of responses of the baseline model with DAFV.

Figure 4.3 and Figure 4.4 display impulse responses of the estimated baseline models to an adverse financial wealth shock in Australia and the US, respectively.

Figure 4.3 Responses to an adverse AU financial wealth shock

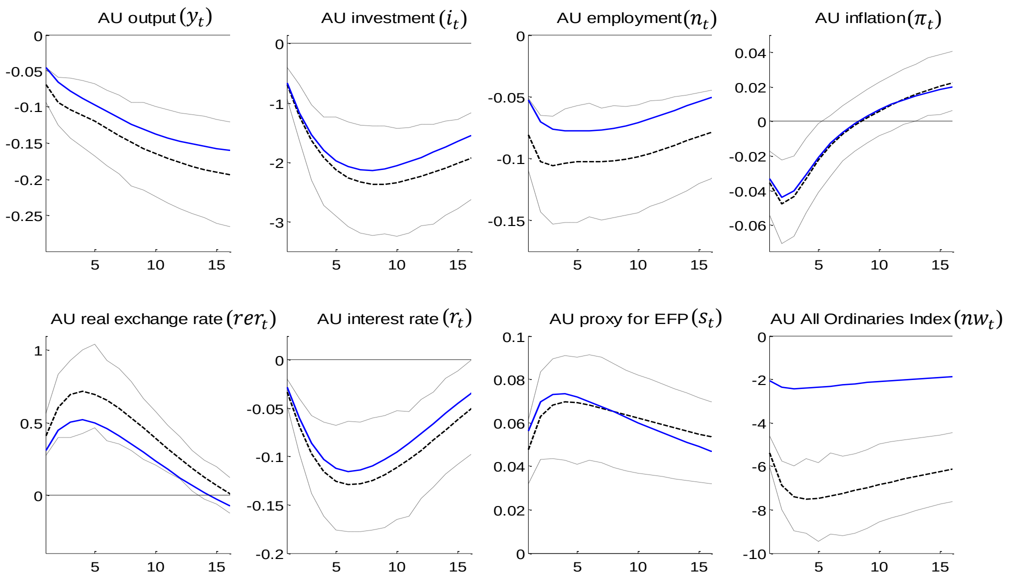
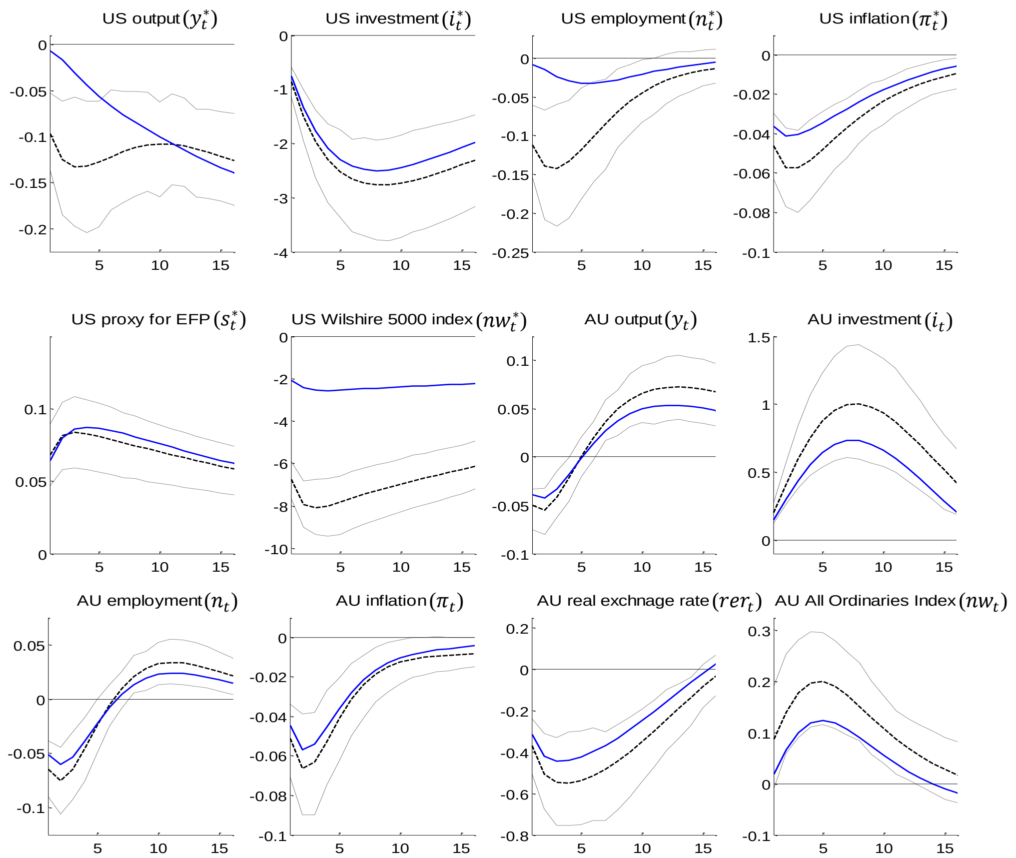


Figure 4.4 Responses to an adverse US financial wealth shock



Notes: Impulse responses to a one standard deviation shock (not equal among models). Black dashed lines represent the posterior mean and 90% posterior probability interval for responses of the baseline model with AFV. The blue solid line represents the posterior mean of responses of the baseline model with DAFV.

In response to the adverse financial wealth shock, the entrepreneurial net worth drops immediately and hence the spread on external finance increases as shown by Christiano et al. (2014). The higher EFP reduces the demand for capital and thereby leads to decreases in investment and output. As highlighted by Christiano et al. (2011), the responses to the shock have some characteristics of a classic demand shock: an adverse wealth shock leads to a reduction in CPI inflation, investment, output and employment in both Australia and the US. According to the baseline model with AFV, a one-standard deviation financial wealth shock has a substantial impact on investment at the one-to-three year horizon in both countries. As found by Jacobs and Rayner (2012) for Australia and by Christiano et al. (2011) for Sweden, the adverse shock leads to the depreciation of the real exchange rate.

4.4.1.2 Responses to non-financial shocks

In this section, impulse responses to non-financial shocks are discussed to study the role of financial sector in propagating shocks, originating in the other sector of the economy. In the case of Australia, about 40 per cent of private debt was borrowed from abroad, which raises a question about the impact of exchange rate depreciation on the macroeconomy passing through the foreign-currency denominated debt channel. The response of the estimated models to a country risk premium shock is presented in Figure 4.B.2 in Appendix 4.B.

The foreign-currency denominated debt channel is operative in Australia, consistent with findings of the 2009 and 2013 Australian Bureau of Statistics (ABS) surveys on foreign currency exposure (FCE) of non-financial corporations discussed by Rush et al. (2013)[114]. According to the baseline models, a positive country risk premium shock leads to a depreciation of real exchange rate, which immediately reduces the entrepreneurial net worth through raising the cost of existing debt. Hence the shock raises the spread on external finance. The rise in EFP enhances the financial accelerator mechanism in the model. As a result, the presence of financial frictions and foreign-currency denominated debt stimulates the response of investment to the shock. This result highlights the

[114]The FCE survey indicates that non-financial sector's foreign currency liabilities has risen in recent years, reflecting an increase in borrowings in foreign debt markets by larger corporations (particularly in the mining sector). In addition, around one-third of non-financial corporations' aggregate foreign currency liability exposures were hedged using derivatives (Rush et al. 2013, p.55).

importance of foreign-currency denominated debt in the estimated open economy model as discussed by Gertler et al. (2007) and Freystätter (2011).

For the purpose of evaluating the impact of the financial frictions on the responses, non-financial shocks are chosen based on the criteria that the size of the chosen shock should be equal in three models. From Table 4.1, it is clear that standard deviation of monetary policy, technology and labour supply shocks in the three estimated models are very closer to each other in both Australia and the US. In addition, the sizes of the US MEI shock in the baseline model with AFV and in the simple model are closer to each other.

Therefore, responses of the three estimated models to these four shocks in both Australia and the US are plotted in Figures 4.B.2-4.B.11 of the Appendix 4.B. In general, the presence of the financial accelerator in the estimated models significantly affects the response of investment and consumption. There is evidence that the presence of the financial accelerator amplifies the effects of monetary policy shocks on investment, output and employment, but dampens those of technology and labour supply shocks in both Australia and the US when financial data is not observed. This result is consistent with the findings stressed by Iacoviello (2005), noticing that the presence of the financial accelerator features an accelerator of demand shocks and a 'decelerator' of supply shocks. However, the results also show that the presence of the financial accelerator dampens the responses of investment and output to the MEI shock for both countries. The decelerator effect of the MEI shock is also found by Christense and Dib (2008). In addition, the impulse responses of the estimated models with financial frictions depend on whether financial data are included in the analysis.

In the presence of financial frictions, monetary policy affects the economy through an additional 'balance sheet channel'[115]. Figure 4.B.3 and Figure 4.B.4 in the Appendix 4.B present responses to an unanticipated monetary policy tightening shock in Australia and the US, respectively. The results suggest that the balance sheet channel of monetary policy transmission is operative in both countries. The result is in line with the empirical evidence provided in data-driven VAR model (i.e., Jacobs and Rayner 2012) for Australia. According to the baseline models, in response to a temporary rise in the interest

[115] The balance sheet channel is one component of the credit channel of monetary policy highlighted by Bernanke and Gertler (1995). According to the channel, a tightening of monetary policy reduces the creditworthiness of borrowers (i.e., by reducing both asset values and cash flows) which increases the EFP and thus intensifies the effect of the policy action.

rate, entrepreneurial net worth is reduced due to the lower capital price and deflation[116]. Owing to the deterioration in the strength of entrepreneurs' balance sheets, the spread on external finance increases, which amplifies the initial policy tightening through further reinforcing the contraction in capital and investment. As a result, the monetary policy shock causes hump-shaped reduction in output, consumption, investment, employment and CPI inflation. Comparing across models, the responses of aggregate variables in the baseline models are stronger than those in the simple model and persist for longer. The results are in line with the findings obtained by Christensen and Dib (2008) and Christiano et al. (2011). It is also apparent that the responses of the baseline models, particularly for real variables, depends on whether financial data is included in the estimation. Comparing across countries (Australia and the US), the financial accelerator mechanism is more evident in the US, as the response of investment shows more amplification and persistence. Monetary policy tightening in the US economy also leads to a reduction in Australian consumption and investment. However, a depreciation of the real exchange rate, driven by the rise in the interest rate differential, increases output and inflation in Australia. This result is robust to the models with and without financial frictions. Moreover, the present results support the policy implication highlighted by Fornari and Stracca (2013) that monetary policy can be well placed to fight financial shocks since responses of macro aggregates to loosening policy shock are found to be the mirror image of the responses to adverse financial shocks.

Figure 4.B.5 and Figure 4.B.6 in Appendix 4.B show responses of the estimated models to MEI shocks in Australia and the US, respectively. The investment shock is a positive shock to the marginal efficiency with which the final good can be transformed into physical capital. Therefore, in response to a positive MEI shock, the price of capital falls as a result of higher supply of capital. The change in the price of capital has two effects: (i) investment increases and (ii) entrepreneurial net worth decreases due to the lower return on capital. The latter effect leads to a rise in the spread on external finance. The rising spread leads to higher cost of funding investment purchases, which dampens the rise of investment. However, the first effect initially dominates, so that investment, output, hours, inflation and interest rate increase before backing off gradually to the steady state gradually. As shown by Christensen and Dib (2008), the presence of financial frictions, therefore, weakens the increase in investment and output. Another interesting

[116] In Australia, the foreign-currency denominated debt mechanism operates in rising net worth because of the real exchange rate appreciation, and its strength is negligible compared to other two mechanisms.

result is that the presence of financial frictions allows the model to produce similar shapes of responses for consumption with those obtained by Justiniano et al. (2010, 2011).

Figure 4.B.7 and Figure 4.B.8 in Appendix 4.B show responses of the estimated models to positive technology shocks in Australia and the US, respectively. The shock has a direct impact on output by making factors more productive, and leads to a decrease in inflation owing to the increase in aggregate supply. In response to the fall in inflation, interest rate decreases immediately according to the Taylor rule. Consumption and investment increase persistently because of lower interest rate and the rise in output. However, unemployment increases temporarily due to the fall in employment. In the baseline models, the fall in inflation also creates the Fisher deflation effect (i.e., increasing the real cost of repaying debt), which reduces entrepreneurial net worth. The decline in net worth raises the spread on external finance, dampening the rise in the demand for capital. As a result, as shown by Villa (2013) among others, the response of investment to the technology shock is weakened when the financial accelerator is present. Comparing across models, the impact of the financial accelerator on output and its components depends on whether financial data are observed in the estimation[117]. When financial data is observed, the response of output is stronger in both countries. However, the components of the output show a different story. There is a weakening of Australian consumption and investment responses, and an amplification of the US consumption and investment responses. In addition, regardless of whether financial frictions are included in the model, the US productivity shock also leads to co-movements of aggregate variables across countries, supporting the view of international business cycles.

4.4.2 Variance decomposition

In order to investigate how financial frictions and shocks are important in driving business cycles in Australia and the US, the variance decomposition is analysed. Since the baseline model is a richer model with many frictions and shocks, the structural estimation of the model can provide an assessment of the contribution of financial shocks 'relative' to other shocks. Figure 4.B.10 in Appendix 4.B presents the contribution of financial shocks and non-financial shocks in the forecast error variances of selected observables evaluated at the posterior mean of the baseline model with AFV.

[117] When financial variables are not observed, the presence of financial accelerator dampens responses of the output and investment in both countries.

Table 4.4 Variance decomposition

	Australia									
	FS $(\epsilon_{cs,t}, \epsilon_{fw,t})$	*TS* $(\epsilon_{a,t})$	*CPS* $(\epsilon_{c,t})$	*MEI* $(\epsilon_{i,t})$	*GSS* $(\epsilon_{g,t})$	*LDS* $(\epsilon_{n,t})$	*MPS* $(\epsilon_{r,t})$	*RPS* $(\epsilon_{rp,t})$	*MS*[##] $(\epsilon_{pm,t}, \epsilon_{\omega,t})$	*FOS*[#] $(\epsilon_{f,t})$
GDP	0.7|23.2	36.7	2.7	5.0	9.7	1.5	2.3	8.3	5.6	4.3
BM-DAFV	1.2|12.7	38.2	0.6	7.0	17.3	2.1	3.0	8.8	6.2	2.9
SM-DAFV	-	50.1	1.1	6.4	8.6	4.4	2.5	11.6	11.9	3.4
Consumption	0.3|13.1	3.1	20.7	1.4	53.0	0.3	0.2	1.4	1.0	5.6
BM-DAFV	0.5|7.1	2.7	4.1	3.0	63.1	0.6	0.3	3.6	2.6	12.4
SM-DAFV	-	4.5	10.0	1.7	64.8	0.8	0.4	4.4	0	13.4
Investment	2.3|38.9	1.3	3.3	8.9	3.1	0.1	0.8	19.5	2.2	19.6
BM-DAFV	3.7|30.8	1.4	0.5	19.2	2.6	0.2	1.5	24.3	4.1	11.7
SM-DAFV	-	4.8	2.6	13.4	15.8	0.9	0.8	35.3	9.4	17.0
Inflation	0.4|7.0	17.5	2.7	2.4	3.7	0.9	8.4	19.0	28.4	9.6
BM-DAFV	0.6|3.3	16.1	0.7	4.0	5.7	1.1	12.2	21.4	29.0	5.9
SM-DAFV	-	18.0	0.8	3.1	3.9	1.7	9.2	20.8	37.9	4.6
Changes in RER	0.3|1.6	2.7	1.6	0.6	6.1	0.2	2.0	67.3	8.9	8.7
BM-DAFV	0.2|0.9	2.2	0.4	0.8	9.1	0.3	2.4	64.5	14.0	5.2
SM-DAFV	-	2.5	0.4	0.8	4.6	0.3	1.5	70.6	13.3	6.0
Unemployment	0.6|1.0	5.6	7.5	12.5	21.6	3.6	7.9	24.9	9.3	5.5
BM-DAFV	0.8|0.5	5.3	1.5	14.5	26.7	3.6	8.9	24.0	11.4	2.8
SM-DAFV	-	7.0	2.3	12.5	20.7	5.8	7.2	27.3	13.6	3.6
Spread	38.0|56.8	0.4	0.6	0.5	1.8	0	0.2	1.2	0	0.5
BM-DAFV	-	-	-	-	-	-	-	-	-	-
SM-DAFV	-	-	-	-	-	-	-	-	-	-
All Ordinary Index	0.4|93.0	0.3	0.3	0.4	1.4	0	0.5	3.1	0.1	0.5
BM-DAFV	-	-	-	-	-	-	-	-	-	-
SM-DAFV	-	-	-	-	-	-	-	-	-	-

	The United States (US)							
	FS $(\varepsilon_{cs^*,t}, \varepsilon_{fw^*,t})$	*TS* $(\varepsilon_{a^*,t})$	*CPS* $(\varepsilon_{g^*,t})$	*MEI* $(\varepsilon_{i^*,t})$	*GSS* $(\varepsilon_{c^*,t})$	*LDS* $(\varepsilon_{n^*,t})$	*MPS* $(\varepsilon_{r^*,t})$	*MS* $(\varepsilon_{pm^*,t}, \varepsilon_{\omega^*,t}$
GDP	6.2|8.0	44.3	15.8	6.0	0.7	7.0	3.0	5.3|3.9
BM-DAFV	2.5|5.0	36.0	47.1	0.6	0.5	2.1	4.4	4.2|0.2
SM-DAFV	-	15.5	73.1	5.8	0.5	1.9	1.1	2.0|0.2
Consumption	10.3|12.9	31.2	31.1	3.8	0.2	6.3	0.8	1.5|1.9
BM-DAFV	3.0|6.4	30.0	54.0	1.0	0.6	2.2	0.9	1.8|0.1
SM-DAFV	-	6.4	89.5	2.5	0	0.8	0.3	0.3|0
Investment	28.9|31.6	8.9	6.7	15.0	0	1.1	1.7	3.7|2.4
BM-DAFV	22.0|32.9	11.7	11.3	4.7	0.4	1.0	6.0	9.8|0.3
SM-DAFV	-	17.0	17.4	54.9	0.6	2.7	1.9	5.2|0.4
Inflation	14.0|10.0	14.4	12.1	7.2	0.4	1.3	12.2	13.4|15.2
BM-DAFV	10.1|7.5	29.7	7.6	2.8	1.7	2.0	21.5	14.6|2.4
SM-DAFV	-	14.1	5.3	35.3	1.0	1.9	17.1	21.3|4.1
Unemployment	4.2|2.2	5.4	13.1	18.7	3.3	4.1	11.5	6.4|31.1
BM-DAFV	8.2|0.5	9.2	5.9	5.1	11.8	10.2	26.5	13.5|9.1
SM-DAFV	-	4.3	4.1	48.0	7.5	6.6	14.5	8.6|6.4
Spread	58.6|38.9	0.5	0.9	0.8	0	0	0.2	0|0
BM-DAFV	-	-	-	-	-	-	-	-
SM-DAFV	-	-	-	-	-	-	-	-
Wilshire 5000	1.7|95.6	0.1	0.8	0.7	0	0	0.8	0.2|0
BM-DAFV	-	-	-	-	-	-	-	-
SM-DAFV	-	-	-	-	-	-	-	-

Notes: For each variable indicated in the first column, variance decompositions are generated by the estimated models evaluated at mean of the posterior distribution. For each variable, results in the first row in the panels are generated by the baseline model with AFV. Results in the rows marked *BM-DAFV* are generated by the baseline model with DAFV. Results in the rows marked *SM-DAFV* are generated by the simple model without financial frictions. In the second column, the number the first figure represents the contribution of credit supply shock and the second figure implies the contribution of financial wealth shock. For the US, in the last column, the first and the second figures respectively imply the contributions of price-markup and wage-markup. ##Figures in the column are sum of contributions of domestic price-markup shock, import price-markup shock and wage-markup shock; #Figures in the column are sum of contributions of all foreign shocks, including foreign financial shocks.

Interesting results include (i) the importance of financial shocks is increasing with forecasting horizons in both Australia, and the US, and (ii) financial shocks are the most important sources of investment fluctuations in the medium and long runs.

Table 4.4 presents the estimated models' unconditional variance decomposition of selected observed variables evaluated at the posterior mean. According to the estimated baseline model with AFV, the results show that financial shocks (i.e., credit supply and financial wealth shocks) are vital for macroeconomic fluctuations in both Australia and the US as shown by recent studies (e.g., Jermann and Quadrini 2012, Chiristiano et al. 2014). In the case of Australia, the financial wealth shock is more important as it explains around 40 per cent of the variation in investment, a quarter of GDP, more than half of the spread on external finance and over 90 per cent of the entrepreneurial net worth. Another interesting result is that 20 per cent of the variation in Australian investment is explained by the US shocks, particularly by the US financial shocks, accounting for 13 per cent. The result supports the view that the international spillovers from the US financial shocks have played a prominent role in international business cycles during the GFC.

Moreover, the financial shocks also play a vital role in explaining variations in nominal variables. For instance, about a one-fourth of the variation of the US inflation is attributed to the financial shocks. The prominence of financial shocks is in line with previous studies in open economy context (e.g., Dib et al. 2008 and Christiano et al. 2011). In the case of the US, financial shocks account for 60 per cent of the variation in investment, 15 per cent of GDP, 40 per cent of the spread and a one-fourth of consumption. Both credit supply and financial wealth shocks are equally important in driving US macroeconomic fluctuations, which is not the case in Australia where financial wealth shocks are more important. The relevance of the credit shock in the US economy is in line with the finding obtained by Gilchrist and Zakrajšek (2012).

The result, showing the financial shock is important in driving macroeconomic fluctuations, depends sensitively on whether the financial data is observed in the estimation. It can be seen by examining the first and second rows in the panels of Table 4.4. For each variable, results in the first row in the panels are generated by the baseline model when the financial data is observed in the analysis. The rows marked BM-DAFV report unconditional variance decompositions at the posterior mean of the baseline model when the financial data is dropped in the analysis. The rows marked SM-DAFV are computed using the simple model discussed in Section 4.3.1, evaluated at the mean of the posterior distribution of its parameters. When all financial variables are not observed, financial shocks lose their importance, and the significance of the MEI shock increases in Australia as found by Christiano et al. (2011) for Sweden. A possible explanation for the change in the significance of the MEI shock is suggested by Christiano et al. (2014)[118]. The relevance of the government-spending shock in driving output and consumption fluctuations increases significantly in both countries when financial data is dropped. In the simple model, the relevance of technology and country risk premium shocks in Australia, and the contribution of the government spending and MEI shocks in the US increase significantly. However, the importance of those shocks is overestimated since the simple model is abstracted from financial frictions, financial shocks and financial observables, which are necessary to improve the model's performance.

From Table 4.4, variance decompositions of unemployment and changes in real exchange rate are robust to different models as financial shocks play a minor role in explaining their variations. The spillover from financial shocks into the labour market is weak in Australia compared to the US economy. In the US, financial shocks account for 6-9 per cent of the unemployment fluctuation. Moreover, the results in Table 4.4 regarding the baseline models are consistent with the empirical facts in a small open economy. For instance, the US shocks account for relatively high shares of the variation in most Australian observables, which have been a challenge for open economy models. Among the US shocks, the financial shocks play more important role in explaining Australian macroeconomic fluctuations. As stressed by Meese and Rogoff (1983), Australian exchange rate fluctuations are weakly related to the domestic macro fundamentals, but mainly explained by the country risk premium shock (65-70 per cent) and the US shocks (6-9 per cent). Among the Australian shocks, government-spending and markup shocks play an important role in explaining the movements in real exchange rate. In addition, monetary policy shock accounts for a significant portion of fluctuation of CPI inflations in both countries, which is consistent with the fact that monetary policy has been an important tool to control inflation and to stabilize the economy.

[118] The MEI shock perturbs the supply curve of the market for capital, and the demand curve is perturbed by the credit supply and financial wealth shocks (Christiano et al. 2014). As shown in the Figure 4.1-4.4 and Figure 4.B.5-4.B.6, though the demand and supply shocks have the same implication for the cyclical properties of investment (i.e., the investment is pro-cyclical), they have opposite implications for the price of capital and, hence, the value of net worth and the spread on external finance. Therefore, the presence of financial data in the analysis is helpful to properly identify the demand shocks, and hence to differentiate between the financial shocks and MEI shock.

4.4.3 Smoothed shock processes and historical decomposition

Figure 4.B.11 in Appendix 4.B presents the smoothed values for the shock processes. During the recent GFC, several shocks in Australia and the US take extreme values. For Australia, extreme low values of the government-spending shock, $\epsilon_{g,t}$, the technology shock, $\epsilon_{a,t}$, the consumption preference shock, $\epsilon_{c,t}$ and the financial wealth shock, $\epsilon_{fw,t}$ contribute to the economic downturn. Extreme high values of the country risk premium shock, $\epsilon_{rp,t}$ and the credit supply shock, $\epsilon_{cs,t}$, and the price-markup shock for domestic firms, $\epsilon_{cp^h,t}$, contributing to macroeconomic fluctuations, are also observed. The monetary policy shock, $\epsilon_{r,t}$ takes an extreme low value in the mid of 2009, implying that the estimated Taylor rule prescribes a higher interest rate than the actual rate. For the US, the extreme low values of the technology shock, $\varepsilon_{a^*,t}$, the consumption preference shock, $\varepsilon_{c^*,t}$, the MEI shock, $\varepsilon_{g^*,t}$ and the financial wealth shock, $\varepsilon_{fw^*,t}$ and high values of the labour disutility shock, $\varepsilon_{n^*,t}$, and the credit supply shock, $\varepsilon_{cs^*,t}$ contribute to the economic downturn. In the beginning of the GFC, the financial wealth shocks were negative and the credit supply shocks were positive. After the GFC, the monetary policy shock, $\varepsilon_{r^*,t}$ takes negative values in general.

The size of some estimated shocks depends sensitively on whether financial variables are included in the analysis. In both countries, the sizes of MEI and financial wealth shocks are significantly reduced, whereas the size of credit supply shocks is considerably increased when financial variables are not observed in the analysis. This result also suggests that the presence of financial data in the analysis is helpful to properly identify MEI and financial shocks and measure their impacts on macroeconomic aggregates.

To assess the source of the recessions in Australia and the US, Figures 4.B.12-4.B.14 in Appendix 4.B show historical decompositions of selected observables that exhibit the contribution of financial, MEI and country risk premium shocks to movements in each observable over the period 1993:Q2-2013:Q4. According to the Figure 4.B.13, financial shocks have played an important role in the sharp drop of investment and inflation in both countries during the GFC as found by Christiano et al. (2014) for the US and by Christiano et al. (2011) for Sweden. The contribution of financial shocks in the US inflation dynamics may provide a supplementary explanation to the fact discussed by Del Negro et al. (2015) and Christiano et al. (2015) that the US inflation declined somewhat in early 2009, but then remained positive during the GFC. When combining contributions of financial shocks (i.e., demand shocks in the capital market) with those of the MEI shock (i.e., supply shock in the capital market), those shocks explain enormously well the movements in investments (Figure 4.B.14). The positive demand and supply shocks in the capital market significantly contribute to higher growth of output in both countries prior to the GFC. Moreover, those shocks contribute only to disinflation (not to inflation) in Australia.

As Australia has a commodity-based economy, the global recession also influences the economy passing through international trade (e.g., negative shock to terms of trade and weak demand for commodities), and hence the nominal exchange rate is depreciated during the recession. This situation can be well captured by the country risk premium shock. Therefore, to analyse impact of the additional channel, the combined contributions of financial, MEI and country risk premium shocks are shown in Figure 4.B.14. An interesting result is that the Australian investment downturn in the beginning of 2000s and the slow recovery of Australian GDP since the GFC are closely associated with country risk premium shocks. The results suggest that the global recessions have influenced the Australian economy passing through both international trade and financial linkages.

4.5 Conclusion

This chapter has assessed the importance of financial frictions and financial shocks in an estimated small open economy DSGE model for explaining macroeconomic fluctuations. The model incorporates important extensions. Financial frictions in the accumulation of capital were introduced following BGG approach. Involuntary unemployment was also included building on the approach proposed by Galí (2011) in which unemployment results from market power in labour markets. Various shocks, including wage markup, labour supply, MEI, credit supply and financial wealth shocks are incorporated based on the recent literature. Several versions of the model are estimated using Bayesian methods on Australian and the US data containing financial data over the period 1993:Q1-2013:Q4.

The key empirical results from the chapter are as follows. First, the inclusion of financial frictions and foreign debt plays an important role in the estimated small open economy model. According to the Bayes factor as the evaluation criterion, the data favours the estimated model with financial accelerator compared to the model with no financial friction. In addition, the data clearly supports the presence of the foreign-currency denominated debt in the model. Second, the elasticity of the EFP with respect to entrepreneurial leverage is estimated away from zero in both cases of Australia and the US. In particular, when the financial data is not observed, the estimated parameters are closer to values obtained in the existing literature (e.g., Elakdag et al. 2006, Christensen and Dib 2008 and Gilchrist et al. 2009). These results therefore suggest that the financial accelerator is evident in both countries, but quantitatively more important in the US. Third, the impulse response analysis suggests the existence of the balance sheet channel of monetary policy and the foreign-currency denominated debt channel in Australia, consistent with findings obtained by Jacobs and Rayner (2012) and Rush et al. (2013). The presence of the financial accelerator amplifies and propagates the effects of monetary policy shocks on investment, output and employment, but dampens the effects of technology and labour supply shocks in both Australia and the US as found by Iacoviello (2005). Moreover, the adverse financial shocks could potentially lead to a domestic recession in both Australia and the US economy. Fourth, financial shocks play an important role in generating business cycle fluctuations in both Australia and the US. In Australia, the financial wealth shock (i.e., shock to entrepreneurial wealth) is vital for explaining macroeconomic fluctuation. In terms of unconditional variance decomposition, the financial wealth shock accounts for around 40 per cent of the variation in investment, a quarter of GDP and more than half of the spread on external finance. In the case of the US, both credit supply and financial wealth shocks are relevant in explaining the business cycle. Fifth, as shown by Christiano et al. (2011) and Christiano et al. (2014), the MEI shock has limited importance in terms of unconditional variance decomposition when the model with financial frictions is estimated to match financial data. This result is more prominent in the case of the US, suggesting the US investment dynamics are highly related to shocks to the demand side of capital market (i.e., financial shocks), not to the supply side of the market (i.e., MEI shock). Finally, the exercise interpreting the recent economic events using the model with AFV shows that the adverse financial shocks (i.e., the sharp increase in the credit spread and the sharp fall in the equity market index) have contributed to the sharp downturns in investments in both countries. The country risk premium shocks have played an important role in the investment downturns of 2001, and also explain the slow recovery of the Australian GDP since the GFC.

Though these results have yielded significant insights about the importance of financial frictions and shocks in a small open economy, the present model can be further extended to fit the data. Future models may (i) incorporate the financial intermediation sector into the model as suggested by Gertler and Karadi (2011) and Gertler and Kiyotaki (2011) to examine the significance of shocks originating within the financial sector, and (ii) allow for financial frictions in working capital loans as shown by Christiano et al. (2015) to investigate the role of the risky working capital channel in the transmission of financial shocks (in which case, financial shocks also play a role as supply shocks). An alternative extension to the model would be to include the interaction between the financial intermediary/banks and households based on the specifications used by Gerali et al. (2010) and Dib et al. (2010a) in order to empirically assess which modelling approach is supported by the data. Future work could also explore the implication of observing market-based data (of the financial and housing sectors) for identifying financial shocks in the estimated model and for improving the model fit.

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Appendix 4.A The steady-state and log-linearized equations

4.A.1 The steady-state equilibrium

The steady-state relations for domestic and foreign economies used to estimate the model are as follows[119]:

$$i_k \equiv I/K = \delta \quad (4.A.1)$$

$$i_y \equiv I/Y = \delta k_y, \text{ where } k_y \equiv K/Y \quad (4.A.2)$$

$$c_y = 1 - g_y - i_y, \text{ where } g_y \equiv G/Y \quad (4.A.3)$$

$$k_y = (N/K^s)^{\Omega-1} \quad (4.A.4)$$

$$N/K^s = ((1-\Omega)/\Omega)\, R^k/(W/P) \quad (4.A.5)$$

$$W/P = \left(\Omega^{\Omega}(1-\Omega)^{(1-\Omega)}/\left(\left(R^k(1+\upsilon_k R)\right)^{\Omega}(1+\upsilon_n R)^{\Omega}\right)\right)^{1/(1-\Omega)} \quad (4.A.6)$$

$$R = 1/\beta - 1 \quad (4.A.7)$$

$$R^k = \frac{1}{\beta}\left(\frac{K}{NW}\right)^{\psi} - (1-\delta) \quad (4.A.8)$$

4.A.2 The log-linearized model

All variables are in log-deviation from their respective steady state values ($x_t = log(X_t/X)$)[120].

4.A.2.1 Domestic Economy

Resource constraint:

$$y_t = c_y(1-\alpha)c_t + c_y\alpha\left((\eta(1-\alpha)+\eta^*)tot_t + \eta^*\psi_{F,t} + y_t^*\right) + c_y^e c_t^e + i_y i_t + u_y u_t + \varepsilon_{g,t} \quad (4.A.9)$$

where $c_y = 1 - g_y - i_y$, $i_y = \delta k_y$, $u_y = R^k k_y$ and $c_y^e = C^E/Y$; y_t and y_t^* are respectively domestic and foreign output; c_t, i_t, u_t, and $\varepsilon_{g,t}$ respectively denote consumption, investment, capital utilization rate and exogenous spending shock (i.e., government spending); α is the share of foreign goods in the aggregate consumption bundle; η is the elasticity of substitution between domestic and foreign goods; $\psi_{F,t} = (e_t + p_t^*) - p_{F,t}$ and $tot_t = p_{F,t} - p_{H,t}$ respectively denote the law of one price gap, so-called by Monacelli (2005) and the terms of trade;

Production function: $y_t = \Omega k_t^s + (1-\Omega)n_t + \varepsilon_{a,t}$ (4.A.10)

Euler equation: $c_t - hc_{t-1} = E_t(c_{t+1} - hc_t) - \sigma^{-1}(1-h)(r_t - E_t\pi_{t+1})$

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119 The steady-state equilibriums are determined as follows: from (4.1), it is certain that $i_k = I/K = \delta$, so $i_y = i_k k_y = \delta k_y$; the resource constraint (4.19) and $a(U) = 0$ yields $c_y = 1 - g_y - i_y$. From the production function (4.5), $k_y = (N/K^s)^{\Omega-1}$ is obtained, and the domestic firm's cost minimization conditions (4.6) yield $N/K^s = ((1-\Omega)/\Omega)\, R^k/(W/P)$, where $R^k = 1/\beta\,(K/NW)^{\psi} - (1-\delta)$ obtained from the steady-state equilibrium of (4.12), (4.13) and (4.14) equations, $W/P = \left(\Omega^{\Omega}(1-\Omega)^{(1-\Omega)}/\left(\left(R^k(1+\upsilon_k R)\right)^{\Omega}(1+\upsilon_n R)^{\Omega}\right)\right)^{1/(1-\Omega)}$, found from the steady-state condition of equation (4.7) where nominal marginal cost equal to the price, and $R = 1/\beta - 1$, obtained from standard Euler equation.

120 Exceptions are: the nominal and real exchange rate are defined as $e_t = \log(\tilde{e}_t/\tilde{e})$ interest rates are specified as $r_t = R_t - R$, the net foreign asset is denoted as $a_t = A_t - A$ and the shocks are described as $\varepsilon_{x,t} = \log(\tilde{\varepsilon}_{x,t}/\tilde{\varepsilon}_x)$, $\varepsilon_{rp,t} = \tilde{\varepsilon}_{rp,t} - \tilde{\varepsilon}_{rp}$.

$$+\sigma^{-1}(1-h)(\varepsilon_{c,t} - E_t\varepsilon_{c,t+1}) \quad (4.A.11)$$

where r_t, π_t and $\varepsilon_{c,t}$ respectively denote the short-term nominal interest rate, overall CPI inflation and the consumption preference shock; h and σ respectively indicate external habit formation parameter and the elasticity of intertemporal substitution.

Investment: $$i_t = \frac{1}{1+\beta} i_{t-1} + \frac{\beta}{1+\beta} E_t i_{t+1} + \frac{1}{\chi''(1+\beta)} q_t + \frac{1}{\chi''(1+\beta)} \varepsilon_{i,t} \quad (4.A.12)$$

where χ''denotes the steady-state value of the second-order derivate of the adjustment cost function, β is the discount factor applied by households, q_t denotes the real value (price) of capital stock, and $\varepsilon_{i,t}$ is the MEI shock.

Capital services: $k_t^s = k_t + u_t$ (4.A.13)

The capital stock: $k_{t+1} = (1-\delta)k_t + \delta(i_t + \varepsilon_{i,t})$ (4.A.14)

Capital utilization: $u_t = u_a r_t^k$, where $u_a = (1-\kappa)/\kappa$ (4.A.15)

Rental rate of capital: $r_t^k = -(k_t^s - n_t) + \omega_t + (\upsilon_n - \upsilon_k) r_t$ (4.A.16)

where $\omega_t = w_t - p_t$ denotes the real wage rate, where w_t and p_t respectively denote nominal wage and price level.

Expected rate of return on capital:

$$E_t r_{t+1}^{e,k} = \frac{R^k}{1-\delta+R^k} E_t r_{t+1}^k + \frac{1-\delta}{1-\delta+R^k} E_t q_{t+1} - q_t \quad (4.A.17)$$

where R^k denote the steady state value of the capital rental rate.

Expected marginal cost of external funds/external funds rate:

$$E_t r_{t+1}^{e,k} = \varpi^d (r_t - E_t \pi_{t+1}) + (1-\varpi^d)(r_t^* - E_t \pi_{t+1}^* + \phi_{t+1} + rer_{t+1} - rer_t) + s_t \quad (4.A.18)$$

where $\phi_{t+1} = -\phi_a a_t - \phi_e(\Delta e_{t+1} + \Delta e_t) + \varepsilon_{rp,t}$.

External finance premium:

$$s_t = \psi(q_t + E_t k_{t+1} - E_t nw_{t+1}) + \varepsilon_{cs,t} \quad (4.A.19)$$

Entrepreneurial net worth:

$$E_t nw_{t+1} = \gamma(R^k + 1 - \delta)\left(\frac{K}{NW} r_t^{e,k} - \left(\frac{K}{NW} - 1\right)\left(s_{t-1} + \varpi^d(r_{t-1} - \pi_t) + (1-\varpi^d)(r_{t-1}^* - \pi_t^* + \phi_t + rer_t - rer_{t-1})\right) + nw_t + \varepsilon_{fw,t}\right) \quad (4.A.20)$$

Consumption of entrepreneurs who close business:

$$c_t^e = \frac{E_t nw_{t+1}}{\gamma(1-\delta+R^k)} \quad (4.A.21)$$

Time-differences in the terms of trade:

$$\Delta tot_t = \pi_{F,t} - \pi_{H,t} \quad (4.A.22)$$

where $\pi_{F,t} = p_{F,t} - p_{F,t-1}$ and $\pi_{H,t} = p_{H,t} - p_{H,t-1}$ respectively denote inflation of imported goods and inflation of domestic goods.

Real exchange rate: $rer_t = e_t + p_t^* - p_t = \psi_{F,t} + (1-\alpha) tot_t$ (4.A.23)

Domestic firms' inflation equation, extended with the cost channel:

$$\pi_{H,t} - \delta_H \pi_{H,t-1} = \beta E_t(\pi_{H,t+1} - \delta_H \pi_{H,t}) + k_H mc_t + \varepsilon_{pm^h,t} \quad (4.A.24)$$

with $k_H = (1-\theta_H)(1-\theta_H\beta)/\theta_H$, where θ_H and δ_H respectively denote the domestic Calvo price stickness and the domestic price indexation parameters; $\varepsilon_{pm^h,t}$ is domestic firm's price markup shock.

Real marginal costs:

$$mc_t = (1-\Omega)\omega_t + \Omega r_t^k + \big((1-\Omega)\upsilon_n + \Omega\upsilon_k\big)r_t + \alpha tot_t - \varepsilon_{a,t} \qquad (4.A.25)$$

Retailers' inflation equation, extended with the cost channel:

$$\pi_{F,t} - \delta_F\pi_{F,t-1} = \beta E_t\big(\pi_{F,t+1} - \delta_F\pi_{F,t}\big) + k_F\big(\psi_{F,t} + \upsilon_F r_t^*\big) + \varepsilon_{pm^f,t} \quad (4.A.26)$$

where $k_F = \frac{(1-\theta_F)(1-\theta_F\beta)}{\theta_F}$, υ_F represents a friction of retail firms' inputs that must be financed in advance, r_t^* is the foreign nominal interest rate, $\big(\psi_{F,t} + \upsilon_F r_t^*\big)$ represents [121], marginal cost, and $\varepsilon_{pm^f,t}$ is the retailers' price markup shock.

Consumer price index (CPI) inflation:

$$\pi_t = \pi_{H,t} + \alpha\Delta tot_t \qquad (4.A.27)$$

Real wage: $$\omega_t = \omega_{t-1} + \pi_t^\omega - \pi_t \qquad (4.A.28)$$

Wage inflation: $$\pi_t^\omega - \delta_\omega\pi_{t-1} = \beta E_t(\pi_{t+1}^\omega - \delta_\omega\pi_t) - \varrho_\omega\big(\mu_{\omega,t} - \mu_{\omega,t}^n\big) \qquad (4.A.29)$$

with $\mu_{\omega,t}^n = 100\cdot\varepsilon_{\omega,t}$ and $\varrho_\omega \equiv \frac{(1-\theta_\omega)(1-\beta\theta_\omega)}{\theta_\omega(1+\varphi\zeta_\omega)}$, where $\varepsilon_{\omega,t}$ represents wage markup shock, θ_ω and δ_ω imply respectively Calvo wage stickness and indexation paratemers, and φ and ε_ω respectively denotes the elasticity of marginal disutility of work and wage elasticity of the relevant labour demand.

Average wage markups and unemployment:

$$\mu_{\omega,t} = \omega_t - \big(z_t + \varphi n_t + \varepsilon_{n,t}\big) = \varphi un_t \qquad (4.A.30)$$

where un_t and $\varepsilon_{n,t}$ respectively denote unemployment rate and the labour supply shock, and $z_t = (1-\vartheta_z)\, z_{t-1} + \vartheta_z\Big(-\varepsilon_{g,t} + (\sigma/(1-h))(c_t - hc_{t-1})\Big)$.

Labour force: $$l_t = n_t + un_t \qquad (4.A.31)$$

Modified UIP condition:

$$r_t - r_t^* = (1-\phi_e)E_t\Delta e_{t+1} - \phi_e\Delta e_t - \phi_a a_t + \varepsilon_{rp,t} \qquad (4.A.32)$$

where ϕ_e is the UIP modification parameter, $\Delta e_t = \pi_t - \pi_t^* + \Delta rer_t$ and a_t respectively denote the change in the nominal exchange rate and net foreign asset, and $\varepsilon_{rp,t}$ represents the risk premium shock.

Net foreign assets: $$a_t = (1/\beta)a_{t-1} - \alpha c_y\big(\psi_{F,t} + tot_t\big) + y_t - \big(c_y c_t + c_y^e c_t^e + i_y i_t + u_y u_t + \varepsilon_{g,t}\big) \qquad (4.A.33)$$

Domestic monetary policy rule:

$$r_t = \rho_R\, r_{t-1} + (1-\rho_R)\big(\chi_\pi\pi_t + \chi_y y_t + \chi_{\Delta y}\Delta y_t\big) + \varepsilon_{r,t} \quad (4.A.34)$$

where $\varepsilon_{r,t}$ is a domestic monetary policy shock.

[121] As discussed by Christiano et al. (2011), it is assumed that the foreign seller extends the working capital loan in the foreign currency, and there is no risk associated with this loan.

4.A.2.2 Foreign economy

The foreign economy is modelled as a closed economy version of the model described by equations (4.A.10)-(4.A.31). Foreign variables and parameters are denoted with superscript "*".

Resource constraint: $y_t^* = c_y^* c_t^* + c_y^{e*} c_t^{e*} + i_y^* i_t^* + u_y^* u_t^* + \varepsilon_{g^*,t}$ (4.A.35)

Production function: $y_t^* = \Omega^* k_t^{s*} + (1-\Omega^*) n_t^* + \varepsilon_{a^*,t}$ (4.A.36)

Euler equation: $c_t^* - h^* c_{t-1}^* = E_t(c_{t+1}^* - h^* c_t^*) - \sigma^{*-1}(1-h^*)(i_t^* - E_t \pi_{t+1}^*)$
$+\sigma^{*-1}(1-h^*)(\varepsilon_{c^*,t} - \varepsilon_{c^*,t+1})$ (4.A.37)

Investment: $i_t^* = \frac{1}{1+\beta^*} i_{t-1}^* + \frac{\beta^*}{1+\beta^*} E_t i_{t+1}^* + \frac{1}{(1+\beta^*)\chi^{*\prime\prime}} q_t^* + \frac{1}{(1+\beta^*)\chi^{*\prime\prime}} \varepsilon_{i^*,t}$ (4.A.38)

Capital services: $k_t^{s*} = k_t^* + u_t^*$ (4.A.39)

The capital stock: $k_{t+1}^* = (1-\delta^*) k_t^* + \delta^* \left(i_t^* + \varepsilon_{i^*,t}\right)$ (4.A.40)

Capital utilization: $u_t^* = u_a^* r_t^{k*}$, where $u_a^* = (1-\kappa^*)/\kappa^*$ (4.A.41)

Rental rate of capital: $r_t^{k*} = -(k_t^{s*} - n_t^*) + \omega_t^* + (\upsilon_n^* - \upsilon_k^*) r_t^*$ (4.A.42)

Expected rate of return on capital:

$$E_t r_{t+1}^{e,k*} = \frac{R^{k*}}{1-\delta^*+R^{k*}} E_t r_{t+1}^{k*} + \frac{1-\delta^*}{1-\delta^*+R^{k*}} E_t q_{t+1}^* - q_t^* \quad (4.A.43)$$

Expected marginal cost of external funds/external funds rate:

$$E_t r_{t+1}^{e,k*} = r_t^* - E_t \pi_{t+1}^* + s_t^* \quad (4.A.44)$$

External finance premium:

$$s_t^* = \psi^*(q_t^* + E_t k_{t+1}^* - E_t nw_{t+1}^*) + \varepsilon_{cs^*,t} \quad (4.A.45)$$

Entrepreneurial net worth:

$$E_t nw_{t+1}^* = \gamma^*(R^{k*} + 1 - \delta^*) \left(\frac{K^*}{NW^*} r_t^{e,k*} - \left(\frac{K^*}{NW^*} - 1\right)(s_{t-1}^* + r_{t-1}^* - \pi_t^*) + nw_t^* + \varepsilon_{nw^*,t}\right) \quad (4.A.46)$$

Consumption of entrepreneurs who close business:

$$c_t^{e*} = \frac{E_t nw_{t+1}^*}{\gamma^*(1-\delta^*+R^{k*})} \quad (4.A.47)$$

Phillips curve: $\pi_t^* - \delta_p^* \pi_{t-1}^* = \beta^* E_t\left(\pi_{t+1}^* - \delta_p^* \pi_t^*\right) + \rho^* mc_t^* + \varepsilon_{pm^*,t}$ (4.A.48)

where $\rho^* = \frac{(1-\theta^*)(1-\theta^*\beta^*)}{\theta^*}$; $\varepsilon_{pm^*,t}$ is a foreign price markup shock, and

Real marginal cost: $mc_t^* = (1-\Omega^*)\omega_t^* + \Omega^* r_t^{k*} + \left((1-\Omega^*)\upsilon_n^* + \Omega^* \upsilon_k^*\right) r_t^*$
$-\varepsilon_{a^*,t}$ (4.A.49)

Real wage: $\omega_t^* = \omega_{t-1}^* + \pi_t^{\omega*} - \pi_t^*$ (4.A.50)

Wage inflation: $\pi_t^{\omega*} - \delta_\omega^* \pi_{t-1}^* = \beta^* E_t\left(\pi_{t+1}^{\omega*} - \delta_\omega^* \pi_t^*\right) - \varrho_\omega^*\left(\mu_{\omega,t}^* - \mu_{\omega,t}^{n*}\right)$ (4.A.51)

with $\varrho_\omega^* \equiv \frac{(1-\theta_\omega^*)(1-\beta^*\theta_\omega^*)}{\theta_\omega^*(1+\varphi^*\zeta_\omega^*)}$ and $\mu_{\omega,t}^{n*} = 100 \cdot \varepsilon_{\omega^*,t}$.

Average and natural wage markups and unemployment:

$$\mu_{\omega,t}^* = \omega_t^* - \left(z_t^* + \varphi^* n_t^* + \varepsilon_{n^*,t}\right) = \varphi^* un_t^* \quad (4.A.52)$$

where $z_t^* = (1-\vartheta_z^*)\, z_{t-1}^* + \vartheta_z^* \left(-\varepsilon_{g^*,t} + (\sigma^*/(1-h^*))(y_t^* - h^* y_{t-1}^*)\right)$.

Labour force: $l_t^* = n_t^* + un_t^*$ (4.A.53)

Foreign monetary policy rule:

$$r_t^* = \rho_R^* r_{t-1}^* + (1-\rho_R^*)\left(\chi_\pi^* \pi_t^* + \chi_y^* y_t^* + \chi_{\Delta y}^* \Delta y_t^*\right) + \varepsilon_{r^*,t} \quad (4.A.54)$$

where $\varepsilon_{r^*,t}$ is a foreign monetary policy shock.

Appendix 4.B Data definitions and figures

4.B.1 Data Definitions

4.B.1.1 Australia

Output: real non-farm GDP, chain volume measures, seasonally adjusted; Australian Bureau of Statistics (ABS) Cat No 5206.0: A2302589X

Consumption: real household final consumption expenditure, chain volume measures, seasonally adjusted; ABS Cat No 5206.0: A2304081W

Investment: real private gross fixed capital formation (real private final investment expenditure), chain volume measures, seasonally adjusted; ABS Cat No 5206.0: A2304100T

Inflation: quarterly inflation, excluding interest payments (prior to the September quarter 1998) and tax changes of 1999-2000, seasonally adjusted; Reserve Bank of Australia (RBA) Statistical Table G1 Consumer Price Inflation

Interest rates: cash rate, quarterly average; RBA Statistical Table F13 International Official Interest Rates

Wage inflation: quarterly percentage changes in average non-farm (current prices) compensation per employee, seasonally adjusted; ABS Cat No 5206.0: A2302622R

Unemployment rate: unemployment rate, at the end of quarter, seasonally adjusted; ABS Cat No 6202.0: A181525X

Employment: Employed persons, at the end of quarter, seasonally adjusted; ABS Cat No 6202.0: A181515V

Real exchange rate: real trade-weighted index; RBA Statistical Table F15 Real Exchange Rate Measures

Terms of trade: terms of trade index, seasonally adjusted; ABS Cat No 5206.0: A2304200A

Net worth: ASX All Ordinaries Index (quarter average), divided by the GDP implicit price deflator; Source: ASX, Wren Advisers and ABS Cat No 5206.0: A2303730T

External finance premium (EFP): From 2005 onwards, it is computed as the weighted average of corporate 10-year BBB-rated bond yield spread and spread between large business lending rate and cash rate. The series is back casted by the large business-lending rate spread.

Large business lending rate: large business weighted-average variable interest rate on outstanding credit, quarterly average; RBA Statistical Table F5 Indicator Lending Rates

Corporate 10-year BBB-rated bond yield spread: non-financial corporate BBB-rated bonds spread to Australian Commonwealth Government securities (CGS) rates – 10-year, quarterly average; RBA Statistical Table F3 Aggregate Measures of Australian Corporate Bond Spreads and Yields: Non-Financial Corporate (NFC) Bonds

Weights: the outstanding stocks of each credit instrument (business loans and business bond liabilities) is used as weight in the measurement of the spread (EFP); RBA Statistical Table E1 Household and Business Balance Sheets

4.B.1.2 The United States (US)

Output: non-farm business output, seasonally adjusted annual rate; U.S. Bureau of Labour Statistics (BLS): PRS85006043

Consumption: real personal consumption expenditures, billions of chained 2009 dollars, seasonally adjusted annual rate; Federal Reserve Bank of St. Louis, FRED database: PCECC96

Investment: real gross private domestic investment, billions of chained 2009 dollars, seasonally adjusted annual rate; Federal Reserve Bank of St. Louis, FRED database: GDPIC1

Inflation: quarterly percentage changes in the GDP implicit price deflator, Index 2009=100, seasonally adjusted; Federal Reserve Bank of St. Louis, FRED database: GDPDEF

Interest rates: Federal funds rate, quarterly average; RBA Statistical Table F13 International Official Interest Rates

Wage inflation: quarterly changes in non-farm compensation per employee, computed as non-farm compensation of employees, seasonally adjusted (BLS: PRS85006063), divided by non-farm employment, seasonally adjusted (BLS: PRS85006013)

Unemployment rate: unemployment rate, at the end of quarter, seasonally adjusted; BLS: LNS14000000

Employment: non-farm employment, seasonally adjusted; BLS: PRS85006013

Net worth: Dow Jones Wilshire 5000 total market index, divided by the GDP implicit price deflator; Federal Reserve Bank of St. Louis, FRED database: WILL5000IND and GDPDEF

External finance premium (FFP): Moody's Seasoned Baa Corporate Bond Yield Relative to Yield on 10-Year Treasury Constant Maturity; Federal Reserve Bank of St. Louis, FRED database: BAA10Y

Figure 4.B.1 Data and one-sided predicted values

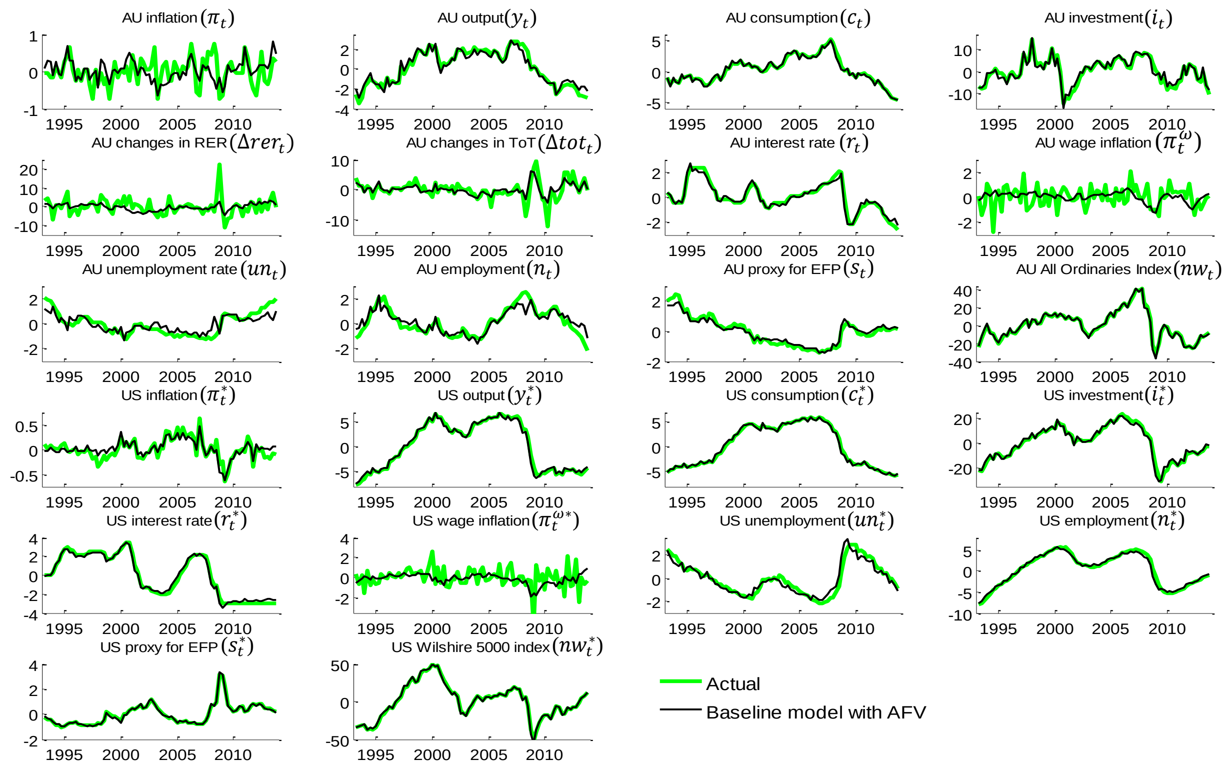


Figure 4.B.2 Responses to a positive AU risk premium shock

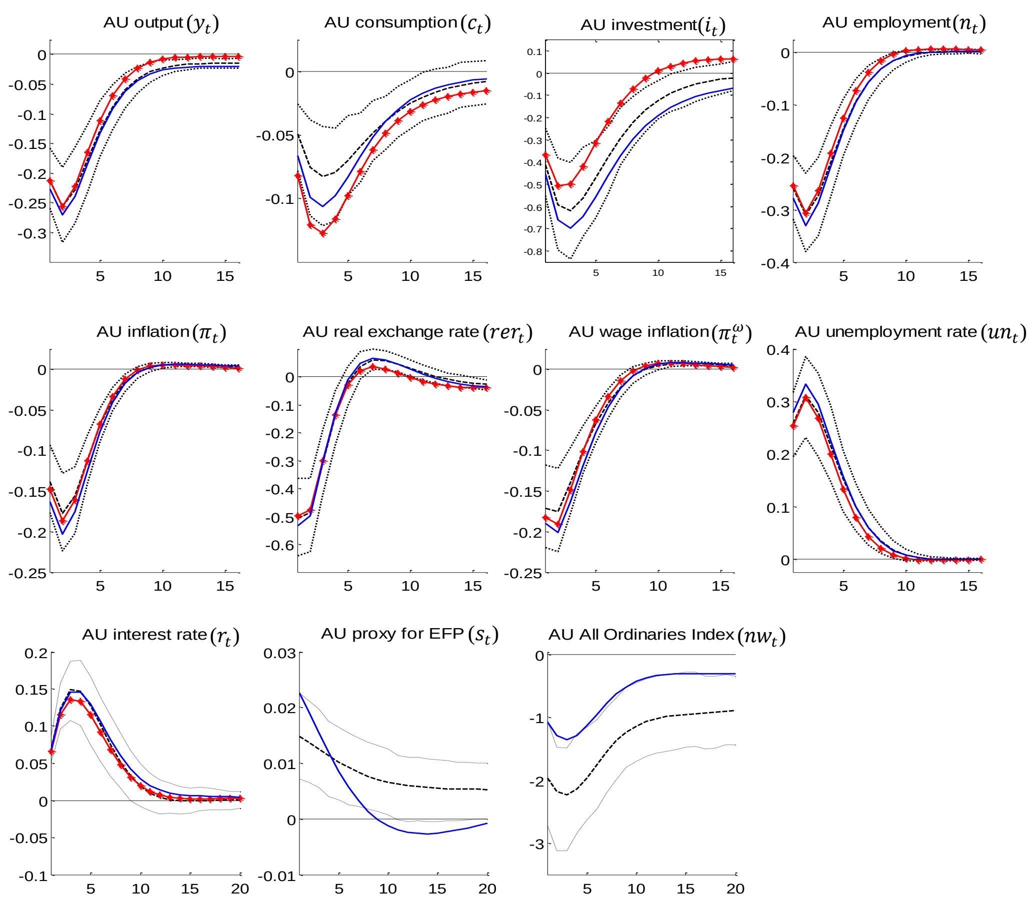


Figure 4.B.3 Responses to a tightening AU monetary policy shock

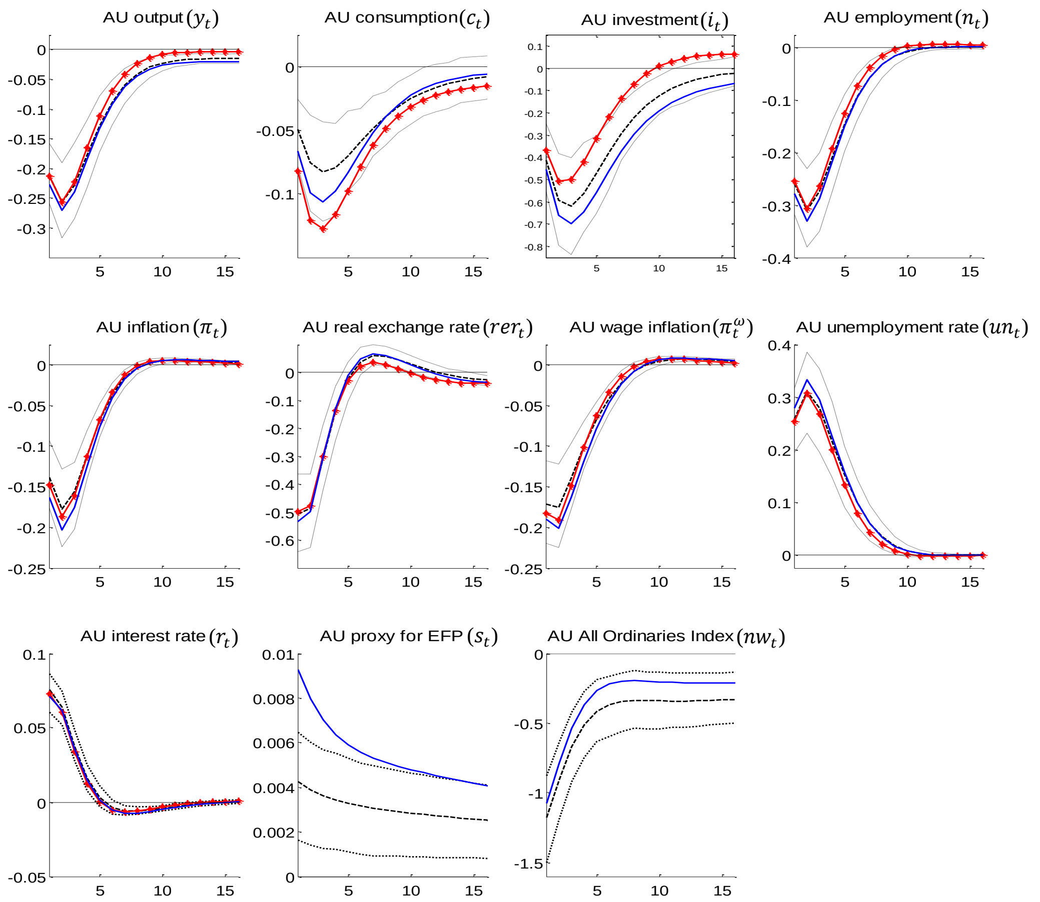
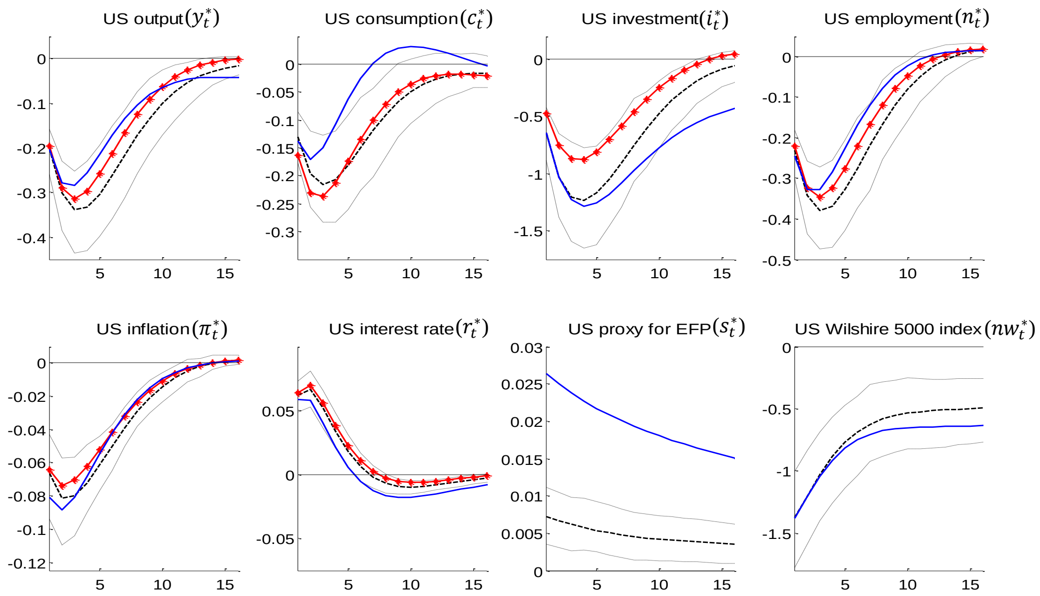


Figure 4.B.4 Responses to a tightening US monetary policy shock



Notes: Impulse responses to equal size (i.e., a one standard deviation) shock. Black dashed lines represent the posterior mean and 90% posterior probability interval for impulse responses of the baseline model with AFV. Blue solid line and red line with marker represent the posterior mean of impulse responses of the baseline model with DAFV and the simple model, respectively.

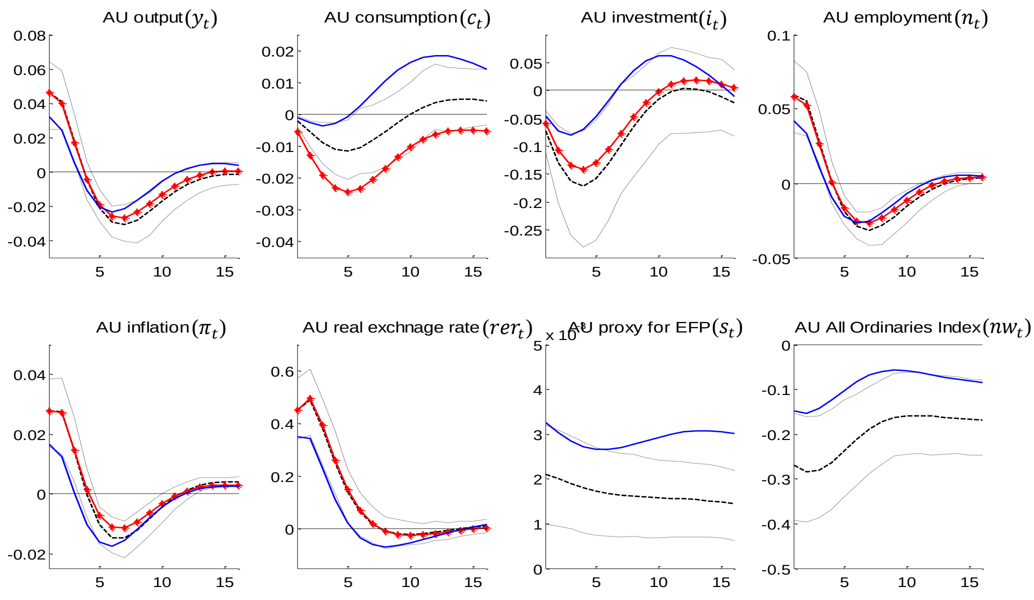
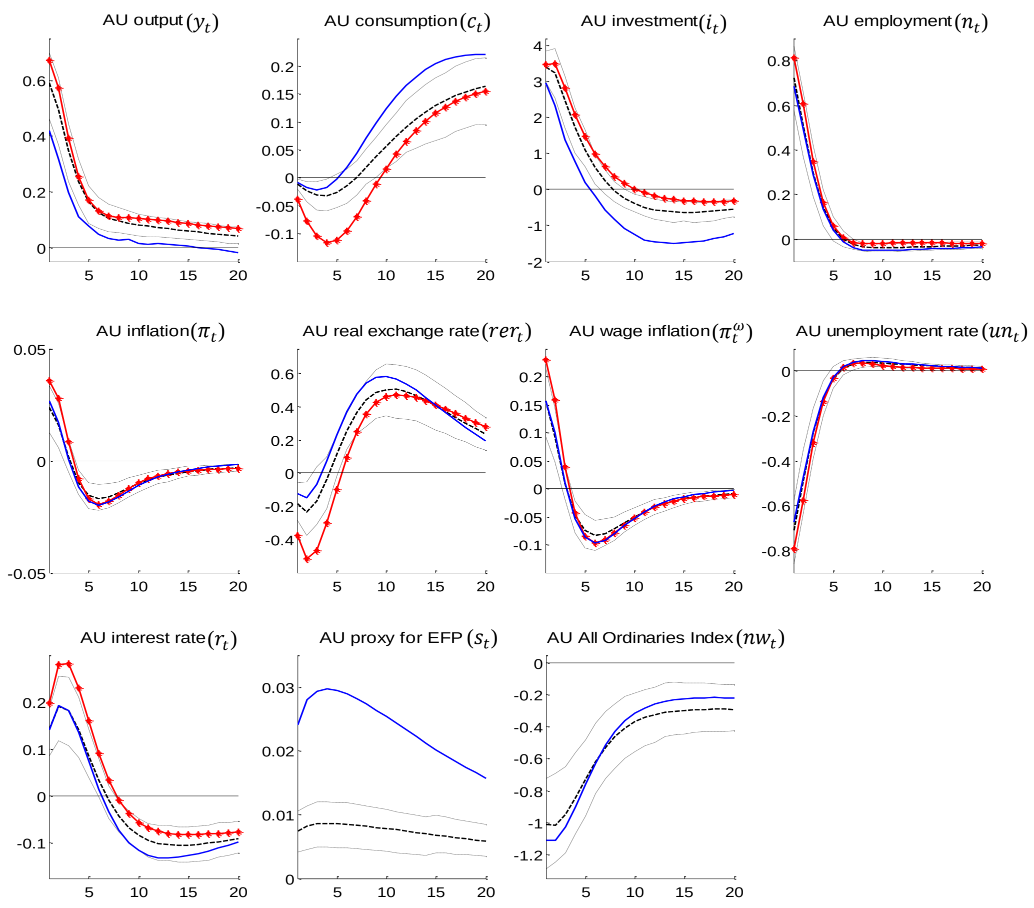


Figure 4.B.5 Responses to a positive AU investment shock



Notes: Impulse responses to equal size (i.e., a one standard deviation) shock. Black dashed lines represent the posterior mean and 90% posterior probability interval for impulse responses of the baseline model with AFV. Blue solid line and red line with marker respectively represent the posterior mean of impulse responses of the baseline model with DAFV and the simple model.

Figure 4.B.6 Responses to a positive US investment shock

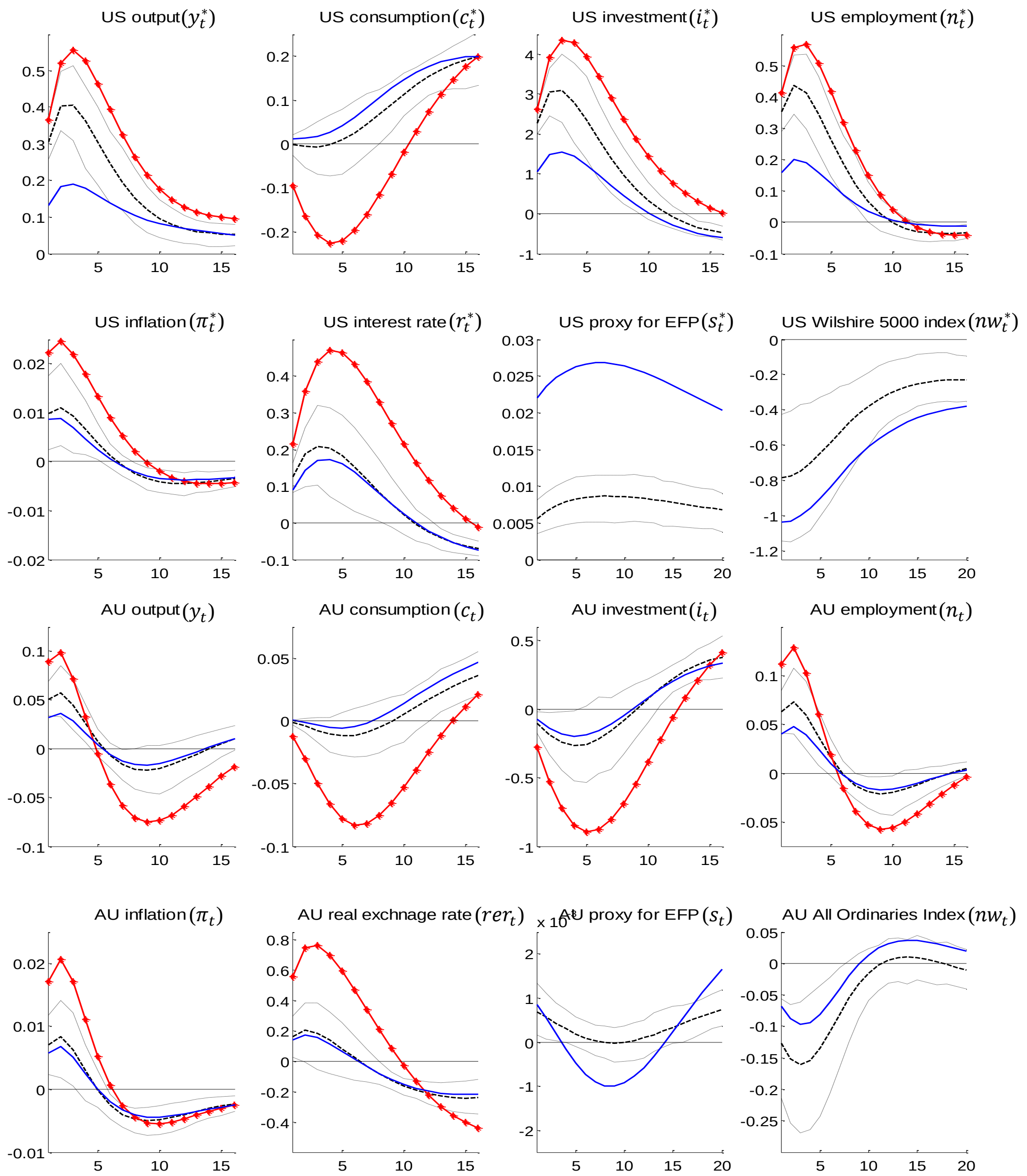
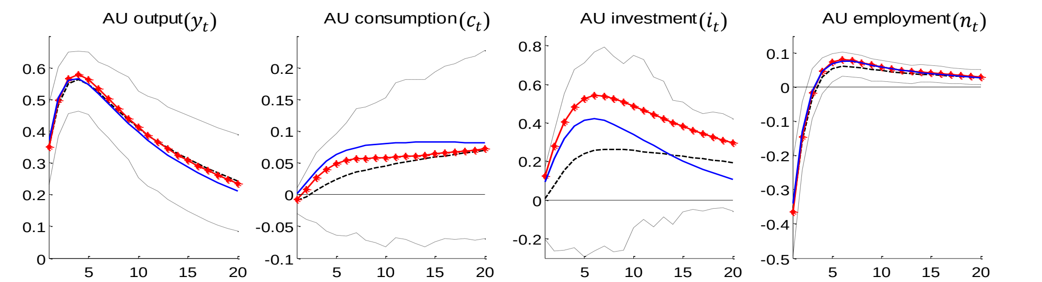


Figure 4.B.7 Responses to a positive AU technology shock



Notes: Impulse responses to equal size (i.e., a one standard deviation) shock. Black dashed lines represent the posterior mean and 90% posterior probability interval for impulse responses of the baseline model with AFV. Blue solid line and red line with marker respectively represent the posterior mean of impulse responses of the baseline model with DAFV and the simple model.

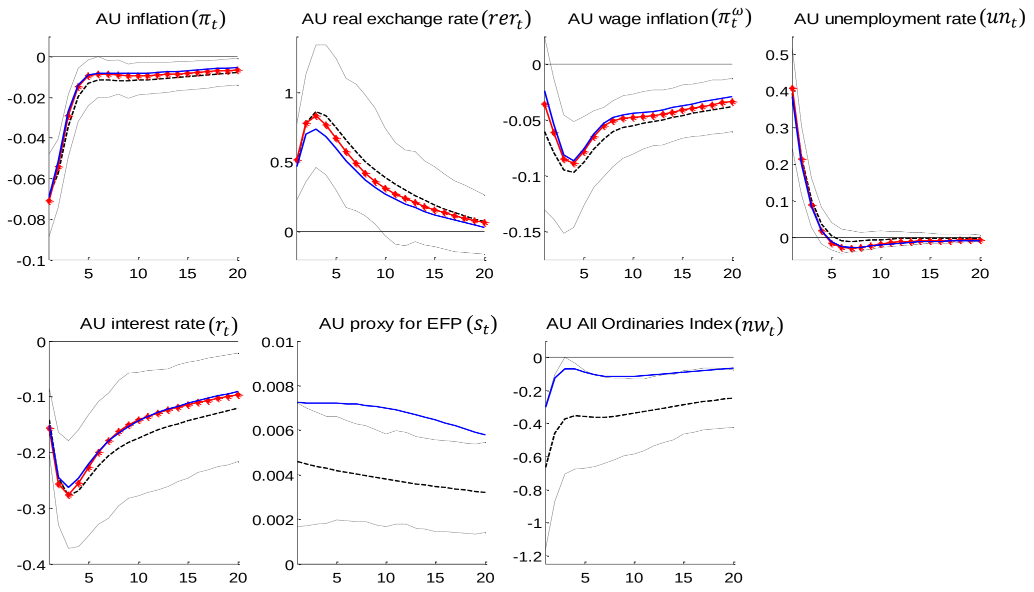
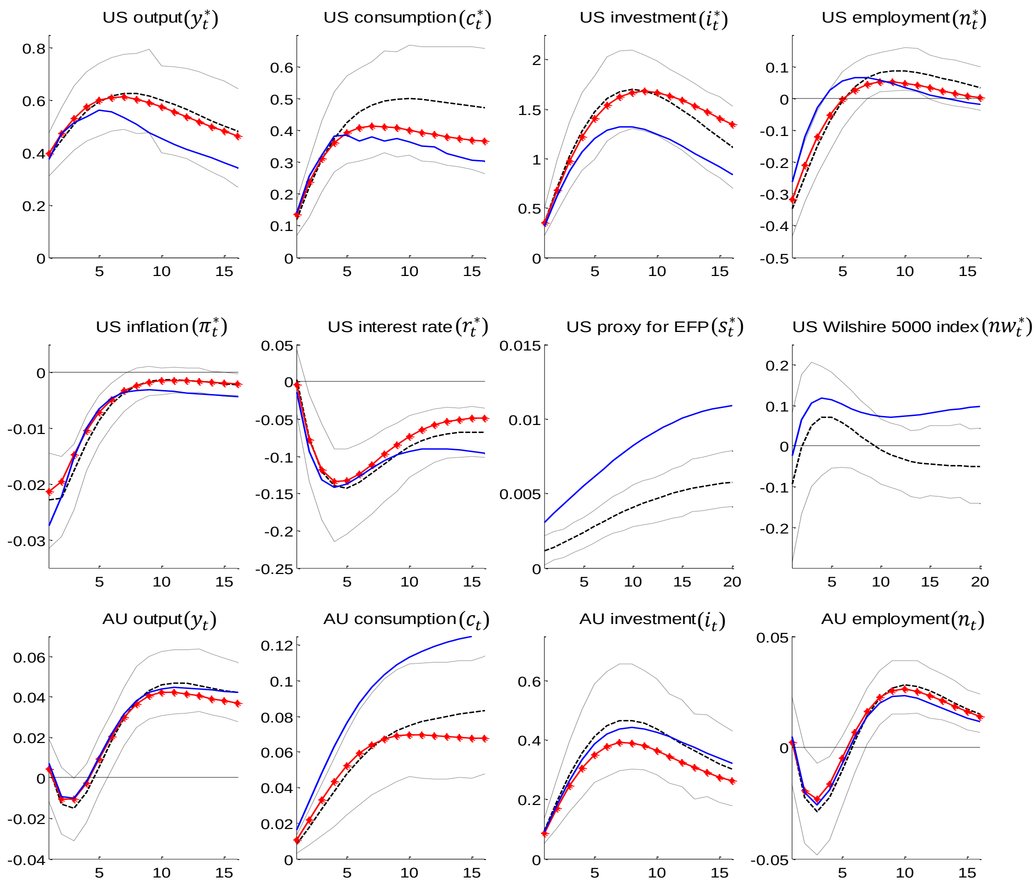


Figure 4.B.8 Responses to a positive US technology shock



Notes: Impulse responses to equal size (i.e., a one standard deviation) shock. Black dashed lines represent the posterior mean and 90% posterior probability interval for impulse responses of the baseline model with AFV. Blue solid line and red line with marker respectively represent the posterior mean of impulse responses of the baseline model with DAFV and the simple model.

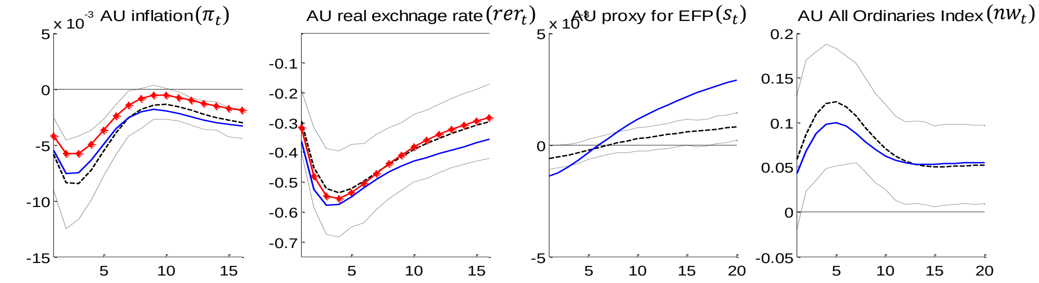
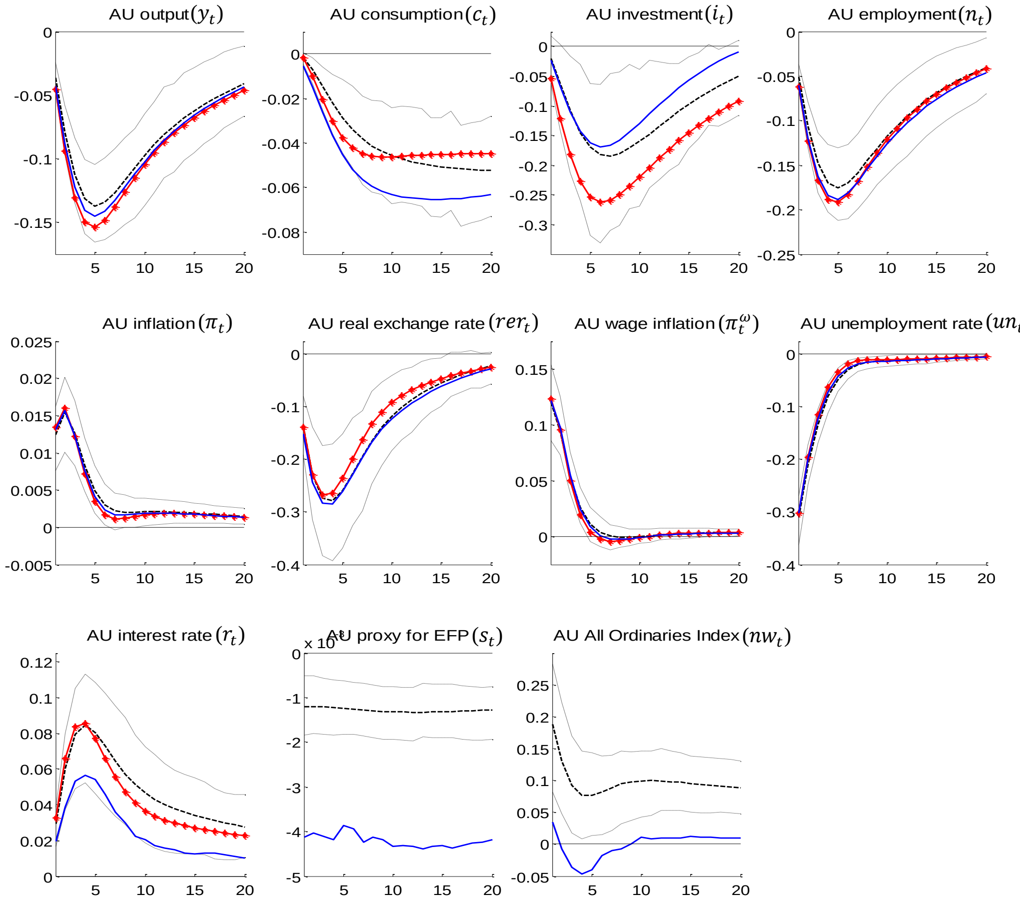
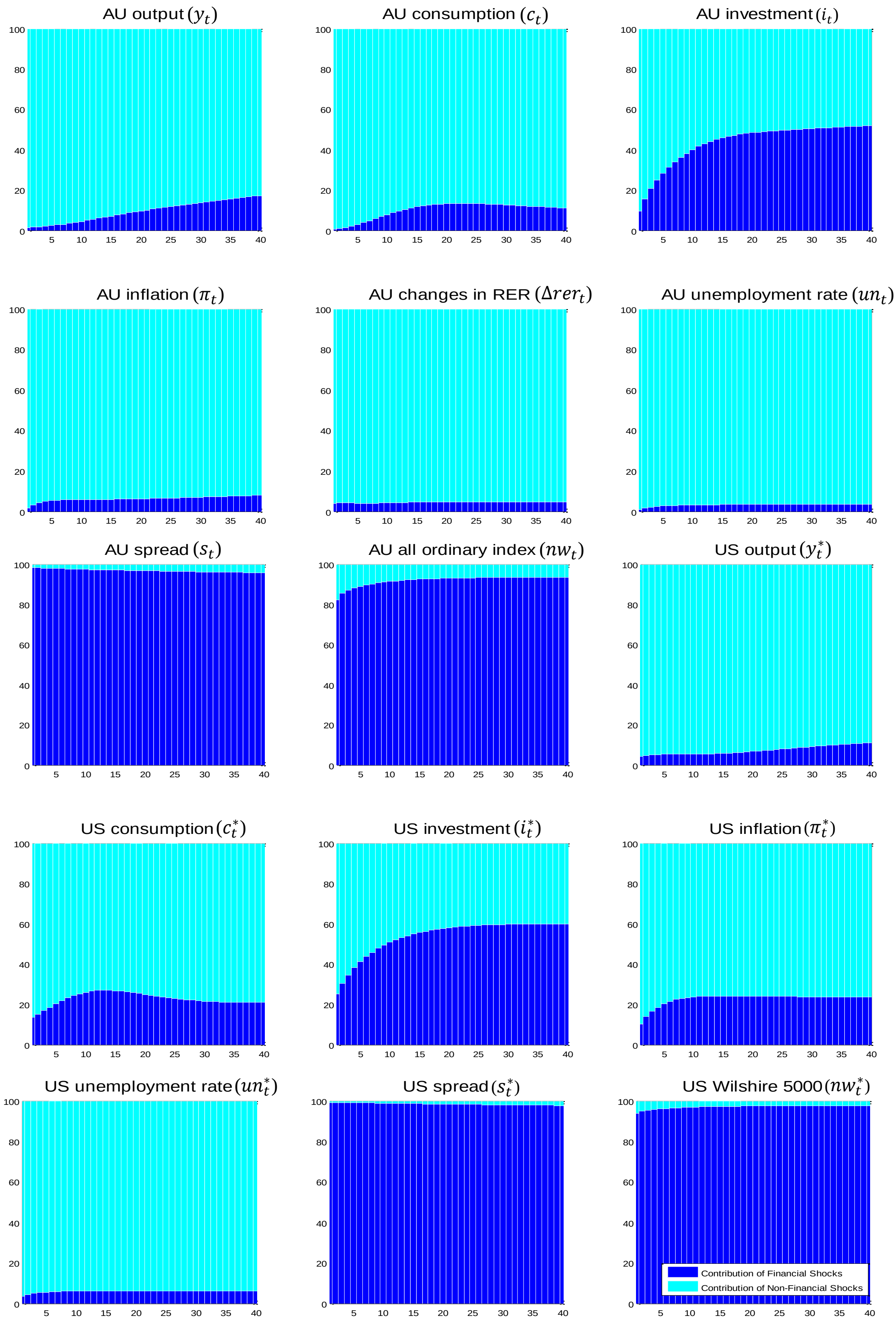


Figure 4.B.9 Responses to a negative AU labour supply shock



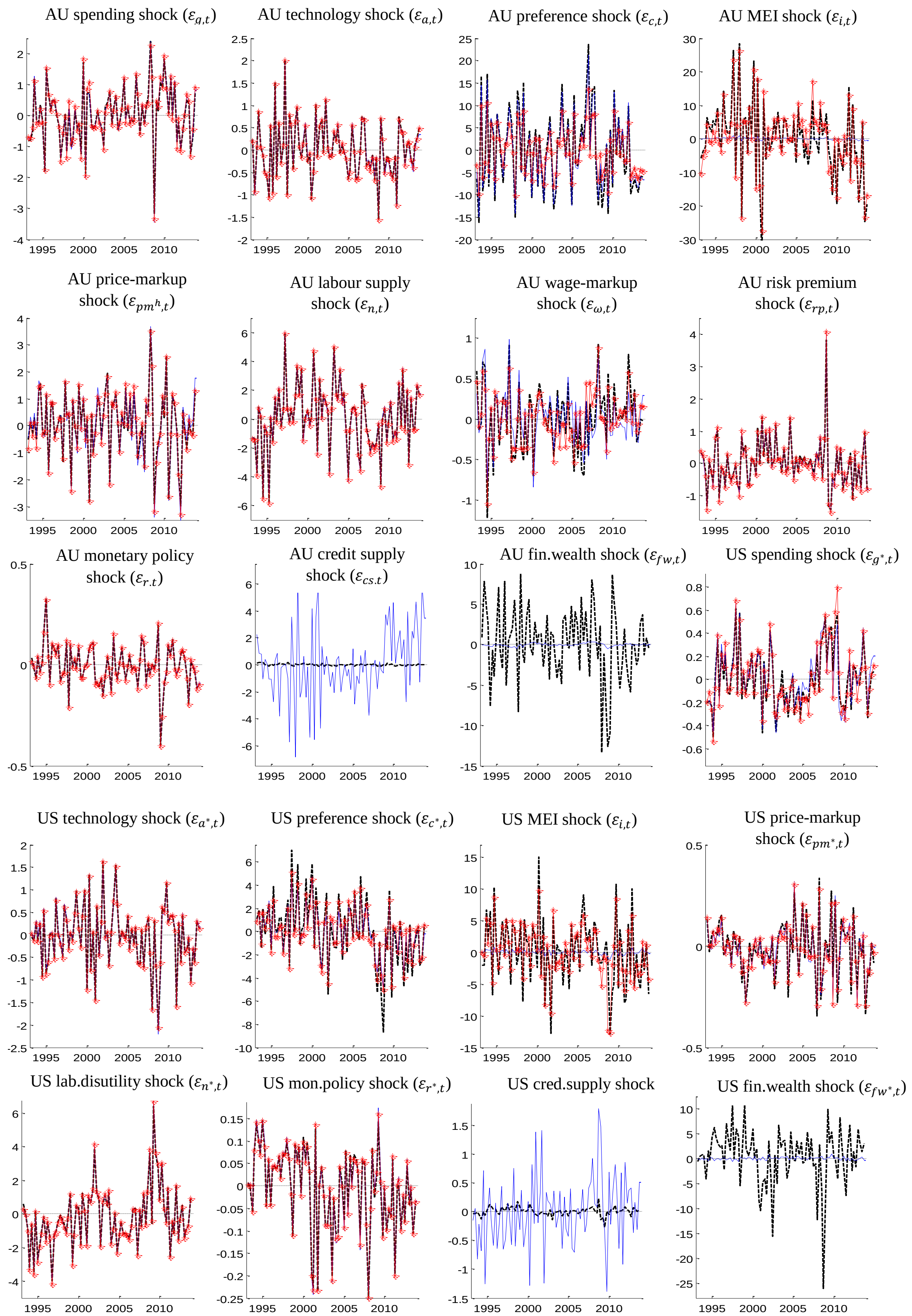
Notes: Impulse responses to equal size (i.e., a one standard deviation) shock. Black dashed lines represent the posterior mean and 90% posterior probability interval for impulse responses of the baseline model with AFV. Blue solid line and red line with marker respectively represent the posterior mean of impulse responses of the baseline model with DAFV and the simple model.

Figure 4.B.10 Forecast error variance decomposition: Financial vs. Non-financial shocks



Notes: Blue and cyan bars respectively represent the contribution of financial shocks and contribution non-financial shocks evaluated at the posterior mean of the estimated baseline model with AFV.

Figure 4.B.11 Smoothed shock processes



Notes: Black dashed lines represent smoothed shocks of the baseline model with AFV. Blue solid line and red line with marker respectively represent smoothed shocks of the model with DAFV and the simple model.

Figure 4.B.12 Data and contribution of financial shocks only

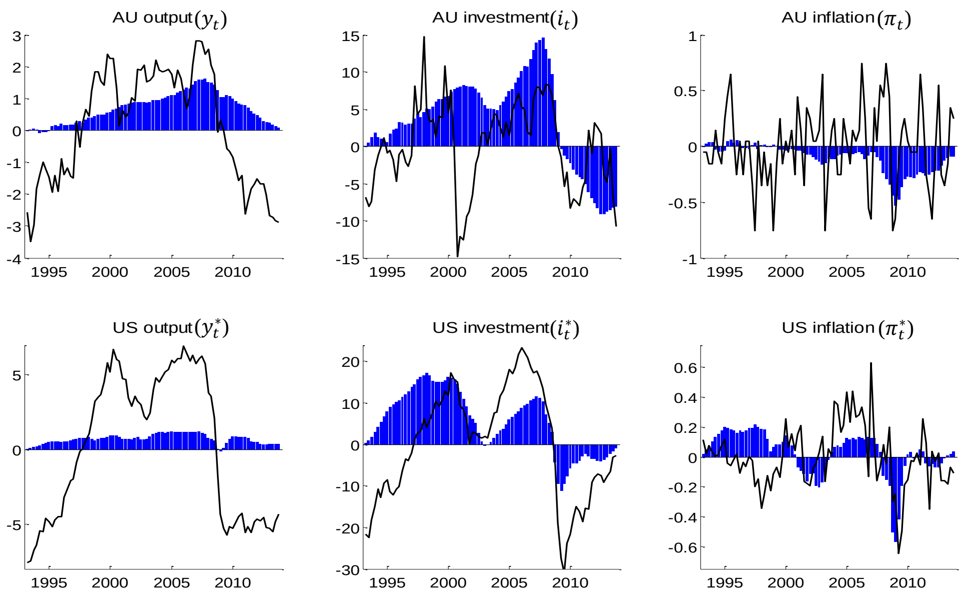


Figure 4.B.13 Data and contribution of both financial and MEI shocks

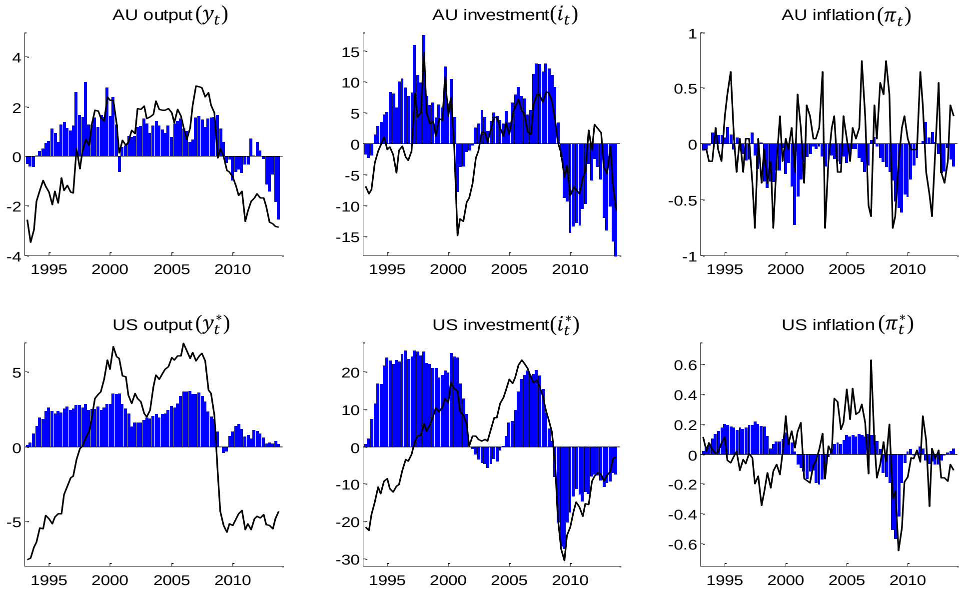
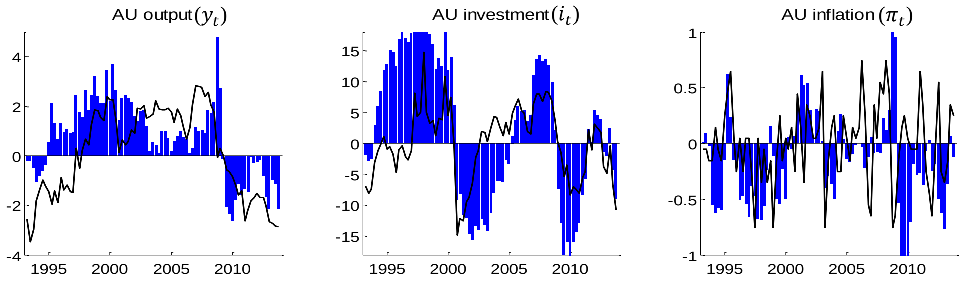


Figure 4.B.14 Data and contribution of financial, MEI and risk premium shocks



Notes: Black dashed line represents actual data. Blue bars represent the contribution of shocks evaluated at the posterior mean of the estimated baseline model with AFV.

Appendix 4.C Derivation of key equations

4.C.1 Introducing capital stock

Capital accumulation: A log-linear approximation to equation (4.1) gives

$$K(1+k_{t+1}) = K + (1-\delta)Kk_t + I\left(i_t + \varepsilon_{i,t}\right)$$

Using $I = \delta K$ that holds in steady state, the above expression can be rewritten

$$k_{t+1} = (1-\delta)k_t + \delta\left(i_t + \varepsilon_{i,t}\right) \qquad (4.C.1)$$

Investment: A representative capital producers choose I_t by maximizing the following expected profit:

$$\mathcal{L}_{t+\tau} = E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \Lambda_{C,t+\tau} \left[Q_{t+\tau} \left((1-\delta)K_{t+\tau} + \tilde{\varepsilon}_{i,t+\tau} \left(1 - \chi\left(\frac{I_{t+\tau}}{I_{t+\tau-1}}\right)\right) I_{t+\tau} - K_{t+\tau} \right) - I_{t+\tau} \right]$$

The first-order condition provides the investment demand equation (4.3)

$$\frac{\partial \mathcal{L}_{t+\tau}}{\partial I_{t+\tau}} = \beta^{\tau}\Lambda_{C,t+\tau}Q_{t+\tau}\left(-\tilde{\varepsilon}_{i,t+\tau}\chi'\left(\frac{I_{t+\tau}}{I_{t+\tau-1}}\right)\frac{I_{t+\tau}}{I_{t+\tau-1}} + \tilde{\varepsilon}_{i,t+\tau}\left(1 - \chi\left(\frac{I_{t+\tau}}{I_{t+\tau-1}}\right)\right)\right) + \beta^{\tau+1}\Lambda_{C,t+1+\tau}Q_{t+1+\tau}\tilde{\varepsilon}_{i,t+1+\tau}\chi'\left(\frac{I_{t+1+\tau}}{I_{t+\tau}}\right)\left(\frac{I_{t+1+\tau}}{I_{t+\tau}}\right)^2 - 1 = 0 \qquad (4.C.2)$$

A log-linear approximation to equation (4.3) around steady state where $Q = 1$ yields

$$q_t + \varepsilon_{I,t} - \chi'' i_t + \chi'' i_{t-1} + \beta\chi'' i_{t+1} - \beta\chi'' i_t = 0 \Rightarrow$$

$$i_t = \frac{1}{1+\beta} i_{t-1} + \frac{\beta}{1+\beta} E_t i_{t+1} + \frac{1}{(1+\beta)\chi''} q_t + \frac{1}{(1+\beta)\chi''} \varepsilon_{i,t} \qquad (4.C.3)$$

4.C.2 Domestic good producers

Aggregate production function: From the production function (4.5), $N_t(i) = \left(Y_{H,t}(i)/\tilde{\varepsilon}_{a,t}K_t(i)^{\Omega}\right)^{1/(1-\Omega)}$ is found. Substituting the expression into aggregate employment index yields

$$N_t \equiv \int_0^1 N_t(i)di = \left(Y_t Z_t / \tilde{\varepsilon}_{a,t} {K_t}^{\Omega}\right)^{1/(1-\Omega)} \qquad (4.C.4)$$

where $Z_t \equiv \int_0^1 \left(Y_{H,t}(i)/Y_t\right)^{1/(1-\Omega)} di \Big/ \int_0^1 (K_t(i)/K_t)^{\Omega/(1-\Omega)} di$. As shown in Appendix D of Galí and Monacelli (2005), equilibrium variations in $z_t \equiv \log Z_t$ around the perfect foresight steady state are of second order. Thus, up to a first order log-linear approximation to equation (4.C.4) gives

$$y_t = \varepsilon_{a,t} + \Omega k_t^s + (1-\Omega)n_t \qquad (4.C.5)$$

***Real rental rate*:** A log-linear approximation to equation (4.6) results

$$R^k\left(1 + r_t^k\right) = R^k + R^k(n_t - k_t^s) + R^k(\omega_t + \upsilon_n r_t) - R^k \upsilon_k r_t \Rightarrow$$

$$r_t^k = -(k_t^s - n_t) + \omega_t + (\upsilon_n - \upsilon_k) r_t \qquad (4.C.6)$$

Real marginal cost: A log-linear approximation to equation (4.7) gives

$$MC(1 + mc_t) = MC + MC(1-\Omega)(\omega_t + \upsilon_n r_t) + MC\Omega\left(r_t^k + \upsilon_k r_t\right) - MC\varepsilon_{a,t} + MC\left(p_t - p_{H,t}\right) \Rightarrow$$

$$mc_t = (1-\Omega)\omega_t + \Omega r_t^k + \big((1-\Omega)v_n + \Omega v_k\big)r_t - \varepsilon_{a,t} + \alpha s_t \quad (4.C.7)$$

where $\omega_t = w_t - p_t$ is the real wage, w_t and p_t respectively denote nominal wage and price, s_t denotes the terms of trade and $r_t = R_t - R$ is nominal interest rate.

4.C.3 Introducing financial frictions

Capital utilization: A log-linear approximation to (4.11) gives

$$R^k\big(1 + r_t^k\big) = a'(U) \ + Ua''(U)u_t$$

Using the steady-state condition, $R^k = a'(U)$, the above can be reduced to

$$u_t = u_a r_t^k \quad (4.C.8)$$

where $u_a = a'(U)/(Ua''(U))$. As assumed by Smets and Wouters (2007), the adjustment cost function can take the functional form of $a(U_t) = a_0 U_t^{1/1-\kappa}$, where $0 \leq \kappa \leq 1$ and a_0 is a constant. In such case, u_a can be obtained as $u_a = (1-\kappa)/\kappa$.

Value of the capital: A log-linear approximation to equation (4.12) yields

$$(1 + R^{e,k})\big(1 + E_t r_{t+1}^{e,k}\big) = (1 + R^{e,k}) + \frac{U}{Q}\big(R^k - a'^{(U)}\big)E_t u_{t+1} + \frac{UR^k}{Q}E_t r_{t+1}^k$$
$$+ \frac{Q}{Q}(1 - \delta\,)q_{t+1} - (1 + R^{e,k})q_t$$

Using the steady-state relations, $U = 1$, $1 + R^{e,k} = R^k + 1 - \delta$, and $R^k = a'(U)$, above equation can be reduced to

$$q_t = \frac{R^k}{R^k + 1 - \delta}E_t r_{t+1}^k + \frac{1-\delta}{R^k + 1 - \delta}E_t q_{t+1} - E_t r_{t+1}^{e,k} \quad (4.C.9)$$

where $R^k = \frac{1}{\beta}\left(\frac{K}{NW}\right)^{\psi} - (1-\delta)$, which is obtained from the steady-state equilibrium of (4.12), (4.13) and (4.14) equations.

External finance premium: A log-linear approximation to equation (4.13) yields

$$S(1 + s_t) = \left(\frac{QK}{NW}\right)^{\psi} + \left(\frac{QK}{NW}\right)^{\psi}\big(\psi(q_t + k_{t+1} - nw_{t+1}) + \varepsilon_{cs,t}\big)$$

Using the steady-state relation, $S = \left(\frac{QK}{NW}\right)^{\psi}$, above expression can be reduced to

$$s_t = \psi(q_t + k_{t+1} - nw_{t+1}) + \varepsilon_{cs,t} \quad (4.C.10)$$

External funds rate: A log-linear approximation to equation (4.15) yields

$$(1 + R^{e,k})\big(1 + E_t r_{t+1}^{e,k}\big) = (1 + R^{e,k}) + (1 + R^{e,k})s_t + \varpi^d S(1+R)(r_t -$$
$$E_t\pi_{t+1}) + (1 - \varpi^d)S(1 + R^*)(r_t^* - E_t\pi_{t+1}^* + \phi_{t+1} + rer_{t+1} - rer_t)$$

where $E_t r_{t+1}^{e,k} = E_t R_{t+1}^{e,k} - R^{e,k}$ and $r_t = R_t - R$, and $1 + R^{e,k} = S\Big(\varpi^d(1+R) + (1-\varpi^d)(1+R^*)\Big)$ is used. Using the steady-state relation, $f = f^d = f^f \Leftrightarrow 1 + R^{e,k} = S(1+R) = S(1+R^*)$, the expression can be reduced to

$$E_t r_{t+1}^{e,k} = \varpi^d(r_t - E_t\pi_{t+1}) + (1-\varpi^d)(r_t^* - E_t\pi_{t+1}^* + \phi_{t+1} + rer_{t+1} -$$
$$rer_t) + s_t \quad (4.C.11)$$

Entrepreneurial net worth: Combining (4.16) with (4.17) gives

$$NW_{t+1} = \gamma_t \Bigg(\left(1+R_t^{e,k}\right) Q_{t-1}K_t - (\varpi^d S_{t-1}(\cdot)(1+R_{t-1})\frac{P_{t-1}}{P_t} +$$

$$(1-\varpi^d)S_{t-1}(\cdot)(1+R_{t-1}^*)\Phi_t \frac{RER_t}{RER_{t-1}}\frac{P_{t-1}^*}{P_t^*})(Q_{t-1}K_t - NW_t) \Bigg) + W^e \qquad (4.C.12)$$

where $\gamma_t = \gamma \tilde{\varepsilon}_{fw,t}$ and $S_{t-1}(\cdot) = \left(\frac{Q_{t-1}K_t}{NW_t}\right)^{\psi} \tilde{\varepsilon}_{cs,t-1}$. A log-linear approximation to equation (4.C.12) yields

$$NW(1+E_t nw_{t+1}) = NW + \gamma QK(1+R^{e,k})r_t^{e,k} - \gamma\varpi^d S(1+R)(QK-NW)$$
$$\left(r_{t-1} - \pi_t + \varepsilon_{cs,t-1}\right) - \gamma(1-\varpi^d)S(1+R^*)(QK-NW)$$
$$\left(r_{t-1}^* - \pi_t^* + \phi_t + rer_t - rer_{t-1} + \varepsilon_{cs,t-1}\right) - \gamma\Big(\varpi^d(1+R) + (1-\varpi^d)(1+R^*)\Big)$$
$$NW\left(-S'\frac{QK}{(NW)^2}(QK-NW) - S\right)nw_t + \gamma(1+R^{e,k})QK(q_{t-1}+k_t) -$$
$$\gamma(\varpi^d(1+R) + (1-\varpi^d)(1+R^*))\left(QKS + QK(QK-NW)S'\frac{1}{NW}\right)(q_{t-1}+k_t) +$$
$$\gamma\Big(QK(1+R^{e,k}) - (\varpi^d(1+R) + (1-\varpi^d)(1+R^*))S(QK-NW)\Big)\varepsilon_{fw,t}$$

where $S = \left(\frac{QK}{NW}\right)^{\psi}$. Using the steady-state equilibrium relations, $Q = 1$, $1 + R^{e,k} = S\Big(\varpi^d(1+R) + (1-\varpi^d)(1+R^*)\Big) = S(1+R) = S(1+R^*) = R^k + 1 - \delta$ and the definition of the elasticity, $\psi = \frac{S\prime}{S}\frac{QK}{NW}$, the expression can be reduced to

$$E_t nw_{t+1} = \gamma(R^k + 1 - \delta)\left(\frac{K}{NW}r_t^{e,k} - \left(\frac{K}{NW} - 1\right)\left(\varpi^d\left(r_{t-1} - \pi_t + \varepsilon_{cs,t-1}\right) +\right.\right.$$
$$(1-\varpi^d)\left(r_{t-1}^* - \pi_t^* + \phi_t + rer_t - rer_{t-1} + \varepsilon_{cs,t-1}\right)\Big) +$$
$$\left.\left(\psi\left(\frac{K}{NW} - 1\right) + 1\right)nw_t - \psi\left(\frac{K}{NW} - 1\right)(q_{t-1} + k_t) + \varepsilon_{fw,t}\right) \qquad (4.C.13)$$

Combining (4.C.13) with (4.C.10) yields

$$E_t nw_{t+1} = \gamma(R^k + 1 - \delta)\left(\frac{K}{NW}r_t^{e,k} - \left(\frac{K}{NW} - 1\right)\left(s_{t-1} + \varpi^d(r_{t-1} - \pi_t) +\right.\right.$$
$$\left.(1-\varpi^d)(r_{t-1}^* - \pi_t^* + \phi_t + rer_t - rer_{t-1})\Big) + nw_t + \varepsilon_{fw,t}\right) \qquad (4.C.14)$$

Consumption of entrepreneurs who close business: A log-linear approximation to equation (4.18) yields

$$C^e(1 + c_t^e) = C^e + (1-\gamma)Vv_t \Rightarrow c_t^e = \frac{(1-\gamma)Vv_t}{C^e} \qquad (4.C.15)$$

Combining equation (4.C.15) with linearization of equation (4.17), $Vv_t = (NWnw_{t+1})/\gamma$, gives

$$c_t^e = \frac{(1-\gamma)NWnw_{t+1}}{\gamma C^e}$$

Using the steady-state equilibrium relations, $C^e = (1-\gamma)V$ and $V/NW = 1 + R^{e,k} = R^k + 1 - \delta$, the expression can be reduced to

$$c_t^e = \frac{E_t nw_{t+1}}{\gamma\left(R^k + 1 - \delta\right)} \qquad (4.C.16)$$

4.C.4 Resource constraint and net foreign assets

Resource constraint: Using domestic and imported good demand functions and the definition of terms of trade and law of one price gap, the resource constraint equation (4.19) can be rewritten as[122]

$$Y_t = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t + \varsigma\left(\Psi_{F,t} TOT_t\right)^{\eta^*} Y_t^* + G_t + I_t + a(U_t)K_{t-1} \quad (4.C.17)$$

A log-linear approximation to the above equation around the zero inflation steady state in which $P = P_H = P_F$ yields

$$\mathrm{Y}(1+y_t) = \mathrm{Y} + C_H\left(c_t - \eta\left(p_{H,t} - p_t\right)\right) + C_H^*\left(\eta^*\left(\psi_{F,t} + tot_t\right) + y_t^*\right) + C^e c_t^e + Gg_t + Ii_t + R^k K u_t \quad (4.C.18)$$

where $s_t = p_{H,t} - p_t$ denotes the linearized terms of trade, $C_H = (1-\alpha)C$, $C_H^* = \varsigma Y^*$ and $\mathrm{Y} = C_H + C_H^* + G + I$. From the steady state version of imported good demand equation, it is found that $C_F = \alpha C$, where C_F is the steady state level of imports. Assuming balanced trade, export of domestic economy, C_H^*, is equal to its import, C_F, in the steady state, $C_H^* = C_F = \alpha C$. Inserting those steady-steady relations into equation (4.C.18) yields the linearized the resource constraint

$$y_t = c_y(1-\alpha)c_t + c_y\alpha\left(\left(\eta(1-\alpha) + \eta^*\right)tot_t + \eta^*\psi_{F,t} + y_t^*\right) + c_y^e c_t^e + i_y i_t + u_y u_t + \varepsilon_{g,t} \quad (4.C.19)$$

where $c_y = C/Y = 1 - g_y - i_y$, $i_y = I/Y = \delta k_y$, $u_y = R^k k_y$, $k_y = K/Y$, $g_y = G/Y$, $c_y^e = C^e/Y$ and $\varepsilon_{g,t} \equiv g_y g_t$. As employed by Smets and Wouters (2007), the term $\varepsilon_{g,t} \equiv (G/Y)g_t$ refers to the exogenous spending shock.

Evaluation of net foreign assets: When apply the assumption that final good producer and capital producer operate in perfectly competitive markets, then the household budget constraint reduces to $\tilde{e}_t B_t = \tilde{e}_t B_{t-1}(1 + \tilde{r}_{t-1}^*)\phi_t + \tilde{e}_t P_{H,t}^* C_{H,t}^* - \tilde{e}_t P_t^* C_{F,t}$.

Using the definitions, $P_{H,t} = \tilde{e}_t P_{H,t}^*$, $A_t \equiv \tilde{e}_t B_t / \bar{Y} P_t$, and $RER_t = \tilde{e}_t P_t^* / P_t$, the above expression can be obtained as

$$A_t = A_{t-1}\frac{\tilde{q}_t}{\tilde{q}_{t-1}}\frac{(1+\tilde{\imath}_{t-1}^*)}{\Pi_t^*}\phi_t + \frac{1}{Y}\left(\left(\frac{P_{H,t}}{P_t}\right)\varsigma\left(\Psi_{F,t} TOT_t\right)^{\eta^*} Y_t^* - RER_t \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t\right) \quad (4.C.20)$$

Linearization of equation (4.C.20) yields[123]

$$a_t = (1/\beta)a_{t-1} + \alpha c_y \begin{pmatrix} p_{H,t} - p_t + \eta^*\left(\psi_{F,t} + tot_t\right) + y_t^* \\ -rer_t + \eta\left(p_{F,t} - p_t\right) - c_t \end{pmatrix} \quad (4.C.21)$$

Combining (4.C.21) with (4.C.19) and definitions, $p_{H,t} - p_t = -\alpha tot_t$, $p_{F,t} - p_t = (1-\alpha)tot_t$ and $rer_t = \psi_{F,t} + (1-\alpha)tot_t$ yields

$$a_t = (1/\beta)a_{t-1} - \alpha c_y\left(\psi_{F,t} + tot_t\right) + y_t - \left(c_y c_t + c_y^e c_t^e + i_y i_t + u_y u_t + \varepsilon_{g,t}\right) \quad (4.C.22)$$

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[122] In contrast to the domestic economy, it is assumed that the law of one price holds for imports of domestic goods to the foreign economy, for instance, $P_{H,t} = \tilde{e}_t P_{H,t}^*$.

[123] Since net-foreign asset (A_t) can take on negative values, the first-order Taylor expansion is used for A_t, and log-linear approximation is applied for all other variables. In the linearization, $A_t = A + a_t$, and $A = 0$ are assumed.

Chapter 5

Conclusion and policy implications

5.1 Overview and key findings

This thesis has examined the importance of various modelling implications (i.e., frictions and shocks) in building empirically viable small open economy DSGE models by using a Bayesian approach to conduct the model estimation and evaluation analysis. In particular, the following issues have been explored: (i) the potential roles played by the presence of the cost channel of monetary policy and the UIP modification in the model; (ii) the importance of news (anticipated) shocks in a small open economy DSGE model for analysing business cycle properties of macroeconomic aggregates, including labour market variables; and (iii) the significance of financial frictions and shocks in a small open economy DSGE model for explaining macroeconomic fluctuations. To this end, each chapter has constructed a small open economy New Keynesian DSGE model in a two-country setting by adding relevant frictions and shocks (e.g., modifying UIP condition, labour market imperfect competition, financial frictions, and labour market and financial shocks). As a main insight of this thesis, the Bayesian estimation and evaluation of the models based on the data for Australia and the US (or G7 for Chapter 2) have provided a comprehensive empirical assessment for the relevance of the modelling frictions.

Chapter 2 focused on the quantitative role of the cost channel of monetary policy and the UIP modification in an estimated small open economy New Keynesian DSGE model. In doing so, Chapter 2 augmented a simple small open economy DSGE model developed by Justiniano and Preston (2010a) to include the cost channel and the UIP modification. Four variants of the model were estimated using the Bayesian maximum likelihood method and the data for Australia and the G7 economy. In order to assess the significance of the additional features in the model, Chapter 2 conducted standard assessments for evaluating the estimated DSGE models, including sensitivity analysis for the estimated parameters, Bayesian posterior model probability comparison and posterior predictive analysis.

Empirical results in Chapter 2 have shown that the presence of the cost channel and the presented UIP modification improves the model's ability to fit the business cycle properties of key macroeconomic variables and to account for the empirical facts on the monetary transmission mechanism. According to the Bayes factor as the evaluation criterion, the result shows that the cost channel of monetary policy is operative as obtained by Chang and Jansen (2014) and the standard UIP condition is violated in Australia. The presence of the cost channel improves the model fit. However it does not improve the fit as much as modifying the UIP condition. The monetary transmission analysis of the model with these extensions shows (i) no evidence of the price puzzle, implying that supply side effects of monetary policy are negligible compared to its demand side effects, and (ii) evidence for the delayed overshooting of exchange rate in response to a monetary policy shock. These are consistent with the existing empirical results provided by Dungey and Pagan (2000), Liu (2010) and Jääskelä and Jennings (2010). The major role played by the cost channel in the model is to generate inflation inertia without obtaining a high estimated degree of domestic price stickiness as found by Christiano et al. (2005). The presence of the UIP modification allows the model to better match the persistence of the observed exchange rate. As a result, the estimated model with such modifications does a good job in generating both persistence and volatility in real exchange rate dynamics, as well as in producing hump-shaped responses of the real exchange rate to exogenous shocks, which have been difficult to obtain from standard small open economy DSGE models.

In addition, some important results regarding small open economy modelling and macroeconomics also emerged from the empirical analysis in Chapter 2. The estimates for structural parameters in the small open economy DSGE model are sensitive to variations in model specifications, implying quantitative changes in the model performance are associated with both the difference in the equation form (Phillips curves and UIP condition) and the changes in the estimated parameters. The variance decomposition analysis shows that monetary policy shocks have been mainly absorbed by the output and have played a minor role in explaining real exchange rate dynamics. Moreover, real exchange rate movements have mitigated the effects of external shocks (i.e., country risk premium shock) on the Australian economy during the inflation-targeting period. For instance, the real exchange rate volatility is mainly driven by the country risk premium shock (more than 70 per cent), which explains only 21-38 per cent of the variance of output in the medium-run. The results support the view that monetary policy plays a vital role in stabilising the economy, and the flexible exchange rate acts as a shock absorber in the case of Australia.

Based on the model derived in Chapter 2, Chapter 3 moved to develop and estimate the small open economy DSGE model in the two-country setting, featuring both labour market imperfections (i.e., unemployment and staggered wage setting) and news shocks. Involuntary unemployment was introduced building on the approach proposed by Galí (2011) in which unemployment results from market power in labour markets. Chapter 3 pointed out that news shocks could lead to Pigovian business cycles by changing agents' expectations about future economic activity. In particular, the chapter highlighted the role of news shocks in driving labour market (i.e., unemployment and wage inflation) fluctuations and business cycles.

Several variants of the model with news shocks were estimated using the Bayesian techniques and data for Australia and the US. The preference shifter parameters, controlling the short-run wealth effects on labour supply, were estimated at 0.06 and 0.11 in Australia and the US, respectively. The lower values imply that the estimated preference is closer to the preference discussed by Greenwood et al. (1988), which features no short-run wealth effects on labour supply. Therefore, the presented utility function with the preference shifter in Chapter 3 helps the model to generate the co-movement of output and labour force (and employment) in response to news shocks about future productivity and monetary policy.

The empirical analysis in Chapter 3 explored the importance of news shocks in developing empirically viable small open economy DSGE models and in driving business cycles. From the view of empirical DSGE modelling, the presence of joint news shocks (i.e., a combination among different types of shocks in Australia and the US) has the potential to improve the relative fit of an estimated open economy model. In addition, the estimated model, augmented to include imperfect labour market, endogenous reference shifter and news shocks, has the ability to qualitatively replicate the results of the VAR analyses on news-driven domestic and international business cycles in small open economies (e.g., Kosaka 2013 and Kamber et al. 2014). In particular, news about future technology, country risk premium and consumption preference in Australia could lead to domestic business cycle fluctuations, whereas the US news shocks on technology and consumption preference could propagate to Australia, generating international business cycles. In addition, the estimated responses of labour market variables to technology news are in line with the VAR result obtained by Theodoridis and Zanetti (2014) in the sense that a positive technology news shock leads to a counter-cyclical unemployment rate and a wage increase in both Australia and the US.

Empirical results show that news shocks have played a crucial role in driving the Australian business cycle during the inflation-targeting period. Exceeding half of the variances in Australian observables is explained by news shocks. Moreover, news shocks were a major source of the Australian recession during the 2008-2009 global financial crisis (GFC). As a novel result, news shocks play a significant role in unemployment dynamics as the shocks account for 35 and 41 per cent of unemployment fluctuations in Australia and the US, respectively. Though news shocks are major sources of the US business cycle, the quantitative comparison shows that the Australian economy has been more news-driven than the US economy in the last two decades. The analysis also reveals the pivotal role of the news about the country risk premium in the Australian business cycle. The risk premium news shock accounts for exceeding one-quarter of the unconditional variances in most Australian observables, consistent with findings provided by Nimark (2009), Liu (2010) and Leu (2011). The Chapter 3 also emphasizes the role of exchange rate in the propagation of news shocks. Impulse response and variance decomposition analyses show that the real exchange rate dynamics play an important role in the propagation of news shocks.

Developing interconnected models in the thesis (e.g., the model in the Chapter 3 augments the model built in the Chapter 2 by adding the labour market imperfection, the endogenous preference shifter and news shocks) also provides an opportunity to assess both quantitative and qualitative impacts of the additional features in the model. A key result is that the parameters governing the cost channel and the UIP modification are generally robust[124], implying the relevance of the cost channel and the presented UIP modification in the models. However, the estimated parameter for the UIP modification, ϕ_e, is sensitive to whether the financial variables are observed in the estimation or not,

[124] In the model estimated in Chapter 2, posterior means of the parameters are $\nu_H = 0.37$, $\nu_F = 0.47$ and $\phi_e = 0.32$, and estimated as $\nu_H = 0.36$, $\nu_F = 0.53$ and $\phi_e = 0.32$ in Chapter 3. This result is also robust in Chapter 4 in the sense that the posterior means of the model with AFV are $\nu_k = 0.48$, $\nu_n = 0.31$, $\nu_F = 0.52$ and $\phi_e = 0.31$.

suggesting that observing financial variables may help to properly estimate the exchange rate dynamics in the model with financial frictions and financial shocks.

Moreover, the comparison of the impulse response and variance decomposition analyses of the models offers the following results. First, responses of Australian output, inflation and real exchange rate to the unanticipated monetary policy shock is more hump-shaped in Chapter 3 than those in Chapter 2. A reasonable explanation for the result is that the introduction of nominal wage rigidities in Chapter 3 improves the model's ability to generate more persistent responses of inflation and output as found by Christiano et al. (2005). For instance, the presence of the nominal wage rigidities reduces the estimated values of the parameters, controlling the price rigidities, in the model built in Chapter 3. Second, the presence of imperfect labour market assumptions, complemented with the theory of involuntary unemployment developed by Galí 2011(a), improve the internal propagation of shocks within the estimated model in Chapter 3. However, labour market shocks (wage markup and labour supply shocks) play a minor role in explaining movements of non-labour market variables in both Australia and the US.

Chapter 4 further extended the model in Chapter 3 to a richer open economy DSGE model in the two-country setting with involuntary unemployment, financial frictions and various shocks. Financial frictions in the accumulation of capital were introduced as developed by Bernanke et al. (1999). In the modelling of external financing for capital, liability dollarization (i.e., debt partially denominated in foreign currency) was assumed in the block of small open economy as modelled by Anand et al. (2010) and Freystätter (2011). Structural shocks in the model include wage markup, labour supply, marginal efficiency of investment (MEI), financial shocks (credit supply and financial wealth shocks) in addition to standard shocks such as monetary policy, technology, consumption preference, price markup and government spending shocks.

The empirical analysis in Chapter 4 focused on the importance of financial frictions and shocks for macroeconomic fluctuations. Several variants of the model with different features were estimated using the Bayesian techniques and data for Australia and the US, containing directly observed financial data. The elasticity of the external finance premium with respect to entrepreneurial leverage was estimated as $\psi = 0.037$ and $\psi^* = 0.042$ in Australia and the US, respectively. As Chapter 4 is the first attempt to estimate the small open economy DSGE model with the financial friction (based on BGG approach) in case of Australia, there is no reference value of ψ for Australia. However, the estimate parameters of ψ and $\psi^*$are closer to the values provided by Elekdag et al. (2006), Christensen and Dib (2008) and Gilchrist et al. (2009). The result implies that the financial accelerator is operative in both countries, but is quantitatively more relevant in the US.

In addition, the relative fit assessments based on the Bayes factor suggests that (i) the presence of financial accelerator and financial shocks improves the model fit, and (ii) the data clearly supports the assumption of partial liability dollarization (the foreign-currency denominated debt) in the model. In fact, the model incorporating both the financial accelerator and the partial liability dollarization significantly outperforms its alternative models, suggesting that both frictions play important roles in improving the model's ability to fit the actual data. The findings also suggest that the real economy of Australia can be affected by changes in foreign lenders' assessments on the economy's outlook as changes in the country risk premium (or exchange rates) has a direct effect on the balance sheet of Australian companies. However, Rush et al. (2013) have shown that the Australian economy has consistently had a net foreign currency asset position, which explains why the whole economy is resilient to external shocks (or an event of a sudden depreciation of the Australian dollar). This supports a result of the thesis (consistently obtained in variance decompositions of Chapters 2-4) that Australia's flexible exchange rate has played an important role in cushioning the economy from external shocks and smoothing fluctuations in the business cycle.

The impulse response analysis has further highlighted the empirical relevance of the financial accelerator mechanism in driving the macroeconomic fluctuations. For instance, there is evidence of the balance sheet channel of monetary policy and the foreign-currency denominated debt channel in Australia, consistent with the finding provided by Jacobs and Rayner (2012). The financial accelerator amplifies and propagates the effects of monetary policy shocks on investment, output and employment, but dampens the effects of technology and labour supply shocks in both Australia and the US. It is also found that the adverse financial shocks could potentially lead to a domestic recession in both countries.

Variance decomposition analysis has emphasized the significance of financial shocks and observing financial data. Financial wealth and credit supply shocks play a central role, but no dominant role, in explaining macroeconomic fluctuations in both Australia and the US. In particular, the financial wealth shock (i.e., shock to entrepreneurial wealth) is vital for the Australian economy as it accounts for around 40 per cent of the variation in investment, a quarter of GDP and more than half of the spread on external finance. In the case of the US, both credit supply and financial wealth shocks are equally important in explaining the business cycle, and account for 60 per cent of the variation in investment, 15 per cent of GDP, 40 per cent of the spread and a quarter of consumption and investment. The US financial shocks account for 13 and 10 per cent of the variation in Australian investment and interest rate, respectively. The findings support the view that the international spillovers from the US financial shocks have played a prominent role in international business cycles and the 2008-2009 GFC.

Another key result is that the importance of MEI shock in the business cycle can be overestimated when the financial data is not directly observed in empirical analysis. The analysis suggests that when the model with financial frictions is estimated to match the financial data, the macroeconomic fluctuation is more related to demand shocks of the capital market (i.e., financial shocks) rather than the supply shocks of the market (i.e., MEI shock). In addition, the comparison of variance decompositions in Chapters 2-4 has shown that the small-scale DSGE models (as used in Chapter 2-3) may overestimate the relevance of the technology and country risk premium shocks in generating macroeconomic fluctuations in the sense that the contribution of the shocks is significantly reduced when MEI and financial shocks are added into the model. These results support the views, suggesting (i) all relevant shocks should be included in the model when someone wants to analyse the contribution of a specific shock in the macroeconomic fluctuations, and (ii) as originally argued by Justiniano et al. (2010) and Christiano et al. (2014), including financial friction/sector into a model and directly observing financial data are helpful to properly measure the contribution of financial shocks (or MEI shock) in the business cycle.

The exercise interpreting the recent economic events using the baseline model with AFV has shown that (i) several shocks in Australia and the US have taken extreme values during the 2008-2009 GFC, and the financial wealth shocks were negative and the credit supply shocks were positive in the beginning of the GFC, and (ii) the adverse financial shocks (i.e., the sharp increase in the credit spread and the sharp fall in the stock market index) have contributed to the sharp downturn in investments in both Australia and the US during the GFC. The country risk premium shocks played a vital role in the investment downturns of 2001, and also explain the slow recovery of the GDP in Australia since the GFC.

Overall, the thesis has shown that the presented modelling frictions and shocks (i.e., the cost channel of monetary policy, modifying UIP condition, labour market imperfection, financial frictions, and news and financial shocks) are vital in building an empirically viable open economy New Keynesian DSGE model for policy analysis and forecasting. Moreover, the thesis contributes to the literature on the business cycle in a small open economy by providing empirical evidence that (i) the business cycle could steam from news about the future economic development and distortions in financial market conditions, and (ii) the business cycle could be affected by the degree of labour and financial market frictions, the degree of liability dollarization, and the economic structure, such as firms' dependence on short-term loans and the degree of violation in the standard UIP condition.

5.2 Policy implications

This thesis has provided some implications for designing macroeconomic policies that stabilize the economy in both developed and developing countries. First, implementing the Taylor principle in monetary policy and the flexible exchange rate would stabilize the economies that have similar characteristics to Australia. The supply side effects (i.e., cost channel) of monetary policy call for a serious rethinking of optimal monetary policy. If the supply side effects of monetary policy are strong enough, then the Taylor principle becomes a source of macroeconomic instability (the same as 'adding fuel to the fire'). The empirical result obtained in this thesis has shown that the supply side effects of monetary policy are not strong enough compared to the demand-side effects in Australia, supporting the view that the conventional monetary policy (i.e., the Taylor principle and the expectation-based rule) promotes macroeconomic stability by avoiding self-fulfilling inflation expectations. Moreover, the thesis has shown that the flexible exchange rate in Australia plays a role as a shock absorber in the sense that the real exchange rate movements have mitigated the impact of the external shock (e.g., country risk premium shock) on the real economy.

Second, the credible policy announcements by the monetary authority and the government are crucial in stabilizing the macroeconomy. As emphasized in Chapter 3, news shocks significantly contribute to macroeconomic fluctuations in both Australia and the US. Moreover, in the case of the US, the contribution of monetary policy news to output, inflation and unemployment fluctuations is larger than the contribution of unanticipated monetary policy shocks. Therefore, policy makers should deliver credible announcements about intended policy actions to achieve a larger impact on the economy and to dampen the impact of adverse news shocks in the early stage. In doing so, policy makers may also affect economic agents' expectation formation rather than dealing with the consequences triggered by adverse news shocks.

Third, promoting financial stability is critical in stabilizing the macroeconomy in the current environment with the high degree of real-financial linkages. As found in Chapter 4, financial shocks (i.e., credit supply and financial wealth shocks) have played a central role in driving macroeconomic fluctuations in both Australia and the US. In particular, during the 2008-2009 GFC, the financial shocks in both countries have taken their extreme values, and significantly contributed to investment downturns. In general, monetary policy can be well placed to fight financial shocks as estimated responses of macro aggregates to loosening policy shock are found to be the mirror image of the responses to adverse financial shocks in both Australia and the US. However, as shown in the variance decomposition analysis in Chapter 4, the conventional monetary and fiscal policies have a limited role in influencing the financial market. Therefore, the findings in the thesis support the view that policy makers should design and employ prudential policy instruments for preventing financial instability and a financial crisis. Designing such instruments is still a challenge for policy makers in the sense that the choice of the instruments should be based on the quantitative analysis on assessing the effectiveness of such instruments in promoting financial and macroeconomic stability. However, this issue is beyond the scope of the research questions set in the thesis.

Fourth, for countries with high foreign debt (or foreign-currency denominated debt), developing financial derivatives to hedge foreign currency risk of corporations is important to avoid from the possible negative impacts of exchange rate volatility on entrepreneurs' balance sheets, passing through the foreign-currency denominated debt channel. Within the well-developed derivative markets, the flexible exchange rate may play a role as a shock absorber instead of a source of shocks in a small open economy such as Australia.

Fifth, for small open economies, where labour unions are influential in setting the wage rate, achieving both micro and macro flexibilities[125] in the labour market while protecting workers and maintaining incentives for workers is important to stabilize the labour market and the macroeconomic fluctuations. For example, in the Australian economy, the labour market is very responsive to both internal and external (and unanticipated and anticipated) shocks, and appreciation/depreciation of the exchange rate increases/reduces the unemployment.

Finally, the thesis offers an appropriate methodological approach in building a country-specific open economy DSGE model to study the monetary policy transmission and the business cycle in developing countries. Owing to the weak labour and financial markets in developing countries, it is more likely that the cost channel of monetary policy is strong, the standard UIP condition is violated, labour market is imperfect, the degree of financial friction is high and the substantial part of debts is also denominated in foreign currency. Therefore, policy makers in developing countries may formulate and estimate their own country-specific monetary DSGE models for policy analysis and decision-making by incorporating the presented modelling frictions and shocks as suggested by the thesis.

[125] Micro flexibility refers to the ability of the economy to allow for the reallocation of workers to jobs needed to sustain growth, while macro flexibility refers to the ability of the economy to adjust to macroeconomic shocks.