ON THE CHINESE HOUSING MARKET AND BUSINESS CYCLES

--A STUDY BASED ON A BAYESIAN DYNAMIC STOCHASTIC GENERAL EQUILIBRIUM MODEL

by

Hua Yu

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Economics

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ABSTRACT

The Chinese housing industry has been growing quickly since the housing market reform was initiated in 1998 and has now become a pillar of the economy. Developments in the housing industry are highly correlated with other industries in China such as finance, iron and steel, mechanics, services, chemistry, and non-ferrous metal. Thus, fluctuations in the housing industry may have significant impacts on the overall economy through these related industries. Additionally, the rapid increase in housing prices raises concerns about a greater occurrence of asset bubbles. This dissertation addresses several issues related to the development of the Chinese housing sector and the business cycle. It examines: i) the driving forces behind movements in the housing sector and business cycle over the past few decades; ii) the spillover effects of the housing sector volatility on the broader economy; iii) the monetary policy response to fluctuations in the housing prices. A Bayesian estimated dynamic stochastic general equilibrium model is used to explore these issues in an empirical way. The model includes a variety of frictions and shocks used in previous literature as well as three additional housing-related shocks: a housing bubble shock, a government policy shock and a credit shock. The three shocks capture a few important characteristics of the Chinese economy and the
housing sector. Estimation results show that investment-specific technology shocks and labor supply shocks account for much of the macroeconomic variations over the whole sample. Although government policy shocks are the dominant force driving market movements, the housing bubble shocks, housing preference shocks and monetary policy shocks also play significant roles, especially the housing bubble shock. Moreover, housing-related shocks also impact the rest of the economy. A counterfactual experiment in which the housing-related shocks are shut down was conducted to further explore the spillover effects of the housing sector on the overall economy. The outcome shows that without these shocks the variances of selected variables are significantly reduced which suggests that the housing sector can generate volatility on the whole economy. Finally, the dissertation evaluates the optimal monetary policy and compares the loss functions of the Central Bank under different policy regimes. According to the results of frontier efficiency curves and the model’s marginal likelihoods, the Chinese Central Bank should moderately respond to housing price fluctuations. The estimation results in the dissertation are robust to changes in the structural parameters and the model specifications.
Chapter 1

THE INTRODUCTION, LITERATURE REVIEW
AND TOPIC DEFINITION

1.1 The Background Introduction

1.1.1 The Importance of the Chinese Housing Industry

The Chinese urban housing reform of 1998 led to the privatization of housing and the improvement on housing conditions. Before the reform, the housing investment and construction were planned by the Chinese government. There was no market for the housing transaction. The government allocated the housings to the work units (which refer to the enterprises, offices and institutions). Residents were only allowed to rent housings from their work units through paying a certain amount of fees to the work units.

Houses are now purchased or rented as a commodity at prices determined by the market. As a result, the housing industry developed at an unprecedented rate and became a pillar industry in the Chinese economy. Statistics\(^1\) show that by the end of the year 2013, the total volume of housing investment reached 1.4 trillion U.S. dollars, an increase of 19.8 per cent over the previous year, and accounts for 15 per cent of GDP in 2013.\(^2\) In particular, residential housing investment is 68.5 per cent

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\(^2\) This proportion was 4 per cent in 1999.
of total housing investment. Housing and its related industries to 30.1 per cent of GDP growth. Moreover, the total transaction volume of commercial housing is approximately 1.3 trillion U.S. dollars which is an increase of 26.3 per cent compared to 2012. In particular, residential sale volume increased by 26.6 per cent. In 2013, the total area of commercial housing sold was 1.3 billion square meters, an increase of 17.3 per cent over sales in 2012. The total sale area of residential housing increased 17.5 per cent. In contrast to the high growth and development in the housing sector in 2013 the annual growth rate of GDP was only 7.7 per cent, much lower than in the years prior to the 2008 financial crisis. The strong growth in housing sector exceeded the growth rate of GDP.

The importance of the housing sector is not only reflected by its large share of the country’s GDP, but also in its close relation with the financial industry. By the end of 2013, the loans from the main financial institutions, small-sized rural financial institutions and foreign banks to the real estate industry have totaled 2.4 trillion U.S. dollars (equivalent to 25.6 per cent of GDP), which rose by 19.1 per cent from the previous year (an increase of 0.4 trillion U.S. dollars). It also accounts for 20.3 per cent of the total lending activities in the same period. Among those loans, the home mortgage loans reached 1.6 trillion U.S. dollars (equivalent to 17.2 per

3 Housing related industries include iron and steel, mechanics, services, chemistry, finance and non-ferrous metal industry.

4 In China, “low-rent housing” cannot be commercialized because it is government owned. This type of housing can be rented at a low fee but cannot be purchased. In addition to the low-rent housing, there is also “affordable housing” provided by the Chinese government for the households with low income. This second type of housing can be purchased at very low prices, but only the poorest families are eligible to apply for them. Affordable housing has a limited market share. In 2010, affordable housing sale areas only accounted for 2.94 per cent of the total commercial housing sale areas.
cent of GDP), increasing by 21 per cent as compared to the same period in the last year. On the other hand, land development loans represent 0.17 trillion U.S. dollars (equivalent to 1.8 per cent of GDP), increasing by 9.8 per cent as compared to the same period in the last year, and housing development loans 0.58 trillion U.S. dollars (equivalent to 6.1 per cent of GDP), increasing by 16.3 per cent as compared to the same period in the last year. Figure 1.1 displays that home mortgage loans have been growing steadily in terms of both absolute value and value relative to GDP.

Figure 1.1: Home Mortgages Growth in Amount and Importance, 1997 – 2012Q1
Source: cited in Barth, Lea and Li (2012).

Figure 1.2 shows that the Chinese home mortgage debt to GDP ratio is still lower than many developed economies, but higher than other developing countries experiencing fast economic growth, such as Russia and Brazil.
1.1.2 The Potential Presence of Price Bubbles in the Housing Market

Chinese housing prices are at unprecedented highs and have kept rising quickly over several years since the market reform, especially since 2005 when the government changed the land supply policy and allowed the land use right to be obtained by the biddings and auctions in addition to the administrative assignments and negotiations.

To outline the current situation of the Chinese housing market development, a cross-country comparison on some common housing-related indicators is made. According to the recent statistics, the housing price-to-average-income ratios and price-to-rental ratios in the first tier cities, such as Beijing and Shanghai, are approaching the levels in Tokyo and Hong Kong at their bubble periods.\(^5\) Land

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\(^5\) Case and Shiller (2003) recognizes the housing price-to-average-income ratio as a critical index to verify whether the housing market is excessively exuberant. Usually, a region with a ratio above 8 is considered to have experiencing a housing bubble according to the studies of United Nations and the data published by NUMBEQO the world’s largest database about cities. In 2013, the average national housing-price-to-income ratio is 7 in China. Beijing has the highest one, reaching 19.1 and Shanghai 17.5. Among the 30 provinces, municipalities and autonomous
value is also an important index that is used to monitor real estate market. In 1990, the total land value of Tokyo was 4.1 trillion U.S. dollars (63.3 per cent of U.S. GDP in the same year). In 1997, the total land value of Hong Kong was 5.7 trillion U.S. dollars (equivalent to 66.3 per cent of U.S. GDP in the same year). In 2012, the total land value of Beijing reached to 10 trillion US dollars (equivalent to 61.6 per cent of U.S. GDP in the same year). The *Beijing Review* in April 8th, 2014 published that “the current situation in China partly resembles the situation in Japan in the 1980s when market participants from large enterprise to vegetable vendors jostled to have a finger in the property pie.”

Large amounts of capital and human resources are invested in the real estate sector because people tend to believe that the housing trade is one of the most lucrative businesses, leading to high housing prices.

The experiences of some developed countries that have encountered housing booms and busts teach us that a slump in housing prices might have comprehensively harmful impact on the real economy, mainly because the housing property is significant collateral underlying bank loans and a major wealth component. As a result, the volatility in the housing markets will be transmitted to regions, 22 of them have ratios above 8. The Japanese housing price-to-income ratio reached to a peak of 9.2 in 1990. In particular, the Tokyo district reached to 19 but fell down to 6.0 in 1992. The ratio remains at approximately 4.5. Before the break out of the Asian financial crisis in 1997, the ratio in Hong Kong reached 18. In U.S., this ratio remains at 2-5 over the period from 2000 to 2012. Data are drawn from the *2013 35 Large and Medium Chinese Cities Housing Price to Income Ratio Rankings Report* published by Nomura Institute of Capital Markets Research. Also, the NUMBEIO Database provides the rankings of house price-to-income ratios for the main 103 countries in 2013. China is ranked fifth. Data are available at http://www.numbeo.com.

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the real economy through many channels and their impacts amplified through several mechanisms. For example, a slump in the housing market not only impacts the housing industry but will reduce employment and growth rates in related industries, which extends its impact to the overall economy. It will also decrease the households’ wealth and tighten the personal credit, which leads to the reductions in consumption and investment. The IMF’s “Global Financial Stability Report” (2011) has warned of “potential financial instability provoked by a lengthy real estate building and pricing boom in China”.

In order to slow the growth of housing prices in cities, Chinese governments have already employed a series of contractual measures, such as adjusting housing transaction taxes, increasing down payment rates, and imposing price limits and purchasing qualifications. Appendix B provides a timeline of key Chinese housing policies between 1998 and 2013. However, housing prices have always been growing despite these policy interferences. Figure 1.3 shows that nationwide residential housing prices have trended up over the past decade despite the government’s tightening efforts.

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7 Purchasing qualification is based on the Chinese household registration system. Chinese household registration system is called the Hukou system. It officially identifies a person as a resident of an area and includes information such as name, date of birth, parents and other identifying information. The housing purchasing qualification prohibits people who are not natives of an area from purchasing housing in that area.
Figure 1.3: Average Residential Housing Price per Square Meter, 2000m1-2013m12.

Source: Based on author’s calculation and data from National Bureau of Statistics of People’s Republic of China. The national average housing price is calculated as the residential housing sales volume divided by the residential housing sale area in the same period. Note that it is a nominal price.

Of course, it should be noted that each country has a unique background in terms of resource endowments, economic and social institutions, culture, and history, all of which will affect the growth and development in a specific market of a country. Therefore, we cannot simply make the conclusions that the Chinese housing market has been irrationally exuberant and that a large amount of bubbles have existed and will burst shortly, only based on comparing the common indicators across different countries. These indicators and statistics, however, draw attention to the potential presence of housing market bubbles and how the rise and burst of these bubbles will influence the broader economy.

One mainstream opinion in the Chinese academia believes that the bubbles exist in the emerging housing market, particularly in the third and fourth tier cities.  

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8 In China, cities are divided into six categories based on their economic and
and the increasing housing prices is primarily caused by the investment and speculative activities in the market.\textsuperscript{9}

To verify this opinion, some important empirical analyses have been made. For example, Jiang (2005) uses a simplified general equilibrium model to find the equilibrium housing price. In the model, the representative consumer maximizes her expected utility and the housing developer maximizes its expected profit. The paper examines the degree of bubbles with data from 1990 to 2004. It argues that the Chinese housing market has bubbles by comparing the real housing price with the theoretical equilibrium price. Wen (2008) estimates the supply and demand elasticity in the Chinese housing market and investigates the relationship between government policies and housing prices in the context of a partial equilibrium model. The results show that the combination of a low supply elasticity and a high demand elasticity sustains the expectation that the housing price will continue to rise in the future. As a result, a feedback loop mechanism is formed by self-fulfilling beliefs, which gradually inflates the price. Similarly, Zhou (2006) uses a partial equilibrium political significance. The first tier cities include Beijing, Shanghai, Guangzhou, Shenzhen and Tianjing. Second tier cities are mainly the capital city of each of the provinces. Additionally, a second tier city must have annual GDP no less than RMB 250 billion (USD 40 billion) and be above the nationwide average rate of economic growth. There are 23 second tier cities. Third and Fourth tier cities generally lag behind first and second tier ones in terms of economic growth, although they were once significant economically and historically. Most of them are located in middle and western China. There are 61 cities are grouped as 3\textsuperscript{rd} tier and 107 4\textsuperscript{th} tier. The total number of administrative cities in China is 657.

\textsuperscript{9} See Yang (2008), Yang et al., (2005), Lu and Li (2004), Wang (2004) and Zuo (2009). Zuo (2009) is recognized as a representative work of this topic, which concludes that the housing investment motive is the dominant source which drives the rapidly increasing housing prices.
model to study the rise and evolution of bubbles. The author assumes that there is excessive financial support and studies the degree of the excessive financial support in China. The empirical results indicate that excessive financial support exists widely in the large cities and is one of the most significant elements that contributed to the surge in housing prices. Dreger and Zhang (2010), with annual data from 35 major Chinese cities over the period 1998-2009, use the panel co-integration method to detect whether bubbles exist in the Chinese housing market. They also apply Granger causality analysis to examine the impact of housing bubbles on inflation rate and GDP growth. Their results show that the growing housing prices lead to a high inflation rate, but do not significantly affect GDP growth. Shi and Du (2001) study the bubbles based on the OLG model of Blanchard and Fisher (1989) in which the representative household can invest in both real capital and bubbles. Bubbles are assumed to be stochastic. In addition to verify the existence of bubbles, Shi and Du (2001) also examine the effect of bubbles on the overall economy. They argue that the Chinese economy is in a transition from a dynamic inefficiency to efficiency. Therefore, it is possible that moderate amounts of bubbles can generate positive effects promoting the dynamic efficiency and optimizing the resource allocation during the transition period. But market bubbles have to be constrained within a reasonable range, i.e. the growth rate of bubbles cannot exceed that of GDP.

These studies point out that the Chinese housing market has bubbles, and argue that the high prices observed are partially due to the existence of bubbles. More importantly, they all mention a common reason that leads to the rising of bubbles -- people are expecting a continuous appreciation of the housing property,
facing the rapidly increasing prices in the current Chinese housing market. What is more interesting is that the expectation can last through a feedback loop supported by a self-fulfilling mechanism. Specifically speaking, suppose that households hold optimistic beliefs about the housing market and they use housing as collateral to back their loans. If everyone believes that the housing market is in a boom, then households will borrow more money and the investments from different channels will flow into the housing market. As a result, the housing price indeed goes up, confirming people’s initial beliefs. Therefore, people’s beliefs on future price increases cause prices to continually grow and to temporarily deviate from their fundamental values, resulting in a rising of bubbles.

On the other hand, contrary to the “housing bubble hypothesis” discussed above, another popular opinion argues that the rapidly increasing housing price is primarily caused by the so-called “fundamental demand” for housings. The fundamental demand for housings reflects people’s desire for a comfortable living condition and is mainly affected by economic fundamentals (see Gu, 2009; Ren, 2004; Hu et al., 2006; Wen, 2014; Zhu, 2014, which are the representative work in this respect). This “fundamental demand hypothesis” highlights that the volatility of housing prices is due to fundamental economic changes. The rapidly increasing housing prices are mainly driven by people’s increased demand of occupying

10 Miao et al. (2013) apply the self-fulfilling mechanism to explain the formation of bubbles in the stock market.

11 Gu (2009), Wen (2014) and Zhu (2014) argue that at least 60 per cent of the housing demand is fundamental demand. Ren (2004) and Hu et al., (2006) also support the opinion that the strong demand on housing is mainly supported by the economic fundamentals.
houings for pleasant living conditions due to the overall economic growth, the household wealth increase, the housing commercialization reform, the nationwide urbanization, \(^{12}\) the population growth, the land supply change and other fundamental elements. The housing prices truly reflect their fundamental values and there is no bubble existing in the market. Hence, the government does not need to take any measure to control the housing price.

1.2 The Motivation and Topic Definition

Section 1.1 shows the importance of the Chinese housing industry, the current situation of housing market development and the debate on the reasons accounting for the rapidly increasing housing prices. These backgrounds raise my interest in doing a research on the following issues:

First, since the housing sector is one of the most significant sectors in the Chinese economy, the volatility in this sector might generate impacts on the rest of the economy. Therefore, it is necessary to examine the dominant forces which drive the volatility in the housing sector and how the volatility in the housing sector affects the rest of the economy.

Second, the debate on the reasons accounting for the rapidly increasing housing prices raises a concern -- to which extent each of the hypotheses can explain

\(^{12}\) In 1978, urban population was 16 per cent of the total population. By the end of 2000 approximately 459.06 million people lived in urban areas, about 36.2 per cent of the total population. At the end of 2013, approximately 731.11 million people lived in urban areas which, was 53.7 per cent of the total population. According to the World Development Indicator Database, the Chinese annual population growth rate is 1 per cent over the period 2000-2013, while the annual urban population growth rate was between 3 per cent and 4 per cent during the same period.
the movements of the housing price. Although both of the “fundamental demand hypothesis” and the “housing bubble hypothesis” have their reasonable places, neither of them has ever made a quantitative comparison between each other to see whether one hypothesis is more powerful than the other one in terms of explaining the housing price movements. Therefore, it is necessary to include both the hypotheses under a same analytical context to examine to which extent each of the hypotheses can explain the movements of the housing price.

The third issue is to examine whether the monetary policy should respond to the volatility in the housing sector if the volatility in the housing sector does impact the rest of the economy. I will focus on whether the monetary policy should respond to the variations of housing prices. There are heated debates on this question. Regardless of the debates, the Chinese government has already used a variety of monetary policies to interfere with the boom and bust of the housing market since 2004. For example, the government has adjusted the benchmark interest rate and required reserved ratio. Therefore, it is necessary to explore whether it is proper for the monetary authority to take into consideration the volatility in the housing prices in China.

13 There is a growing literature which studies the role played by the housing market and the conduct of monetary policy. Those studies consider the scope for targeting house prices in a monetary policy rule using New Keynesian DSGE models in the presence of a multi-sector structured economy, nominal rigidities, and financial frictions on the household side (i.e. a portion of households face credit constraint, and use their residential properties as collateral), e.g. Paries and Nptarpietro (2013), Notarpietro and Siviero (2013), Ratto, et al. (2010) and Roger and Veld (2009), Andres et al (2011), Aspachs-Bracons and Rabanal (2011), Forlai and Lambertini (2011), Finocchiaro and Queijo von Heideken (2012), Iavoviello (2005), Monacelli (2009) and Rubio (2011), and Jeske and Liu (2012)).
In summary, there are three main issues to be examined in this dissertation: i) the primary shocks that cause the fluctuations in the housing sector, ii) the spillover effects of volatility in the housing sector on the broader economy, and iii) the monetary policy responses to fluctuations in the housing prices.

It should be noted that most of the housing-related issues addressed in this dissertation refer to the urban housing sector. There are significant differences between the Chinese urban area and rural area with respect to the housing and land systems. However, since the rural housing sector plays a very limited role in the overall economy in terms of its economic scale, it is not approached by this research.

1.3 Research Methodology Introduction and Main Empirical Findings

1.3.1 Research Methodology Introduction

A Bayesian Dynamic Stochastic General Equilibrium (DSGE) model with a variety of frictions and shocks is estimated to investigate the above issues. In particular, the inclusion of three housing-related shocks to the model helps capture some important characteristics of the Chinese economy and the housing sector. These three shocks are a housing bubble shock, a government policy shock and a credit shock in my research. The definitions of these three shocks and the reasons for including them to the model are to be carefully discussed in the next chapter. I consider an infinite-horizon economy that consists of a representative final good producer, a representative retailer, a monetary authority and two types of households – a patient household and an impatient household according to their different inter-temporal discount rates. Impatient household faces a credit constraint.
Heterogeneous production sectors are included to examine the movements of different types of investments with a multi-sector model. The final good producer is assumed to produce both consumption goods and housings. A household’s utility depends on non-housing consumption, the amount of housing purchased and leisure. The household heterogeneity generates an equilibrium debt as a result of the inter-temporal borrowing between the patient and impatient households. Housing is introduced to the model as a collateral asset. The consumption goods production requires labor and capital as inputs, while housing production requires labor, capital and land as inputs. Additionally, the borrowing capacities of impatient households are constrained by the value of collateral assets due to imperfect contract enforcement.

The reason of selecting the DSGE model to develop my research is due to the outcome of the literature review work. Since the Chinese housing sector is still in an early stage of its development, the amount of related literature is not considerable. There are certain numbers of studies which address the issues similar to the ones in my research. For example, Liang et al. (2006) apply the co-integration and HP-filtering methods to calculate the equilibrium housing price and the deviations of real price from the equilibrium using data from 1995Q1 to 2005Q3. Additionally, they use a time-varying parameter model to estimate the effects of GDP and interest rates on housing prices. Moreover, a multivariate VAR model is applied to examine how real estate industry impacts GDP and other industries. Using a SVAR model, Zhao (2010) uses quarterly data from 1999Q1 to 2009Q2 to estimate the dynamic impacts of supply shocks, demand shocks and monetary shocks on the fluctuations
of housing prices as well as the effect of housing market related shocks on inflation rate, output growth rate and monetary stock growth rate. Ma et al. (2008) make comparisons between the macro business cycle and the housing cycle. They use the GDP growth rate and a composite housing cycle index to study the movements of the two cycles. Their results show that the housing cycle leads the macro business cycle in expansion and lags during recessions. Zhou et al. (2010) employ a multivariate VAR model with time-varying parameters to estimate the interactions between the Chinese housing sector cycle and the macro business cycle with data from 1995Q1 to 2009Q3. In their study, they use the logarithmic form of GDP per capita to capture the movement of macro business cycles and the logarithmic forms of real housing investment volume, real domestic loan value to the housing industry, and average housing price to represent the volatility in the housing market. Wang (2005) explores the relationship between housing industry development and economic growth as well as the relationship between housing industry development and the business cycle. He uses a simple linear model to explore the relationship between real estate industry development and economic growth as well as a qualitative method based on data at the macro level to study the relationship between real estate industry development and macro business cycles.

What can be seen is that most of the existing studies still use VAR, SVAR and other traditional econometric methods to study the issues of the Chinese housing sector. In comparison to these econometric methods, DSGE models are firmly grounded in economic theories. “These [DSGE] models draw links between the structural parameters describing private agents’ tastes and technologies and the
time-series behavior of endogenous variables … these parameters should remain invariant to changes in policy regimes.” (Ireland, 2004) The parameters estimated by DSGE models are believed not subject to the “Lucas Critique” in Lucas (1975). Hence, a DSGE model is an ideal model to study the economic dynamics. In addition, because one primary goal in my research is to study the interaction between the housing sector and the broader economy, it is necessary to have a model that is able to fit the data well and to capture the primary sources and propagation mechanism of business cycles. Apparently, DSGE models have become a benchmark in this respect. Therefore, the DSGE model is selected to develop my research.

There is also some literature which has already used the DSGE model to study the Chinese housing sector. For example, Liang and Li (2011) examine the relationship between monetary policy and the housing price in China with a DSGE model in which the real estate is the only collateral households can use to obtain loans from financial institutions. Households obtain utility from housing consumption. It is shown that, in general, cost shocks to the real estate industry are the main driver of housing price fluctuations in China. Their paper includes preference, cost, monetary policy and credit constraint shocks. Similarly, Zheng and Di (2012) use a DSGE model in which household heterogeneity and the financial accelerator mechanism are incorporated to study how housing prices and other economic variables respond to shocks. The main shocks in their paper are the preference, technology, inflation and fiscal policy shocks. Wang et al. (2013) use a DSGE model to study the fluctuations in housing prices and housing supply. They
show that monetary policy shocks and housing preference shocks account for more than 60 per cent of the volatility in housing prices. Technology shocks, wage markup shocks and monetary policy shocks are the primary sources that cause changes in housing supply.

The difference between their research and my research is that in my research the DSGE model is extended to include some important features of the Chinese housing sector and the economy. The three aforementioned housing-related shocks are added to the model. To the best of my knowledge, my research is the first one that explores the dynamic effect of housing bubbles on the Chinese housing sector and the wider economy.

1.3.2 Main Empirical Findings of Dissertation

The empirical results of impulse responses, forecast error variance decompositions and historical decompositions reveal: i) investment-specific technology shocks and labor supply shocks explain a large portion of the macroeconomic variations over the whole sample period; ii) government policy shocks are the dominant force behind housing sector fluctuations but housing bubble shocks, housing preference shocks and monetary policy shocks also play significant roles, especially the housing bubble shocks; iii) housing-related shocks also have effects on the rest of the economy and the housing sector can generate volatility in the economy; iv) according to the results of frontier efficiency curves and the model’s marginal likelihoods, the Chinese Central Bank should respond moderately to housing price fluctuations. The estimation results in the dissertation are robust to changes in structural parameters and the model specifications.
1.4 The Structure of Dissertation

The rest of the dissertation proceeds as follows. In chapter 2, I introduce an extended model of Iacoviello and Neri (2010) and the new features added to the model. Chapter 3 proceeds to describe the data and explain estimation methods. Estimation results, interpretations and robustness analysis are summarized in Chapter 4. Chapter 5 concludes the dissertation.
Chapter 2
THE MODEL INTRODUCTION

2.1 The Background Introduction of Model

As mentioned in Chapter 1, my dissertation addresses three issues concerning the Chinese housing sector development and the business cycle: i) the driving forces behind the movements in the housing sector and business cycles over the past few decades; ii) the spillover effects of the volatility in the housing sector on the broader economy; and iii) the monetary policy response to fluctuations in the housing prices. A Bayesian Dynamic Stochastic General Equilibrium (DSGE) model with a variety of frictions and shocks is estimated to investigate the above issues.

Early DSGE literature that studies the relationship between the housing sector and the wider economy usually constructs a multi-sector structure which includes housing and non-housing products or investments in a Real Business Cycle (RBC) model. It is an extension of the home production model that considers household capital as a complement to both business capital and labor inputs in production, e.g. Baxter (1996), Greenwood and Hercowitz (1991), Benhabib et al. (1991), Campbell and Ludvigson (1998), Chang (2000), Gomme et al. (2000), Davis and Heathcote (2003), Einarsson and Marquis (1997), Fisher (2005), McGrattan et al (1997), Hornstein and Praschnik (1997), and Peril (1998). However, most of them rely heavily on strong technology shocks to explain the business cycle fluctuations.
and are unable to reconcile their empirical findings with the observations that the household investment leads the non-residential business fixed investment over the business cycle.

Recently, macroeconomic literature has shown a growing interest in exploring the impact of households’ credit constraint on the business cycle and monetary policy conduct. A common trend in these studies is to emphasize the role played by the housing collateral in the household’s optimal decision. These studies assume that there exists a fraction of households in the economy who face a binding collateral constraint when participating in loan and mortgage markets. As a result, institutional arrangements in these markets can affect a household’s decisions on consumption and home purchasing in a significant way. For example, Gerais (2002), Peterson (2002), Diaz and Luengo-Prado (2010), Ortalo-Magne and Rady (2006) study the role of housing collateral in models with incomplete markets and financing frictions in the household sector. However, they still abstract from aggregate shocks.

In comparison to the studies mentioned above, there are other studies that include all the primary elements found in the existing literature to study the housing sector and business cycles. These elements are nominal rigidities, financing frictions faced by households, a rich set of shocks and a multi-sector structure with housing and non-housing goods.

One important work is Iacoviello (2005). Iacoviello (2005) constructs a DSGE model which is a variant to Bernanke et al. (1999) in which two features are added: sectoral heterogeneity and house being used as collateral for loans. In the extended model, both firms and impatient households are facing credit constraints.
He allows the nominal rigidity of price and highlights the housing demand shocks, inflation shocks and technology shocks. The model is used to explain both the business cycle facts and the interaction between the housing price and the macroeconomy. His paper estimates some key structural parameters by minimizing the difference in the impulse responses between a DSGE model and an unrestricted VAR model.

Based on his analysis framework, more types of shocks and frictions are introduced to enrich the model in the following literature. Liu et al. (2013) study the dynamic impact of land-price on the macro-economy in a general equilibrium framework. They assume that firms, instead of households, face credit constraints. Land is introduced as a collateral asset in a firm’s credit constraint. This assumption helps capture the co-movement between land prices and business investment. In addition to the shocks in Iacoviello (2005), a credit shock is also identified. Iacoviello and Neri (2010) present a Bayesian estimated DSGE model to model the price and quantity side of the housing market. They explore possible shocks and frictions which could explain the dynamics of residential investments and housing prices as well as the impacts of fluctuations in the housing market on the wider economy. In addition to price rigidity, they also include wage rigidity in both the housing and non-housing sector. Solomon and Yang (2009) integrate household financing frictions with bank financing frictions and housing price fluctuations in a DSGE model to study the link between financial stress levels of the household and bank sectors, given that the bank cannot fully diversify shocks to its borrowers. Forlati and Lambertini (2010) develop a DSGE model in which housing investment
is subject to an idiosyncratic risk. They also assume the possibility for loans to be defaulted on, which results in an endogenous borrowing constraint. The housing price as well as the ex post price of housing stock are subject to the idiosyncratic risk. This price risk could explain the fact that the housing price displays a geographical variation.

Following Iacoviello and Neri (2010), the model used in my research is a New Keynesian Dynamic Stochastic General Equilibrium model which is extended to incorporate some important features of the Chinese housing sector. Based on Iacoviello & Neri (2010), I consider an infinite-horizon economy that consists of a representative final good producer, a representative retailer, a monetary authority and two types of households – a patient household and an impatient household according to their different inter-temporal discount rates. Impatient household faces a credit constraint. Heterogeneous production sectors are included to examine the movements of different types of investments with a multi-sector model. The final good producer is assumed to produce both consumption goods and housings. A household’s utility depends on non-housing consumption, the amount of housing purchased and leisure. The household heterogeneity generates an equilibrium debt as a result of the inter-temporal borrowing between the patient and impatient households. Housing is introduced to the model as a collateral asset. The consumption goods production requires labor and capital as inputs, while housing production requires labor, capital and land as inputs. Additionally, the borrowing capacities of impatient households are constrained by the value of collateral assets due to imperfect contract enforcement.
2.2 Key Factors in the Model

There are three key components in the model. First, agents may face credit constraints where housing is used as the collateral. Second, bubbles are assumed to exist in the housing market. Third, government policies play an important role in the housing sector. The inclusion of a credit shock, a housing bubble shock and a government policy shock in the model captures the above three elements and allows for the study of their effects on the economy.

First, there is a credit constraint assumed to be faced only by impatient households. If an investor is credit constrained, his/her borrowing capacity and investment decision will change when the tightness of credit market and the collateral asset value changes. The change in investment will cause output to fluctuate, which in turn influences the current asset price. Kiyotaki and Moore (1997) formalize this idea in a model of a dynamic economy which features durable assets as collateral for loans. In such an economy, a dynamic interaction between the credit constraint and asset prices is generated and becomes a significant transmission channel through which the effects of exogenous shocks persist and are amplified. This idea is well established in many following works of Kiyotaki and Moore (1997).

In my research, housing is introduced as a collateral asset in the credit constraint of an impatient household. A practical reason for including the housing as collateral asset in my research is because a large proportion of a household’s borrowings are secured by real estate properties in China.\footnote{According to China Household Finance Survey 2014, housing is the primary loan collateral for Chinese households, accounting for approximately 80 per cent of the}
of the household is limited by the value of its collateral assets and the tightness of credit market. If the borrowing constraint is binding, an increase in the housing price will relax the constraint, which results in an expansion of consumption, investment and output. The expanded output and investment in turn will raise the borrowing capacity of the household, relax the credit constraint and inflate the housing price further. On the other hand, a rise in the tightness of credit market will tighten the constraint, which results in a reduction of consumption, investment and output. The reduced output and investment in turn will weaken the borrowing capacity of the household and tighten the credit constraint further. Additionally, the reduced output and investment may influence the asset prices negatively.

Several times over the past two decades, the Chinese government adjusted the home mortgage down payment requirement (refer to Appendix B). These adjustments can be considered a credit shock to the tightness of the credit market, personal credit and collateral value. The effect of a credit shock can spill over from the credit market to the housing sector via housing collateral and to the rest of the economy. Therefore, by including the credit shock it is possible to evaluate the impact of credit changes on the housing sector and the wider economy. The shock is included in the credit constraint of impatient household. The credit shock can also be used to study the effect of the government policy on the housing sector and the total household loans in 2014. Moreover, about 50 per cent of urban household loans are used to purchase housing and for the rural households the proportion is 35 per cent. Chinese Household Finance Survey is the only nationally representative survey in China that has detailed information about household finance and assets. It interviews households covering 29 provinces, 262 counties and 1,048 communities.
broader economy, because it is brought about by the Chinese government policy intervention in the home mortgage market.

Second, a housing preference shock and a housing bubble shock are included, both of which are housing demand shocks. The former shock is included in the household utility function, while the latter is in the arbitrage condition for the housing investment. The arbitrage condition is derived from the first order condition of the household utility maximization problem with respect to the quantity of housing purchased.

Following the idea in Iacoviello and Neri (2010), housing preference shocks can be interpreted as “representatives of the cyclical variation in the availability of resources needed to purchase housing or other social and institutional changes that shift tastes for housing.” Hence, the housing preference shock is used to capture the impact of changes in economic fundamentals on housing demand. Therefore, by including the housing preference shock, it is possible to test the “fundamental demand hypothesis” of the Chinese housing price mentioned in Chapter 1.

The housing bubble shock is defined as a shock to forecast of expected utility returns in the model that distorts the investment component of the demand for housing in my research. According to previous work done by Ioannides and Rosenthal (1994), Rosen (1996), Lin and Lin (1999), Arrondela and Lefevre (2001), Cassidy et al. (2008), and Chen et al. (2012), housing demand can be divided into service demand and investment demand. Service demand for housing simply represents the pleasure a person enjoys from occupying a home (which is very approaching to the idea of the “fundamental demand hypothesis” of the Chinese
housing price) while investment demand originates from a person’s belief about the future appreciation of the home. In general, service demand for housing can explain long-run housing price movements, and investment demand often leads to an excessive demand of housing, causes asset bubbles to arise, and generates considerable short-run volatility of housing prices.

Hence, a housing bubble shock is included in my research to reflect the changes in households’ beliefs about future housing prices that distorts the investment demand for housing. People’s beliefs on future price increases or decreases cause prices to continually grow or fall and to temporarily deviate from their fundamental values, resulting in the rise and burst of bubbles.

The assumption on the existence of bubbles in the Chinese housing market is reasonable. First, the information presented in Chapter 1 confirms that there are a large amount of empirical studies that argue the existence of bubbles in the Chinese housing market. Second, the limited number of financial investment channels available in China makes the real estate industry a prime investment option, especially with the dramatic increase in household wealth and the fast urbanization in China. Figure 2.1 shows the 5-year-and-above mortgage loan rates and short term loan rates, while figure 2.2 displays 1-year and 5-year rates of Chinese treasury securities. We can see that the 5-year-and-above mortgage loan rate is generally higher than the treasury security rates by 1-2 per cent, which to some extent means

When Case and Shiller (2004) discuss housing as an investment, they say that “expectations of future appreciation of the home are a motive for buying that deflects consideration from how much one is paying for housing services. That is what a bubble is all about: buying for the future price increases rather than simply for the pleasure of occupying the home. It is this motive that is thought to lend instability to bubbles, a tendency to crash when the investment motive weakens.”

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that the housing investment has a higher return rate than the treasury security does.

The high return rate of housing investment might attract a large amount of capital flowing into the housing market, which could result in the rising of bubbles.

Figure 2.1: 5-year-above Mortgage Loan Rate and Short Term Interest Rate, 2000m1-2013m12. The vertical axis measures the rates in percentage. Source: People’s Bank of China.

Figure 2.2: 1-year and 5-year Yields for Chinese Treasury Securities 2004m1-2014m1. The vertical axis measures the rates in percentage. Source: Xinlang Finance available at http://finance.sina.com.cn/money/forex/hq/GZSYL.shtml.

In addition to those statistics and empirical work mentioned in the previous sections, the most up-to-date statistics also to some extent support the existence of
bubbles. The newest data of the residential housing price indices (of both the new housings and the second-hand housings) of 70 large and medium-sized major cities in China show that the YoY rates and the MoM rates of the residential housing price indices in those cities kept falling since the beginning of 2014. 16 The data cover the first-tier, second-tier, third-tier and fourth-tier cities. If there is no bubble in the housing prices, it is hard to explain why the housing prices suddenly kept falling in cities since 2014, especially in the third and fourth cities which encountered a larger drop of housing prices than the first and second tier cities did. The overall economic development was stable and the household income was still increasing during this time period. So why did the housing prices suddenly drop if the rapidly increasing housing prices are completely caused by the economic fundamental changes? If the housing prices were not overvalued, they should not have dropped so quickly and continually. Therefore, I think to some extent the recent housing market volatility can support the statements of bubbles.

Including both a housing preference shock and a housing bubble shock allows testing of the “bubble hypothesis” against the “fundamental demand hypothesis” about the Chinese housing price. The housing preference shock is used to examine the impact of shifts in the fundamental demand for housing. The housing bubble shock is used to capture the changes in households’ beliefs about future housing prices which lead to the temporary deviation of asset prices from their fundamental values. The changes in beliefs may be due to noise traders, herd

behavior or waves of optimism or pessimism. In my research, the household faces the housing bubble shocks not the entrepreneur, since the household owns capital and makes decisions on investments. To the best of my knowledge, my study is the first one that explores the dynamic effects of housing bubbles on the Chinese housing market and the wider Chinese economy.

Third, a government policy shock is included to examine how the uncertainties in government policies can impact the housing sector and the rest of the Chinese economy. One important feature of the Chinese economy is that the government uses fiscal, monetary and administrative policies to intervene in the market system. The government plays a very significant role in the business activities in China, much more than in other countries. The uncertainties induced by the policy changes can generate fluctuations in the markets. Therefore, this feature is emphasized in the model.

In the housing sector, the Chinese government frequently uses policies that include adjusting the mortgage down payment rates and housing transaction tax rates, imposing price limits and purchasing qualifications (based on household registration system) and many more policies to control and regulate housing demands (see Appendix B). Moreover, the Chinese government also affects the supply side of housing. Land in China is state-owned or rural-collective-owned. Under the current property rights regime, the right to use land for specified periods (for example, this could be from 40 to 70 years depending on the land use purpose) can be obtained from the governments through paying land-use fees. The fees are determined by the location, type and density of the proposed development. The
Chinese government adjusted the land supply policy in 2005 since when the right to use land can be acquired through biddings, auctions or by a negotiation with the local governments on the land-use fee. However, the main channel to obtain the land-use right in China is still through a negotiation between a housing developer and the government. The sale of land-use rights is a primary source of funding local government expenses, accounting for 25 to 75 per cent of local government’s fiscal revenues. Therefore, governments have the motive to control the land supply in order to obtain more land-use fee revenues, which leads to the scarcity of available land and the high cost of housing construction. So government policy plays a significant role in the housing sector, especially on the housing production side.

Another government policy which has significantly affected the Chinese housing sector is the housing market reform being initiated in 1998. Owing to the housing market reform, resources are more efficiently allocated and used to build houses. Moreover, private enterprises are allowed to participate and compete in the housing development market. As a result, the overall productivity of the industry has greatly changed and housing supply has increased.

Therefore, a government policy shock is included to the model. Due to the significance of the Chinese government policy in the housing production side, this research focuses on the government policy shocks to the housing supply. By including the shock in the housing production function, this research studies how the shocks to the housing supply impact the housing sector and the broader economy.

Yang (2008) discusses the possibility of this motive.
A labor supply shock, an inter-temporal preference shock, a monetary policy shock, a total factor productivity shock in consumption goods sector, a mark-up shock and an investment-specific technology shock are also included.

2.3 The Model Setting

Households

There is a continuum of households of measure unity. A fraction \( \theta \) of all households is patient, and \( 1 - \theta \) impatient. Patient households have full access to the financial market, while impatient households face a credit constraint. Each type of household derives utility from consumption, housing and leisure according to the following expected utility function:

Patient household

\[
E \sum_{t=0}^{\infty} \beta^t Z_t \left\{ \log(C_t - \gamma_c C_{t-1}) + \theta_t \log h_t - \frac{\psi_t}{1 + \eta}(n_{c,t}^{1+\xi} + n_{h,t}^{1+\xi\eta}) \right\} \tag{2.1}
\]

Impatient household

\[
E \sum_{t=0}^{\infty} \beta'^t Z_t \left\{ \log(C'_t - \gamma_c' C'_{t-1}) + \theta_t \log h'_t - \frac{\psi_t}{1 + \eta'}(n'_{c,t}^{1+\xi'} + n'_{h,t}^{1+\xi'\eta'}) \right\} \tag{2.2}
\]

where \( C_t \) and \( C'_t \) denote consumption, \( h_t \) and \( h'_t \) denote housing holdings, and \( n_{c,t}, n'_{c,t}, n_{h,t}, n'_{h,t} \) denote labor inputs to the consumption good and housing sectors respectively. The parameters \( \beta \) and \( \beta' \), where \( \beta' < \beta \in (0, 1) \), are subjective discount factors for each type of household, \( \gamma_c \) measures the degree of consumption habit persistence and \( \eta \) and \( \eta' \) are the inverse labor supply elasticity. \( Z_t \) is the
inter-temporal preference shock, $\psi_t$ is the labor supply shock, and $\theta_t$ is the housing preference shock. $\xi$ and $\xi'$ are the substitution elasticity of labor across the non-housing and housing sectors. If $\xi$ is equal to zero, it implies that labor is perfect substitutable across sectors, while positive value of $\xi$ allows for some degree of sector specificity.

The inter-temporal preference shock $Z_t$ follows the stochastic process

$$lnZ_t = \rho_z lnZ_{t-1} + \sigma_z \epsilon_{zt} \quad (2.3)$$

where, $\rho_z \in (-1, 1)$ is the persistence parameter, $\sigma_z$ is the standard deviation of the innovation, and $\epsilon_{zt}$ is an i.i.d. standard normal process with mean zero.

The labor supply shock follows the stationary process

$$ln\psi_t = \rho_\psi ln\psi_{t-1} + \sigma_\psi \epsilon_{\psi t} \quad (2.4)$$

where $\rho_\psi \in (-1, 1)$ measures the persistence, $\sigma_\psi$ is the standard deviation of the innovation, and $\epsilon_{\psi t}$ is an i.i.d. standard normal process with mean zero.

The housing preference shock follows the stationary process

$$ln\theta_t = \rho_\theta ln\theta_{t-1} + \sigma_\theta \epsilon_{\theta t} \quad (2.5)$$

Where $\rho_\theta \in (-1, 1)$ measures the persistence, $\sigma_\theta$ is the standard deviation of the innovation, and $\epsilon_{\theta t}$ is an i.i.d. standard normal process with mean zero.

Patient household is the net lender in equilibrium. It makes decisions on investment to build capital stock which the final good producer can then rent. It also owns the profits of the final good producer. It maximizes expected utility subject to the following budget constraint:
\[ C_t + I_{c,t} + I_{h,t} + q_t h_t + \frac{B_{t-1} R_{t-1}}{\pi_t} + a(u_{c,t}) k_{c,t} + a(u_{h,t}) k_{h,t} \]

\[ \leq \sum_{i=c,h} w_{i,t} n_{i,t} + \sum_{i=c,h} r_{i,t} u_{i,t} k_{i,t} + B_t + q_t (1 - \delta_h) h_{t-1} + \Pi_t \] (2.6)

where \( q_t \) is the relative price of housing in terms of consumption units, \( R_t \) is the gross real loan rate, \( w_{i,t} \) is the real wage rate in each sector, \( \pi_t \) is the capital rental rate in each sector, \( \pi_t = \frac{p_t}{p_{t-1}} \) is the money inflation rate in the consumption sector, \( u_t \) is the capital utilization rate, \( k_{i,t} \) is the capital stock in the end of period \( t-1 \), \( a(u_t) \) is the cost associated with variations in the degree of capital utilization, \( \delta_h \) is the depreciation rate of housing, and \( B_t \) is the borrowing (lending if it is negative).

In period 0, a household with \( h_{-1} > 0 \) units of housing, and \( B_{-1} > 0 \) units of borrowing. Borrowing, \( B_t \), is greater than some larger number \( \overline{B} \), that is \( B_t > -\overline{B} \).

An impatient household does not own capital. It maximizes expected utility subject to the following budget constraint:

\[ C_t' + q_t h_t' + \frac{B_{t-1}' R_{t-1}}{\pi_t} \leq \sum_{i=c,h} w_{i,t} n_{i,t}' + B_t' + q_t (1 - \delta_h) h_{t-1}' \] (2.7)

As in Kiyotaki & Moore (1997) and Iacoviello (2005), a limit on the obligations of borrowers is assumed. Suppose that if borrower defaults, a lender can then acquire borrower’s assets by paying a proportional transaction cost \((1 - m)E_t(q_{t+1} h_t')\). In this case, the maximum amount of money that an agent can
borrow is bounded by \( m_E_t \left( \frac{q_{t+1} h_t}{r_t} \right) \pi_{t+1} \). Therefore, the impatient household also faces the following collateral constraint:

\[
B'_t \leq m_t E_t (q_{t+1} h'_t) \pi_{t+1} \frac{R_t}{r_t} \tag{2.8}
\]

where \( m_t \) is the credit shock reflecting the uncertainty in the tightness of the credit market, caused primarily by changes in the Chinese government policies in my research. The credit shock \( m_t \) is assumed to be an independently and identically distributed shock.

Additionally, the assumption \( \beta' < \beta \) is kept, following Kiyotaki and Moore (1997). This assumption guarantees that in equilibrium the credit constraint is binding for the impatient household. The binding constraint allows an interaction between asset prices and investments, which will capture the financial accelerator effect.

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Firms

There is a continuum of final goods producers of measure unity. Following Iacoviello and Neri (2010), a final good producer is assumed to produce two products – consumption good and housing, using different technologies described below. Firms use a Cobb-Douglas constant-returns-to-scale technology that uses labor, capital and land as inputs.

Firm maximizes its profits

\[ \Pi_t = Y_t + q_t l H_t - \sum_{i \in c,h} w_{i,t} n_{i,t} - \sum_{i \in c,h} w_{i,t} n'_{i,t} - \sum_{i \in c,h} r_{i,t} u_{i,t} k_{i,t} - R_{t,t} l_t \]  

(2.9)

subject to technologies in consumption good production sector and housing production sector, where \( l_t \) is the land input in the housing production sector, \( R_{t,t} \) is the assignment fee or rental rate charged by government for the use of land\(^1\), \( B'_t \) is the borrowing of firms (lending if it is negative), \( w_{i,t} \) is the real wage rate in each sector, \( r_t \) is the real rental rate of capital, \( k_{c,t} \) is the capital used in the consumption good sector, and \( k_{h,t} \) is the capital used in the housing sector.

The consumption good production function is given by

\[ Y_t = A_{c,t} u_{c,t} k_{c,t}^\alpha (n_{c,t}^\theta n'_{c,t}^{1-\theta})^{\frac{1}{1-\alpha}} \]  

(2.10)

\(^1\) The determination of the rent is an issue. It is a stretch to assume that it is equal to the marginal product of land, because in China the land use fee is not completely decided by the land market. The good thing is that a government policy shock is included in the housing production function in this research. The first order condition of the land rent \( \mu_{t,t} q_t l H_t = R_{t,t} \) shows that the government policy shock can affect the land rent, where \( R_{t} \) is the land rent and \( l H \) is the housing production function which includes the government policy shock. So through this channel, the government policy shock can open a gap between the market land price (rent) and the marginal cost of land. Therefore, the land rent does not have to be equal to the marginal cost.
where $A_{c,t}$ is the total factor productivity shock, and $k_{c,t}$ is the capital in the consumption good sector. The output elasticities of inputs is measured by $\alpha$. The relative sizes of the patient and impatient household in the society is $\theta$ and $1 - \theta$ respectively.

The housing production function is given by

$$IH_t = G_t l_t^{wh}(u_{h,t} k_{h,t})^{\mu_h} (n_{c,t}^{\theta} n_{c,t}^{1-\theta})^{1-\mu_h-\mu_l}$$  \hspace{1cm} (2.11)

where $IH_t$ denotes new housings produced in each period, $l_t$ is the land and $k_{h,t}$ is the capital in the housing sector. The output elasticities of inputs are measured by $\mu_h$ and $\mu_l$. $G_t$ is the government policy shock to the housing supply. Note that following Iacoviello and Neri (2010), the labor inputs of patient and impatient households are assumed in a Cobb-Douglas fashion in the equations 2.10 and 2.11 instead of being as an aggregate.\(^{20}\) The government policy shock follows the stationary process

$$\ln G_t = \rho_G \ln G_{t-1} + \sigma_G \varepsilon_{gt}$$  \hspace{1cm} (2.4)

where $\rho_G \in (-1, 1)$ measures the persistence, $\sigma_G$ is the standard deviation of the innovation, and $\varepsilon_{gt}$ is an i.i.d. standard normal process with mean zero.

Assume that the technology shock $A_t$ in consumption good sector is composed of a permanent component $A_t^P$ and a transitory component $A_t^T$ such that $A_t = A_t^P A_t^E$.

The permanent component follows stochastic process

\(^{20}\)Iacoviello and Neri (2010) mentioned that “by assuming the labor inputs of patient and impatient household in a Cobb-Douglas fashion, some complementarity of the professional skills across the two groups is allowed.”
where $\rho_{at}$ measures the degree of persistence, $\sigma_a$ measures the standard deviation of innovation, and $\epsilon_{at}$ is an i.i.d. standard normal process with mean zero.

The transitory component follows AR(1) stochastic process

$$lnA^c_t = \rho_{ac} lnA^c_{t-1} + \sigma_{ac} \epsilon_{ac_t}$$

where $\rho_{ac}$ measures the persistence, $\sigma_{ac}$ is the standard deviation of innovation, and $\epsilon_{ac_t}$ is an i.i.d. standard normal process with mean zero.

Capital stock evolves according to

$$k_{h,t} = (1 - \delta_{hk})k_{h,t-1} + \left[1 - s \left(\frac{I_{h,t}}{I_{h,t-1}}\right)\right] I_{h,t}$$

$$k_{c,t} = (1 - \delta_{ck})k_{c,t-1} + \varphi_t \left[1 - s \left(\frac{I_{c,t}}{I_{c,t-1}}\right)\right] I_{c,t}$$

where $\delta_{i}$ is the depreciation rates, $\varphi_t$ is the investment-specific technology shock, $I_{h,t}$ and $I_{c,t}$ are the investments in each sector. Let $s \left(\frac{I_{h,t}}{I_{h,t-1}}\right) = \psi_h \left(\frac{I_{h,t}}{I_{h,t-1}} - \delta_{h}\right)^2$ and $s \left(\frac{I_{c,t}}{I_{c,t-1}}\right) = \psi_c \left(\frac{I_{c,t}}{I_{c,t-1}} - \delta_{c}\right)^2$, where $\psi_h$ and $\psi_c$ are investment adjustment cost elasticities.

---

21 The investment-specific technology shock is only assumed in the consumption good production, because it mainly refers to changes occurring in the equipment, software and information technology constructions in a non-IT intensive industry.
Nominal Rigidities

The price rigidity is only allowed in the consumption good production sector.\textsuperscript{22} As in Bernanke et al. (1999), the assumption of monopolistic competition in the retail sector and homogeneous retailers adjusting nominal prices following Calvo pricing is made. In each period, a fraction $1 - \theta_\pi$ of retailers can optimally adjust prices, while the fraction $\theta_\pi$ cannot. Additionally, retailers sell products at a markup $\mu_t^P$ defined as a difference between the retail price and the marginal cost.

Based on these assumptions, a forward-looking Phillips Curve in consumption good sector can be derived as below\textsuperscript{23}

$$
\ln \pi_t - \tau_\pi \ln \pi_{t-1} = \beta (E_t \ln \pi_{t+1} - \tau_\pi \ln \pi_t) - \kappa_\pi \ln \mu_t^P + \ln \lambda_{pt} \quad (2.17)
$$

where $\tau_\pi$ is the elasticity of index prices to the previous period inflation rate and $\kappa_\pi = \frac{(1-\theta_\pi)(1-\beta\theta_\pi)}{\theta_\pi}$. $\lambda_{pt}$ is the mark-up shock which follows an AR (1) process:

$$
\ln \lambda_{pt} = \rho_p \ln \lambda_{p,t-1} + \sigma_p \varepsilon_{pt} \quad (2.13)
$$

where $\rho_p$ measures the degree of persistence, $\sigma_p$ measures the standard deviation of innovation, and $\varepsilon_{pt}$ is an i.i.d. standard normal process with mean zero.

Following Smets and Wouter (2007), wage rates are assumed to evolve gradually to the desired wage mark-up due to nominal wage stickiness and partial

\textsuperscript{22} Barsky et al (2007) argue that sales prices for new homes could be flexible. Because “houses are expensive on a per unit basis, if menu costs or other impediments to price flexibility have important fixed components, it is natural to think that prices would be negotiated. Additionally, many new homes are price for the first time only after they have been built”.

\textsuperscript{23} Derivations of Phillips Curve can be found in Bernanke et al. (1999), pp1388-1389 and the Model Appendix of Smets and Wouter (2007).
indexation of wages to inflation due to the incompleteness of labor market.  So we have

\[
\ln w_{c,t-1} = \beta (E_t \ln w_{c,t+1} - \nu_{wc} \ln \pi_t) - \nu_{wc} \ln w_{t-1} = \beta \nu_{wc} \ln \pi_t - \nu_{wc} \ln w_{t-1} = \beta (E_t \ln w_{c,t+1} - \nu_{wc} \ln \pi_t) - \nu_{wc} \ln w_{t-1}
\]

where \( \nu_{wc} \) and \( \nu_{wh} \) are wage rate index to the previous wage, \( \nu_{wc} \) is equal to \( 1 - \theta_{wc} \) and \( \nu_{wh} \) is equal to \( 1 - \theta_{wh} \). \( \theta_{wc} \) and \( \theta_{wh} \) are the fractions of the labors unable to re-optimize wages, \( \mu_{wc} \) and \( \mu_{wh} \) are the wage markups which are the difference between the marginal product of labor and the real wage rate in the non-housing and housing sectors respectively.

Monetary Policy and Fiscal Policy

The central bank conducts monetary policy according to the following Taylor rule which responds gradually to inflation and GDP growth

\[
R_t = R_{t-1} + \rho_r \left( \pi_t - \pi_t \frac{GDP_t}{GDP_{t-1}} \right) \rho_y e_t^r
\]

where \( GDP_t = Y_t + q_t H_t \), \( \rho_r \), \( \rho_{\pi} \) and \( \rho_y \) are the response parameters, and \( e_t^r \) is the monetary policy shock which is assumed to be identically and independently distributed.

---

24 Derivations of the two sticky wage curves can be found in Smets and Wouter (2007). In their work, an intermediate labor union is assumed to buy homogeneous labor from the households and sell them to the labor packers. The labor union creates a gap between the marginal product of labor and the real wage rate due to its market power.

25 The similar equations can be found in Iacoviello and Neri (2010) and the derivations of them can be found in the Model Appendix of Smets and Wouter (2007).
Finally, assume that government collects lump sum tax and follows a Ricardian fiscal policy rule. Hence, under these assumptions, tax policy has no impact on aggregate economic variables and there is no need to explore fiscal policy. Additionally, the main role played by the government policy (including the fiscal policy) in my research is assumed to distort the housing sector, the land market and the marginal cost of land. To realize this role, a government policy shock is included in the housing production function. So the fiscal authority is omitted to simplify the model.

**Equilibrium**

The goods market produces consumption and investment. The housing market produces new houses. The equilibrium conditions in the non-housing and housing markets respectively are

\[
C_t + \sum_{i=c,h} I_{i,t} + a(u_{c,t})k_{c,t} + a(u_{h,t})k_{h,t} = Y_t \quad (2.21)
\]

\[
H_t - (1 - \delta_h)H_{t-1} = IH_t \quad (2.22)
\]

where \( H_t = h_t + h_t' \) is the stock of housing at period \( t \).

In the loan market

\[
B_t + B_t' = 0 \quad (2.23)
\]

In the labor market

\[
\sum_{i=c,h} n_{i,t} = \sum_{i=c,h} N_{i,t}
\]

Total land is fixed and normalized to one.
The equilibrium is an allocation \( \{c_t, c'_t, Y_t, N_{i,t}, k_{i,t}, l_t, h_t, h'_t, B_t, B'_t\}_{t=0,i=c,h}^\infty \) together with \( \{w_{i,t}, R_t, r_t, p_{i,t}, q_t\}_{t=0,i=c,h}^\infty \), solving the problems of the households and firms, and satisfying the market clearing conditions for the consumption goods, housing, loan and labor markets, given \( \{h_{t-1}, k_{i,t-1}, B_{t-1}, c_{t-1}\}_{t=0,i=c,h}^\infty \) and following the law of motion of capital \( k_t = (1 - \delta)k_{t-1} + \left[1 + s\left(\frac{I_t}{I_{t-1}}\right)\right]I_t \).

The equations that determine the equilibrium of the economy are summarized in Appendix C.
3.1 The Estimation Strategy and Data

The estimation strategy follows a Bayesian approach. As mentioned in Chapter 2, one outstanding advantage of DSGE models is that they are grounded on economic theories. “Yet because they rely so heavily on economic theory, DSGE models are often regarded as being too stylized to be taken directly to the data, making traditional econometric methods for estimation, hypothesis testing and forecasting inapplicable.”

However, recent years have witnessed the advancement in estimation methodology for DSGE models. In particular, the Bayesian estimation method has attracted great amount of attention as a competitive alternative to the traditional methods and has become increasingly popular empirically in macroeconomics and macro-econometrics. An important feature of the Bayesian method is deriving the posterior probability distributions of structural parameters using raw data and prior knowledge of the probability distributions of these parameters. Tommaso (2013) mentions that “the Bayesian method allows priors to work as weights in the estimation procedures so that the posteriors are prevented from peaking at those unexpected points where the likelihoods peak. The Bayesian approach is able to fit

---

the completely solved model since it bases its estimation process on the likelihood generated by a DSGE model, different from GMM estimation and others which are based on some particular restrictions or equilibrium relations.” Hence, Bayesian estimation is considered a mix of the calibration method and the marginal likelihood maximization method which are two classical approaches for estimating DSGE models. It gives priors and maximum likelihoods different weights and connects them through the Bayes’ rule. The estimation process is summarized below in details.

The prior probability distribution of a parameter is in the form of

\[ p(\theta|M) \]

where \( M \) stands for specific model, \( \theta \) represents the deep parameters in the model.

The likelihood function describes the density of observed data and is written as

\[ L(\theta|y_T, M) = p(y_T|\theta, M) \]

where \( y_T \) are the observations up until period \( T \).

Given the prior distributions of the deep parameters and the likelihood function, we can then use Bayes’ rule to identify the posterior distributions of the parameters. The posterior kernel or un-normalized posterior density can be written as

---

27 GMM estimation is based on specific equilibrium conditions such as the Euler conditions for households. Additionally, many empirical studies tend to estimate DSGE models based on discrepancies between impulse response functions obtained from the DSGE models and those obtained from vector autoregression (VAR) models.
\[ p(\theta | y_T, M) \propto p(y_T | \theta, M)p(\theta | M) \]

This is the primary equation that helps us find the posterior moments of the parameters of interest. The next step is to estimate the likelihood function with the Kalman filter.

The reduced form of a linearized DSGE system can be written in a state-space form:

\[ x_t = A(\theta)x_{t-1} + B(\theta)\epsilon_t; \]
\[ \epsilon_t \sim N(0, \Sigma_{\epsilon}); \]
\[ y_t = Cx_t + u_t; \]

where the first function is the transition function which corresponds to the solution of the model and the third function is the observation function which connects the observable variables to the variables of the model.\(^{28}\) \(x_t\) collects all predetermined variables that are known to rational agents at time \(t\). \(\epsilon_t\) collects all exogenous shocks. \(\Sigma_{\epsilon}\) is the variance-covariance matrix of \(\epsilon_t\). Since we usually assume that shocks are independent of each other, \(\Sigma_{\epsilon}\) is actually a diagonal matrix with the variance of each shock on the diagonal. \(u_t\) is the measurement error that enables Bayesian estimation to address the model misspecification problem (optional in practice). Both matrix \(A\) and \(B\) are functions of \(\theta\) which are the deep parameters or structural parameters, for example, the elasticity of inter-temporal

\(^{28}\) For more detailed discussions on state space and the Kalman Filter, refer to Hamilton (1994) chapter 13.
substitution, the Calvo pricing index, or the elasticity of substitution among varieties in the bundle of commodities in Dixit-Stiglitz aggregator. The application of the Kalman filter is possible using the equations in the state space mentioned above as long as these equations are linear in the endogenous and exogenous variables, which is made possible using a mathematical transformation such as log-linearization.\textsuperscript{29}

With the help of the Kalman filter, we can finally obtain the log-likelihood function $\ln L(\theta|Y_T)$, and the log posterior kernel can be written as

$$\ln k(\theta|Y_T) = \ln L(\theta|Y_T) + lnp(\theta)$$

where $Y_T$ is the observables variables in the observation equations.

Theoretically, it is possible to find the modes of posterior densities by maximizing this log posterior kernel with respect to $\theta$. The modes can then be used as defined values of the parameters to make implications. However, it is not easy in practice because the likelihood function is usually analytically intractable. Therefore, we have to resort to the Markov Chain Monte Carlo method (MCMC) to solve this log posterior kernel explicitly.

The fundamental idea of MCMC is to produce a Markov chain whose ergodic distribution is $k(\theta|Y_T)$ or to approximate $k(\theta|Y_T)$ by the empirical distribution generated by a Markov chain. A popular approach known to simulate

\textsuperscript{29} For the Kalman filter algorithm, refer to Hamilton (1994) Chapter 13. One thing to highlight is that the Kalman filter is usually applied when the transition and measurement equations are linear and the shocks are normally distributed. When the state space is not in linear form or shocks are not normally distributed, a Particle filter is more favored.
the Markov chain is the Metropolis-Hasting algorithm. The algorithm based on An and Schorfheide (2007) proceeds as follows:

Step 1. Use a numerical optimization routine to maximize $\ln L(\theta|Y_T) + \ln p(\theta)$;

Step 2. Let $\tilde{\Sigma}$ be the inverse of the Hessian matrix computed at the posterior mode $\tilde{\theta}$ form step 1;

Step 3. Specify an initial value $\theta^0$ (typically the posterior mode) or directly draw $\theta^0$ from $N(\tilde{\theta}, c^2\tilde{\Sigma})$;

Step 4. Draw a sample $\theta_t$ from the proposal distribution or the jumping distribution $N(\theta_t, c^2\tilde{\Sigma})$;

Step 5. Compute the acceptance ratio $r$ or metropolis ratio

$$r(\theta_{t-1}, \theta|y_T) = \frac{L(\theta|Y_T)\ln p(\theta)}{L(\theta_{t-1}|Y_T)\ln p(\theta_{t-1})};$$

Step 6. Set $\alpha = \min(1, r(\theta_{t-1}, \theta|y_T))$ and pick a value $\rho$ form the uniform PDF on the unit interval $U(0,1)$;

Step 7. Accept $\theta$ as the new sample with probability $\alpha$ or reject it with probability $1 - \alpha$. Set

$$\theta_t \begin{cases} 
\theta & \text{ with probability } \alpha \\
\theta_{t-1} & \text{ with probability } 1 - \alpha 
\end{cases}.$$

Repeat step 4 to step 7 for sufficient number of times to create a histogram for those accepted candidate parameter values. Drawing samples repeatedly help smooth the histogram so that the width of each bar in the histogram is infinitely small. Finally, the smoothed histogram shows the posterior distribution of deep parameters of interest.

---

The equations that define the equilibrium are linearized around the balanced growth path. Parameters are classified into two groups. One group contains parameters to be calibrated. These comprise of the parameters not separately identifiable, the ones difficult to be estimated with the data available, as well as the parameters that could be derived from the steady state relationships, microeconomic data or the so-called great-ratios. The other group includes parameters to be estimated by the Bayesian method.
The measurement equations that connect the real data with the variables in the model are

\[
Y_t = \begin{pmatrix}
c_{obt} \\
ic_{obt} \\
i_{k}obt \\
pi_{obt} \\
q_{obt} \\
R_{obt} \\
Rl_{obt} \\
H_{obt} \\
y_{obt}
\end{pmatrix} = \begin{pmatrix}
\bar{c}_{t-1} c_t - c_{t-1} \\
\bar{i} c_t - i c_{t-1} \\
\bar{i} k_t - i k_{t-1} \\
\bar{p} i_t \\
\bar{q} t - q_{t-1} \\
\bar{R} t \\
\bar{R}l_t - Rl_{t-1} \\
\bar{H} t - H_{t-1} \\
\bar{y} t - y_{t-1}
\end{pmatrix}
\]

where \( y_{ob}, c_{ob}, ic_{ob}, ik_{ob}, q_{ob}, R_{ob}, pi_{ob}, Rl_{ob} \) and \( H_{ob} \) are corresponding to the data of the following observables: GDP (not including the housing production value), consumption, non-housing investment, housing investment, house price, nominal interest rate, inflation, land price, and housing sale areas which are used in the estimation of the model. \( \bar{c} \) and \( \bar{c}' \) are the steady state consumption of the patient and impatient households respectively. The items in the right bracket are the percent deviations from the steady state of each variable. In Appendix F, Figures F.1 – F.6 plot the time series from 2000m1 to 2013m12 of seven of the above listed variables. The monthly data on consumption, housing investment, non-housing investment are divided by population, transformed into real terms, seasonally adjusted, and transformed again to log-differenced values. X-13 ARIMA method is applied to process the data. The monthly housing prices are transformed into real terms, seasonally adjusted and log-differenced. The monthly housing sale areas are divided by population, seasonally adjusted and log-differenced. Data on consumption, non-housing investment, housing investment, inflation rate, land prices, housing sale areas and housing prices are directly
collected from or indirectly computed based on the National Bureau of Statistics of the People’s Republic of China. The nominal interest rates are collected from the People’s Bank of China. Note that the Chinese statistics authority does not publish monthly GDP data, but it does publish monthly data of the value added of industry. Research shows that there is a high positive correlation between the growth rate for the Chinese value added of industry and the growth rate of GDP in China. According to the investigation conducted by the State Information Center of China, the correlation coefficient over these two variables remains above 0.90 over the past few decades. Therefore, many studies of the Chinese economy use the growth rate for value added of industry as a substitute for the growth rate of GDP to do empirical analysis. Following the tradition of these studies, the growth rate for value added of industry is used as an approximation. It also should be noted that the value added of industry does not include the newly added value of housing production. This definition is exactly consistent with the variable “$Y_t$” defined in the model. Table 3.1 shows the summary statistics of the key variables and Table 3.2 shows the correlations across selected variables. The Full descriptions of data and sources used are provided in Appendix A.

31 Value added of industry is defined as value added in mining, manufacturing, construction, electricity, water and gas in the reference period and only includes those enterprises whose annual business avenues are above 5 million RMB, or approximately 0.81 million US dollars. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources.
Table 3.1: Summary Statistics of Selected Variables.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Obs</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>165</td>
<td>.0092</td>
<td>0.006</td>
<td>-.0036</td>
<td>.0198</td>
</tr>
<tr>
<td>Consumption</td>
<td>167</td>
<td>.0104</td>
<td>.0510</td>
<td>-.0878</td>
<td>.0966</td>
</tr>
<tr>
<td>Housing</td>
<td>166</td>
<td>.0170</td>
<td>.1954</td>
<td>-.3225</td>
<td>.3173</td>
</tr>
<tr>
<td>Non-housing</td>
<td>166</td>
<td>.0170</td>
<td>.1334</td>
<td>-.5157</td>
<td>.4735</td>
</tr>
<tr>
<td>Housing Price</td>
<td>166</td>
<td>.0049</td>
<td>.1068</td>
<td>-.1876</td>
<td>.1770</td>
</tr>
</tbody>
</table>

**Notes:** The GDP, consumption, housing, non-housing refer to the growth rate of value added of industry, real consumption per capita, real housing investment per capita, real non-housing investment per capita. The raw data of growth rate for value added of industry are seasonally adjusted and demeaned. The raw data of consumption, housing investment and non-housing investment are divided by population, transformed into real terms, seasonally adjusted, and transformed again to log-differenced values. The monthly housing prices are computed as the housing sales volume divided by the housing sale area in the same period, and then transformed into real terms, seasonally adjusted and log-differenced. SD stands for standard deviation. Min and Max stand for the smallest and largest values in each of the data series.

Table 3.2: Correlations across Selected Variables.

<table>
<thead>
<tr>
<th></th>
<th>GDP</th>
<th>Consumption</th>
<th>Housing</th>
<th>Non-housing</th>
<th>Housing Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption</td>
<td>0.3493 (0.0000)</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing</td>
<td>0.6969 (0.0000)</td>
<td>0.4420 (0.0000)</td>
<td>1.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-housing</td>
<td>0.8312 (0.0000)</td>
<td>0.2521 (0.0027)</td>
<td>0.7759 (0.0000)</td>
<td>1.0000</td>
<td></td>
</tr>
<tr>
<td>Housing Price</td>
<td>0.6775 (.0000)</td>
<td>0.4297 (.0000)</td>
<td>0.8721 (.0000)</td>
<td>0.7543 (.0000)</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

**Notes:** The GDP, consumption, housing, non-housing refer to the growth rate of value added of industry, real consumption per capita, real housing investment per capita, real non-housing investment per capita. The raw data of growth rate for value added of industry are seasonally adjusted and demeaned. The raw data of consumption, housing investment and non-housing investment are divided by population, transformed into real terms, seasonally adjusted, and transformed again to log-differenced values. The monthly housing prices are computed as the housing sales volume divided by the residential housing sale area in the same period, and then transformed into real terms, seasonally adjusted and log-differenced. P-values are in the brackets.
Figure F.1 shows that the simulated GDP is above its trend by 5 per cent points in the second quarter of 2007, and below its trend by 1 per cent point in the fourth quarter of 2009. Figure F.5 indicates the inflation rate volatility. Between 2000 and 2003, the Chinese economy experienced a period of deflation. After then, inflation became relatively volatile between 2007 and 2012. Figure F.2 – F.4 d show the movements of real consumption, real housing investment and real non-housing investment. Consumption and investment are much more volatile than output. Figure F.6 displays the variations of output, housing investment, non-housing investment and housing price. It indicates that the housing investment, non-housing investment and housing price are strongly pro-cyclical. Additionally, it can be seen that the housing price is sensitive to interest rates. It also implies that there is a close relationship between the housing sector movements and the broader economy performance.

In terms of interest rate policy, before 2003, People’s Bank of China sets 34 categories of interest rates, but normally uses the one-year deposit rate as a benchmark against which other rates are determined. It also defines a floor lending rate for commercial banks, which was between 70 per cent (for personal mortgage loan) and 90 per cent of the benchmark rate. Only lending by rural and urban credit cooperatives is given a ceiling, which is presently at 230 per cent of the PBC benchmark. Beginning in October, 2004, when marketing reform of the interest rate was introduced, financial institutions were allowed to fix the saving and lending rates independently and were no longer constrained to lending floors and ceilings. However, most commercial banks still set their loan rates equal to or close to the
benchmark rate due to the strong competition in credit market, although they are permitted to decide the rate level (Miao and Peng, 2011). The relatively slow liberalization of the interest rate is due to the concern to avoid undesired market competition and the concern to maintain the stability of the financial system.

3.2 Calibrated Parameters

Eight parameters are calibrated according to the traditions in previous literature and the observations in many empirical analyses. The research literature on the Chinese economy provides useful parameters that reflect the unique features of the Chinese economy. The parameters not discussed in this research on Chinese economy are borrowed from significant foreign research literature.

The structural parameters to be calibrated in my research include the output elasticity of capital $\alpha$, the depreciation rate of capital in consumption good production $\delta_{ck}$, the depreciation rate of capital in housing production $\delta_{hk}$, the depreciation rate of housing $\delta_h$, discount rates for patient household $\beta$ and impatient household $\beta'$, the output elasticities of inputs in housing production function $\mu_h$ and $\mu_l$, as well as the relative shares of patient and impatient households $\theta$ and $1 - \theta$.

The empirical analysis result from the State Information Center of China in 2014, which uses a Cobb-Douglas production function to estimate the capital-output elasticity and the labor-output elasticity, is used to determine $\alpha$. The result shows that for the period stretching from 1978 to 2013, the Cobb-Douglas production function for Chinese economy is of the following form
\[ \ln Y_t = -1.6135 + 0.5519 \times \ln K_t + 0.4481 \times \ln L_t + 0.0286 \times t + 0.06375 \text{DUM} \]

where \( Y \) is the annual GDP, \( K \) is the annual fixed capital formation which is recorded based on the perpetual inventory system, \( L \) is the annual employment, \( t \) is a trend variable, and \( \text{DUM} \) is a dummy variable which is equal to 1 if it is after year 2002, otherwise 0. The output elasticity of capital is set to be 0.5519 and the output elasticity of labor is 0.4481.

The depreciate rates of capital in the non-housing sector and capital in the housing sector are set equal to 0.0026 and 0.0024. The depreciation rate of housing is set equal to 0.003. Together with the capital share in output, the assumed depreciation rates guarantee that the ratio of consumption to GDP, the ratio of non-housing investment to GDP and the ratio of housing investment to GDP are approximately 30 per cent, 45 per cent and 15 per cent respectively in their steady states. The steady state values are close to the real data.

The relative size of a patient household and an impatient household are set to be 61.78 per cent and 38.22 per cent respectively according to the China Household Finance Survey 2012 which shows that 38.22 per cent of the total households interviewed have varied kinds of loans. Housing is the primary loan collateral for Chinese households which accounts for approximately 80 per cent of the total household loans in 2012. Moreover, about 50 per cent of urban household loans and 35 per cent of rural household loans are used to purchase housing. According to Iacoviello and Neri (2010), 38.22 per cent is the share of impatient household which is a proportion large enough to generate a positive substitution effect between housing and non-housing consumption after a shock on the demand side of housing.
This effect of positive because an impatient household has a lower discount factor which implies a higher marginal propensity to consumption.

In housing production function, capital share $\mu_h$ is set equal to 0.04. Together with other parameters, it guarantees that the share of the capital used in the housing sector to the GDP is approximately 15 per cent in steady state. The land share $\mu_l$ is set to be 0.095 which is the ratio of land cost against the total housing sale volume on average throughout 2000 to 2013, which is derived based on the steady state relationship of variables. 32

The discount rates of households follow Iacoviello and Neri (2010) where it is 0.99 for a patient household (implying a steady-state ratio of interest rate equal to 3.5 per cent) and 0.97 for an impatient household. “This value guarantees an impatience motive for impatient households large enough that they are arbitrarily close to the borrowing limit, so that the linearization around a steady state with bind borrowing limit is accurate (Iacoviello and Neri, 2010)”.

32 The computation is based on the annual data published by the National Statistics Bureau of China. From the steady state relation we have $\mu_l = \frac{R_l}{q_i H}$ where land is normalized to 1. So it implies that $\mu_l$ can be roughly considered as the ratio of land cost over the total housing sale volume.
Table 3.3: Calibrated Parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.9900</td>
<td>discount rate for patient household</td>
</tr>
<tr>
<td>$\beta'$</td>
<td>0.9700</td>
<td>discount rate for impatient household</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.5519</td>
<td>capital-output elasticity</td>
</tr>
<tr>
<td>$\delta_h$</td>
<td>0.0030</td>
<td>depreciation rate of housing</td>
</tr>
<tr>
<td>$\delta_{ck}$</td>
<td>0.0026</td>
<td>depreciation rate of capital in consumption good production</td>
</tr>
<tr>
<td>$\delta_{hk}$</td>
<td>0.0024</td>
<td>depreciation rate of capital in housing production</td>
</tr>
<tr>
<td>$\mu_h$</td>
<td>0.0500</td>
<td>capital share in housing production function</td>
</tr>
<tr>
<td>$\mu_l$</td>
<td>0.0950</td>
<td>land share in housing production function</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0.6178</td>
<td>relative size of patient household</td>
</tr>
</tbody>
</table>

3.3 Prior Distributions of Structural Parameters

The Dynare 4.2 package is used to carry out the estimation. In order to run the Bayesian estimation, the prior distributions, prior mean and prior standard deviations of the structural parameters are needed. Note that the priors do not have to be very precise but have to be reasonable, since the Bayesian estimation method finds the posterior modes of parameters by recursively updating the prior information with the real data, given the prior assumptions are reasonable. Therefore, in practice scholars may use the values of the parameters found in the existing literature and just use the same values for the prior means and standard deviations of the parameters for all shocks (see Iacoviello and Neri, 2010; Liang and Li, 2011; Wang et al., 2013). Following this tradition, the priors of the structural parameters in
my research use the values from Iacoviello and Neri (2010), Liang and Li (2011), Wang et al. (2013) and Zheng and Di (2012).  

Estimated parameters include the elasticity of index price to previous period inflation rate $\epsilon_\pi$, the Calvo price stickiness $\theta_\pi$, the wage rate indices to previous wage $\epsilon_{wc}$ and $\epsilon_{wh}$, the Calvo wage stickiness $\theta_{wc}$ and $\theta_{wh}$, the habit persistence of consumption $\gamma_c$ and $\gamma_c'$, the inverse elasticity of labor supply $\eta$ and $\eta'$, the substitution elasticity of labor across two production sectors $\xi$ and $\xi'$, the degree of interest rate smoothing in Taylor rule $\rho_r$ and the response coefficients to output growth and inflation in Taylor rule $\rho_\gamma$ and $\rho_\pi$, and the ratio of first order of utilization function to its second order $aac$ and $aah$. In addition, all AR(1) coefficients of lagged variables in the exogenous shock processes and shock innovations are to be estimated as well. 

The inverse elasticity of labor supply $\eta$ and $\eta'$ are assumed to follow a Gamma distribution with mean of 0.5 and standard deviation of 0.1; the substitution elasticity of labor across the two production sectors $\xi$ and $\xi'$ have a Normal distribution with mean of 1 and standard deviation of 0.1, following Iacoviello and Neri (2010). According to Sun and Sen (2010), the elasticity of index price to previous period inflation rate $\epsilon_\pi$, the Calvo price stickiness $\theta_\pi$, the wage rate

33 In the DSGE literature, one way to determine the priors of the parameters in the shock process is to minimize a measure of the distance between the empirical impulse responses of a VAR model and the responses of a DSGE model (see, e.g., Iacoviello, 2005 and Ireland, 2004). However, it is technically complicated and practically impossible to apply this method to my research. There are ten exogenous shocks in my study. If I applied a VAR model, I have to use at least ten time series data to make estimations, which means that there will be at least one hundred parameters to estimate. So it is practically impossible to estimate.
indices to previous wage \( t_{wc} \) and the Calvo wage stickiness \( \theta_{wc} \) all follow a Beta distribution. To simplify the analysis, the assumption is made that the patient and impatient households have the same habit coefficient of consumption \( \gamma_c \) and \( \gamma_e \) has a Beta distribution with mean of 0.5 and standard deviation of 0.1. Degree of interest rate smoothing in Taylor rule \( \rho_r \) follows a Beta distribution with mean of 0.93, while response coefficients to output growth and inflation in Taylor rule \( \rho_y \) and \( \rho_\pi \) are assumed to have a Normal distribution with mean of 1.68 and 0.5. Following Smets and Wouter (2007), the ratio of the first order of utilization function to its second order \( aac \) and \( aah \) have a Normal distribution. Finally, following the tradition in much of the previous work, such as Smets and Wouter (2007), Iacoviello (2005) and Iacoviello and Neri (2010), all AR(1) coefficients of lagged variables are assumed to have a Beta distribution. The innovations of Shocks follow an inverse Gamma distribution. This assumption guarantees positive variances.

### 3.4 Posterior Distributions of Structural Parameters

Five thousand, 5000, draws are generated from the posterior distribution of selected structural parameters using a jumping distribution which is Gaussian. Finally, 2500 of the 5000 draws are kept to make inferences. The scale parameter of the jumping distribution’s covariance matrix is set at 0.3\(^{34}\) initially and results in an acceptance rate of 0.33.

\(^{34}\) The jumping scale value must guarantee that an acceptance ratio of 25%-33% in the Metropolis-Hastings algorithms is obtained. The idea to pick an appropriate value of the jumping scale is to increase the variance if the acceptance ratio is too high, and decrease the same variance if the acceptance ratio is too low.
In Appendix H, Table H.1 and Table H.2 report the prior means, standard deviations, prior distributions, posterior means, modes, standard deviations and 90 per cent Highest Posterior Density (HPD) intervals of the estimated structural parameters. Table H.3 and H.4 report the p-value of the chi squared test. The estimation results show that all of the posterior modes of parameters are within their 90 per cent HPD intervals and significantly different from zero. It turns out that the posterior means of the main structural parameters are typically relatively close to the prior assumptions.

Patient household has a moderate degree of habit persistence of consumption with a $\gamma_c$ of 0.2988, while impatient households have a higher habit persistence coefficient $\gamma_c'$ of 0.3785. These findings are consistent with previous empirical literature. Iacoviello and Neri (2010) provide a persuasive explanation of the higher habit persistence of an impatient household. Inverse labor supply elasticity for each the patient household is 0.5142 and 0.4914 for the impatient household, which implies a high degree of labor supply elasticity. This is considered to be consistent with the reality. In China, there is abundant resource of labor supply. In addition, the Chinese income level is not fairly high and the wage income is still one primary

---

35 The 90 per cent Highest Posterior Density Interval is the interval with the smallest width among all credible intervals which contain 90 per cent of posterior probability mass of parameters. The Chi-square test is used to test the equality of means in the beginning and the end of the MCMC chain.

36 Iacoviello and Neri (2010) point out that since impatient households do not own capital and cannot smooth consumption by saving, a high habit persistence degree is needed to match the persistence of aggregate consumption implied by the real data.
household income source. Therefore, the labor supply decisions made by the households are very sensitive to the wage changes, plus the large stock of labor supply, which results in a high degree of labor supply elasticity. People are more likely to work more if the wage increases. Moreover, there is a large amount of rural surplus labor migrating to the urban areas and moving from the agriculture to the industry. Even a small wage difference between the agriculture and the industry is sufficient to stimulate a large amount of rural population to increase their labor supply. Actually, it is usually believed that the labor supply elasticity in China is infinite.\(^{37}\) To be conservative, I do not assume an infinite labor supply elasticity.

The substitution elasticities of labor across the two sectors \(\xi\) and \(\xi'\) are 0.6752 and 0.9373 respectively. Both of them are less than 1, which indicates a relatively low mobility across the different sectors. Note that the impatient household has higher substitution elasticity of labor across sectors compared to that of the patient household. One possible explanation is that the labor supply decision made by an impatient household is more sensitive to wage changes since an impatient household has relatively lower income than a patient household who owns capital. Moreover, usually labor with lower income tends not to be well trained and concentrates in labor-intensive industries which do not require high skills. In China, the manufacturing industry and housing industry are the two main sectors that absorb a large amount of low-skilled labor. Many jobs in these two industries do not require high expertise, so labors with little skill are more likely to move across sectors if there is a wage difference between sectors. These characteristics may

explain why the impatient household has both higher labor supply elasticity and higher substitution elasticity of labor across sectors.

Another important group of parameters are the ones that capture features of price and wage movements in China. Price stickiness is 0.6305, wage stickiness in the non-housing and housing sector is 0.7336 and 0.7739. It indicates longer contracts of both price and wages in China than in European countries or in U.S. 38

Estimates of response coefficients in the Taylor rule are consistent with previous literature. Moreover, the AR(1) coefficients in the exogenous processes of technology shock, investment-specific technology shock, labor supply shock, housing preference shock, housing bubble shock, government policy shock and inter-temporal preference shock are highly persistent, which implies that the forecast error variances of observable variables in the long run will be mainly explained by these shocks.

38 Sun and Sen (2012) estimate a Bayesian New Keynesian DSGE model to evaluate the effects of monetary policy on the Chinese business cycles. They summarize the estimation results of selected parameters of different countries. My conclusion is based on their study.
4.1 The Empirical Results Summary and Discussions

4.1.1 Impulse Responses of Selected Variables to Traditional Shocks

The impulse responses of selected variables to shocks are presented in Appendix I. The impulse responses of key macroeconomic variables to traditional shocks, i.e. productivity shocks to consumption good production, investment-specific technology shocks, monetary policy shocks, price mark-up shocks and inter-temporal preference shocks, are in line with the main findings in many previous literature. The key macroeconomic variables are real output, real consumption, real investment, inflation and the real interest rate. Most of the impulse responses fall within the 95 per cent error bands.

The impulse responses of housing related variables such as housing price and housing investment are worth mentioning. They show that a positive productivity shock in consumption good production and a positive investment-specific technology shock increase the housing price and housing investment in the short run. On the other hand, a positive monetary policy shock and a positive mark-up shock decrease the short run housing price and housing investment. These two variables return to their equilibrium after 40 periods. The positive productivity shocks and investment-specific technology shocks increase the
output. Because of the high correlation between the output and the housing investment, there are an expansion on the housing investment and an increase of the housing price. The positive investment-specific technology shocks also lower the relative price of capital invested in non-housing sector, which implies the housing investment return rate becomes relatively higher. Therefore, money is attracted to the housing sector which results in the increases of housing investment and housing price. On the other hand, a positive monetary policy shock and a positive mark-up shock both decrease the output. Due to the high correlation between the output and the housing investment, the housing investment is reduced as well. Additionally, the positive monetary policy shocks tighten the credit market, which increases the cost of housing investment financing. As a result, the housing investment is reduced and the housing market cools down in company with a falling price.

4.1.2 Impulse Responses of Selected Variables to Housing-Related Shocks

Of most interest to me are the impulse responses of variables to the housing related shocks, i.e. the housing preference shock, housing bubble shock, government policy shock and credit shock. These results are also attached in Appendix I. Overall, the outcomes of impulse responses of selected variables to housing-related shocks are consistent with reality and economic intuition.

Studying the government policy shock is an important mission in my research. It is known that an important feature of the Chinese economic development is government interferences with the economy. Although China initiated the market economy reform in 1978, governments still play a significant role in economic development. Governments usually use fiscal measures,
administrative regulations and monetary policies to manage the economy. Moreover, in contrast to many developed countries, the Chinese government is accustomed to using administrative measures to regulate the economy. Therefore, in my research, a government policy shock is included in the housing production function in order to study the impacts of government policy on the housing sector and the broader economy.

A positive government policy shock increases the interest rate, output, and housing investment in the short run while lowering the housing price and consumption and non-housing investment. The results show that a positive government policy shock brings about a temporary crowd-out effect of non-housing investment. However, the effect of a government policy shock on the interest rate, consumption and non-housing investment are limited in comparison to its effects on the housing price, housing investment and output. Variables all return back to the equilibrium path within 40 periods. Government policy shocks can be explained as the changes of government policy in the housing supply in my research. The Chinese housing market reform is a significant policy shock to the housing supply. Owing to the market reform, resources are more efficiently allocated and used to build houses. Moreover, private enterprises are allowed to participate and compete in the housing development market. As a result, the overall productivity of the industry has greatly changed and housing supply has increased. There are also other policy changes which may have effects on the housing supply, such as the land policy change and the tax policy change. These policy changes are all captured by the government policy shock to study the effect of changes in the government policy on the housing
supply. The results of impulse responses show that a supportive government policy can greatly promote the development of housing sector while may depress other sectors of the economy in the short run.

Next to be discussed is the housing preference shock. A positive housing preference shock leads to an immediate expansion of housing investment, output and an increase in the housing price. It also raises the interest rate and consumption but to a smaller degree than the housing price, housing investment and output. Similarly to the government policy shock, housing preference shocks also cause a crowd-out effect of non-housing investment. Variables go back to the equilibrium path within 40 periods.

Iacoviello and Neri (2010) point out that housing preference shocks can be interpreted as the cyclical variations in housing demand. These cyclical variations are due to social and institutional changes that shift preferences for housing or due to changes in availability of resources needed to purchase housing.

The housing market reform is an important institutional change which shifts people’s taste for housing. Before the reform a housing market did not exist. Demand for larger and better houses was not met because the supply was insufficient. The reform enables people to purchase housing in a market. The overall economic growth is also a significant fundamental economic change which affects a person’s housing wish. The increased household wealth stimulates their desire for better living conditions. As a result, the demand for varied kinds of house increases and moves with the change in the housing market and economic growth.
Urbanization is another significant factor which affects housing preference in China. Over the past few decades, China has been experiencing an unprecedented urbanization process which is evident in the large-scaled migration from rural areas to urban areas and from small-medium cities to large cities. The growing urban population increases the aggregate fundamental demand for houses. In addition, increased household wealth shifts people’s tastes for housing and stimulates housing purchases. As a result, the housing investment and housing price both rise to a higher level after the economy is hit by a positive housing preference shock. Moreover, housing is purchased not only for consumption but also for investment and appreciation purposes. Higher housing prices increase household wealth in the meanwhile. Therefore, the wealth effect may lead to an expansion in consumption. This can explain why we observe an increase in consumption with a positive housing preference shock.

A housing bubble shock is an important feature in my study and therefore needs careful discussion. A bubble can be positive or negative. Bernanke and Gertler (1999) model the rise of a bubble as an exogenous shock to asset prices. In my study, a housing bubble shock is modeled as a shock to the expected housing price. It is a shock to forecast of expected utility returns in the model that distorts the investment component of the demand for housing. The expectation on the future appreciation stimulates aggregate housing demand and investment, potentially leading to an exuberant housing market and economy. The increasing housing price can stimulate consumption, investment and aggregate output through the household balance sheet.
change and through wealth effects, though the latter one is quantitatively less significant.

As mentioned in Chapter 2, the housing bubble shock is assumed to capture the temporary deviation of asset prices from their fundamental values due to, for example, noise traders, herd behavior or waves of optimism or pessimism. It reflects the beliefs about how real estate will appreciate, and these beliefs will affect a person’s housing investment decision and leads to the rising of bubbles. Therefore, by including the housing bubble shock, it is feasible to test the “bubble hypothesis” about the Chinese housing price.

The housing bubble shock is included in the housing investment arbitrage conditions that are derived from the first order conditions of the utility maximization problem for both patient and impatient households. The functions are as follows

\[
\frac{z_t \theta_t}{h_t} = \lambda_{c,t} q_t + \beta E_t \left( \mu_t \lambda_{c,t+1} q_{t+1} (1 - \delta_h) \right) \tag{4.1}
\]

\[
\frac{z_t \theta_t}{h_t'} = \lambda'_{c,t} q_t + \beta E_t \left( \mu_t \lambda'_{c,t+1} q_{t+1} (1 - \delta_h) \right) - \lambda_t \mu_t m_t E_t \frac{q_{t+1} \pi_{t+1}}{R_t} \tag{4.2}
\]

where \( \mu_t \) is the housing bubble shock on housing demand that follows the stochastic process

\[
\ln \mu_t = \rho_{\mu} \ln \mu_{t-1} + \sigma_\mu \varepsilon_{\mu t} \tag{4.3}
\]

where \( \rho_{\mu} \) measures the persistence, \( \sigma_\mu \) is the standard deviation of innovation, and \( \varepsilon_{\mu t} \) is i.i.d. standard normal process with mean zero.

The housing bubble shock directly impacts the collateral values of impatient households whose borrowing capacity is constrained. When the housing price is
expected to increase, the credit constraint of the impatient household is relaxed. A rise in the housing value increases the value of available collateral, leads to a reduction in leverage on the part of borrowers, and allows for more borrowings. With the relaxing of the borrowing constraint, the impatient household now has a greater incentive and accessible funds to invest in houses and other assets, which could result in a further rise in housing prices. Moreover, housing bubble shocks also have an impact on a patient household through the wealth effect. The growing housing price leads to an appreciation in the house value which accounts for a large proportion of the household wealth of many families. Patient households are likely to spend more money on consumption when their wealth is expected to be higher in the future. Therefore, through the balance sheet effect and wealth effect, the existence of bubbles may stimulate housing prices to grow at a fast rate in the short term.

Impulse responses to housing bubble shocks indicate that after a positive housing bubble shock there is an immediate rise in all key variables in the economy except the non-housing investment. In particular, the housing investment and housing price turn out to be quite sensitive to this shock and increase by at least 1 per cent and 0.3 per cent respectively. The effects of the housing bubble shock usually last for 40 periods. Moreover, the impulse responses show that housing bubble shocks have a larger immediate effect on the key aggregate variables such as output, consumption and investment than housing preference shocks.

It raises a concern about the economic consequences if people become pessimistic toward the future appreciation of housing prices. The impulse responses
already show that after a positive bubble shock, output, consumption, investment, housing investment and the housing price immediately rise and return to equilibrium path within 40 periods. Therefore, it is reasonable to infer that if there is a negative housing bubble shock due to some unexpected negative event or news, the macroeconomy will be in danger of recession. This finding invites us to consider a longstanding debate — should monetary policy respond to housing price variations? A further discussion on this topic is found in section 5.5.

Last but not least is the credit shock which now be explored. In my research, credit shocks can be interpreted as changes in the required down payment to purchase houses. Between 2005 and 2013, the required down payment rates were raised multiple times, which tightened the households’ credit constraints. So the credit shock affects the households’ borrowing capacity. The impulse responses of selected variables to a credit shock show us how the rate adjustment affects the housing sector and the whole economy. A positive credit shock relaxes the credit constraint of household. As a result, there is an increase in the housing price, investment and other aggregate variables. However, the effect of a credit shock is temporary. In addition, its influence is limited in comparison to other housing–related shocks.

One possible explanation accounting for the limited effect of a credit shock is that commercial banks, for their own benefit, did not enforce government requirements of higher down payment rates. Moreover, as mentioned in Chapter 3,
the households that face credit constraints in China are the minority of the total population, only accounting for 38.22 per cent. Hence, the amount of households that will be greatly affected by the tightness of credit constraint is not quite large. More importantly, if households were unable to borrow money from formal financial institutions, they would turn to the informal financial sector to borrow money. Despite the fact that the loan rate required by the informal financial sector is usually higher than the rate in the formal sector, people are still willing to borrow money through informal channels as long as they believe the housing price and housing investment return will continue to rise. These observations can explain why the effect of a credit shock is relatively limited.

In general, the results of the impulse responses of the variables indicate that the shocks that caused the greatest impact to the least impact are the government policy shocks, housing bubble shocks, housing preference shocks and monetary shocks. Other shocks play relatively limited roles influencing the housing market.

4.1.3 Forecast Error Variance Decompositions

Forecast error variance decompositions investigate contributions of shocks to future forecast uncertainties. Figures 5.1 - 5.5 show the forecast error variance decomposition of output, non-housing investment, consumption, housing investment and housing price that are computed based on the mode of parameters’ posterior distributions reported in Chapter 4.

Output variations over different horizons are primarily driven by investment-specific technology shocks, productivity shocks to consumption good for the housing industry. This is obvious during 2005 and 2008.
production and labor supply shocks. A large share of both short and long run investment volatility is caused by investment-specific technology shocks. In the short run, movements in real consumption are mainly driven by labor supply shocks and inter-temporal preference shocks which together account for more than 50 per cent of the forecast error variance of consumption. However, in the long run, investment-specific technology shocks turn out to be the most significant factor that accounts for the volatility in consumption.

However, movements in the housing market are driven by different factors. Housing investment is mainly affected by the government policy changes in housing sector. The government policy shock probably first comes from the housing market reform that was initiated in 1998. In addition to government policy shocks, housing bubble shocks and housing preference shocks are the two demand shocks that play important roles in the fluctuations within housing investment. In particular, housing bubble shocks contribute more than housing preference shocks to the housing investment variations in the short run, while they account for approximately equal shares in the long run.

The forecast error variance decomposition of the housing price has similar patterns to that of housing investment. Government policy shocks, housing bubble shocks and housing preference shocks are still the main forces moving the housing price. Moreover, over an extending forecast horizon, Government policy shocks become increasingly important. So it implies that in the long run, the housing price is predominantly affected by the government housing policies. In addition to these three shocks, monetary policy shocks are important to housing price variations.
However, the effects of monetary shocks are relatively limited in comparison to the shares contributed by the other shocks. Credit shocks account for less than 3 per cent of the variations of both housing investments and housing prices. Moreover, the effects of this shock are temporary.

Investment-specific technology shocks and labor supply shocks play significant roles in the movements of the key macroeconomic variables. These findings are to some extent consistent with the Chinese economic development model. Previous studies conclude that investment-specific technology shocks affect the relative price of capital as well as the supply and demand of capital, while labor supply shocks change the relative price of labor as well as the supply and demand of labor. Over the past three decades, both private and public investments have become an engine to promote Chinese economic development. They account for a large share of GDP growth. According to the World Development Indicator Database of the World Bank, the average ratio of investment to GDP over the period 2000-2013 is 0.42. This large share of investment as a part of GDP growth explains why the investment shock greatly impacts the economy as a whole. Moreover, it is known to all that the Chinese economy is highly dependent on the labor-intensive industries over the past few decades due to abundant resources of labor and relative disadvantage in technology. Since labor is one of the most important production inputs in China, changes in labor supply and demand will greatly affect every aspect

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40 According to World Bank World Development Indicator, Chinese ratios of investment to GDP in per cent throughout 1996-2013 are 42, 40, 38, 37, 37, 35, 36, 38, 41, 43, 42, 43, 42, 44, 48, 48, 48 and 49. Gross capital formation (formerly gross domestic investment) consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories.
of the economy. This is the intuition to explain why the labor supply shock is so important.
Figure 4.1: Forecast Error Variance Decomposition of Output (At the mode of the posterior distribution).

Figure 4.2: Forecast Error Variance Decomposition of Non-housing Investment (At the mode of the posterior distribution).
Figure 4.3: Forecast Error Variance Decomposition of Consumption (At the mode of the posterior distribution).

Figure 4.4: Forecast Error Variance Decomposition of Housing Investment (At the mode of the posterior distribution).
4.1.4 Historical Decompositions

The historical decompositions indicate the contribution of each shock to the volatility of variables over a certain sample period. Figures 5.6 – 5.11 show the historical decompositions for selected variables. Results in this part share some common features with those of the forecast error variance decompositions.

The results on the historical decomposition of GDP show that investment-specific technology shocks, productivity shocks to consumption good production, and labor supply shocks are the main factors accounting for GDP fluctuations (deviation from its trend growth) over the whole sample period. In comparison, monetary shocks and mark-up shocks account for far less of the GDP fluctuations. The results on the historical decomposition of investment variations reveal that fluctuations in this variable are primarily due to labor supply shocks and
investment-specific technology shocks. Mark-up shocks and productivity shocks to the consumption production sector are also important explanatory factors. The results on the historical decomposition of the volatility of consumption suggest that investment-specific technology shocks and productivity shocks to the consumption production sector play dominant roles; these are followed by labor supply shocks and mark-up shocks. Note that housing bubble shocks impact output, consumption and investment beginning in 2005 when the Chinese housing price started rising at a faster rate. However, the influence of a housing bubble shock on these variables is limited in comparison to a non-housing related shock.

The historical decomposition of the volatility of inflation can mainly be explained by mark-up shocks and monetary policy shocks. These findings are generally in line with our intuition and the present reality. The historical decomposition of the volatility of the housing investment is explained primarily by government policy shocks, housing bubble shocks and monetary policy shocks. Credit shocks play a limited role in the long term. Finally, the results on the historical decomposition of the housing price reveal that much volatility in the housing price is caused by government policy shocks, housing bubble shocks, housing preference shocks and lastly monetary policy shocks. Chinese housing prices experienced an unprecedented growth during the period 2005 – 2008. The historical variance decompositions show that the volatility of housing investments and housing prices are primarily caused by housing bubble shocks during that time.

Findings in sections 4.1.3 and 4.1.4 imply that bubbles affect the Chinese housing sector and the overall economy in a meaningful way. The recent exuberance
of the housing market is not only an outcome of fundamental demand on housing, but is also a product of the “animal spirit”.41

Housing price bubbles are triggered by people’s beliefs on the continuous appreciation of housing prices which results in a large amount of capital flowing into the housing sector since 2004 and have continued to stimulate rapid increases in housing prices (see e.g., Lu and Li, 2004; Wang, 2004; Yang et al., 2005). In China, the investment channels are quite limited, comprising mainly of stocks, government bonds and commercial bank savings. When the housing sector began to boom, a large amount of capital flowed into it because of a high return rate of housing investment. 42 Appendix K shows the year-to-year growth rates of housing investment financed by different sources. Notice that the growth rates of the housing investment financed by the domestic loans, the housing sale earnest and the housing sale advances are fairly high, especially between 2005 and 2007, a time period during which the Chinese housing sector grew the most rapidly. The rates dropped in 2008, but then bounced back quickly and reached high in 2013. The statistics also show that the foreign capital flowed into the market rapidly between

41 The term John Maynard Keynes used in his 1936 book The General Theory of Employment, Interest and Money to describe the instincts, proclivities and emotions that ostensibly influence and guide human behavior, and which can be measured in terms of, for example, consumer confidence. It has since been argued that trust is also included in or produced by "animal spirits"

42 From 2005 to 2013, the ratios of the total volume of housing investment to the total investment in per cent are 21, 20.7, 21.5, 20.6, 18.7, 20, 20.4, 19.7, 19.7, remaining at approximately 20 per cent. Moreover, the year-on-year growth rates of housing investment are significantly higher than the rates of total investment. For example, through February to December in 2013, the year-on-year growth rates of housing investment in per cent are 33.4, 30.4, 35.7, 30.5, 30.6, 29.4, 27.4, 27.2, 26.1, 26.4 and 26.9. While for the total investment, these rates are 23.8, 19.6, 20.9, 20.2, 20.2, 20.1, 20.5, 20.5, 20.4, 20.5, 20.4, 20.2, 20.2 and 20.1.
2005 and 2007. These statistics provide some evidence that a great amount of
domestic and foreign capital was invested in the housing sector, which is an
important factor to drive the housing prices to increase. In addition, the housing
sector has received support from the government due to its close connection with
many industries and local fiscal revenues. This made investors feel very confident
about investing in the housing market. As a result, the housing bubble began to
expand and was strengthened by a feedback loop supported by a self-fulfilling
mechanism as mentioned before.

Figure 4.6:  Historical Decomposition of Output.
Notes: The shocks from the top to the bottom in order are credit shock, inter-temporal
preference shock, mark-up shock, monetary policy shock, labor supply shock, housing
bubble shock, investment-specific technology shock, housing preference shock,
government policy shock and total productivity shock to consumption good sector. The
solid black line depicts the movement of output growth above or below its trend growth. The
colored bars correspond to the contribution of the respective smoothed shocks to the
deviation of the smoothed output growth from its steady state. Initial value in the graph
refers to the part of deviations from steady state not explained by the shocks.
Figure 4.7: Historical Decomposition of Investment Growth.

Notes: The shocks from the top to the bottom in order are credit shock, inter-temporal preference shock, mark-up shock, monetary policy shock, labor supply shock, housing bubble shock, investment-specific technology shock, housing preference shock, government policy shock and total productivity shock to consumption good sector. The solid black line depicts the movement of non-housing investment growth above or below its trend growth. The colored bars correspond to the contribution of the respective smoothed shocks to the deviation of the smoothed non-housing investment growth from its steady state. Initial value in the graph refers to the part of deviations from steady state not explained by the shocks.
Figure 4.8: Historical Decomposition of Consumption.

Notes: The shocks from the top to the bottom in order are credit shock, inter-temporal preference shock, mark-up shock, monetary policy shock, labor supply shock, housing bubble shock, investment-specific technology shock, housing preference shock, government policy shock and total productivity shock to consumption good sector. The solid black line depicts the movement of consumption growth above or below its trend growth. The colored bars correspond to the contribution of the respective smoothed shocks to the deviation of the smoothed consumption growth from its steady state. Initial value in the graph refers to the part of deviations from steady state not explained by the shocks.
Figure 4.9:  Historical Decomposition of Housing Investment.

Notes: The shocks from the top to the bottom in order are credit shock, inter-temporal preference shock, mark-up shock, monetary policy shock, labor supply shock, housing bubble shock, investment-specific technology shock, housing preference shock, government policy shock and total productivity shock to consumption good sector. The solid black line depicts the movement of housing investment growth above or below its trend growth. The colored bars correspond to the contribution of the respective smoothed shocks to the deviation of the smoothed housing investment growth from its steady state. Initial value in the graph refers to the part of deviations from steady state not explained by the shocks.
Figure 4.10: Historical Decomposition of Housing Price.

Notes: The shocks from the top to the bottom in order are credit shock, inter-temporal preference shock, mark-up shock, monetary policy shock, labor supply shock, housing bubble shock, investment-specific technology shock, housing preference shock, government policy shock and total productivity shock to consumption good sector. The solid black line depicts the movement of housing price growth above or below its trend growth. The colored bars correspond to the contribution of the respective smoothed shocks to the deviation of the smoothed housing price growth from its steady state. Initial value in the graph refers to the part of deviations from steady state not explained by the shocks.
Figure 4.11: Historical Decomposition of Inflation Rate.
Notes: The shocks from the top to the bottom in order are credit shock, inter-temporal preference shock, mark-up shock, monetary policy shock, labor supply shock, housing bubble shock, investment-specific technology shock, housing preference shock, government policy shock and total productivity shock to consumption good sector. The solid black line depicts the movement of inflation rate above or below its trend growth. The colored bars correspond to the contribution of the respective smoothed shocks to the deviation of the smoothed inflation rate from its steady state. Initial value in the graph refers to the part of deviations from steady state not explained by the shocks.

4.2 Robustness Analysis

This section examines the roles played by frictions and shocks in explaining the movements of the economy. To do this, my model is re-estimated by shutting off one friction or shock each time following the method in Smets and Wouter (2007).

The robustness analysis focuses on frictions including Calvo price and wage stickiness, price and wage indexations, and investment adjustment cost on capital. Christiano et al., (2005) discuss the role played by some important nominal frictions. They argue that a model with only wage rigidity can compete with a model with both
wage and price rigidities. However, the model with only price rigidity performs poorly, which does not generate persistent movement in output unless the price contract duration is assumed to be extremely long. Also, if only moderate stickiness of price and wage is allowed to generate inertia in inflation and persistence in output, it is crucial to allow for variable capital utilization.

The table in Appendix J presents the posterior modes of the structural parameters when each friction or shock is dramatically reduced. Notice that when price and wages are allowed to be very flexible, the estimated results of some parameters are changed. A very low degree of price stickiness leads to a dramatic decrease in the elasticity of adjustment cost which reduces from 13.3811 to 8.1139 in the non-housing sector and from 9.9563 to 6.3199 in the housing sector. It also increases the variance of mark-up shocks from 0.018 to 0.0337. The other parameters are relatively less affected. A low degree of wage stickiness in the both housing and non-housing sectors increases the variance of housing preference shock from. A low degree of wage stickiness in the non-housing sector also significantly increases the variance of labor supply shocks from 0.026 to 0.1108. Similarly, a low degree of wage stickiness in the housing sector increases the variance of labor supply shocks from 0.0026 to 0.1373. Another important friction is the investment adjustment cost for consumption good production. A low degree of elasticity of investment adjustment cost drastically decreases price indexation. It also increases the variances of investment-specific technology shocks and housing investment shocks, at the same time significantly increases the variances of the housing
preference shocks. In comparison to these frictions mentioned above, other frictions or shocks matter little for the model’s performance.

Overall, the above sensitivity analysis results show that most of the estimated values of the structural parameters are robust to changes in nominal and real frictions. Price and wage stickiness as well as investment adjustment cost for consumption good production are the frictions that have large effects on the parameter estimates, while price and wage indexations and investment adjustment cost for housing production play limited roles in the model dynamics.

Next, the data sample is split into two subsamples and the structural parameters are re-estimated based on each subsample in order to further investigate the robustness of the full sample estimation results. The first subsample covers the period between 2000 and 2008 and the second one between 2009 and 2013. The year 2008 is used as a break point due to that the global financial crisis broke out in this year. The 2008 financial crisis affected the Chinese economy significantly. For example, between 2000 and 2008, the annual GDP growth rate was 10 per cent on average. However, the GDP growth rate began to drop and remains at approximately 7.5 per cent since 2008. Therefore, the year 2008 is selected as the break point to divide the full sample into the two subsamples due to the effect of the financial crisis on the Chinese economy.

Table 4.1 summarizes the posterior modes and standard deviations of the structural parameters being estimated based on the two subsample data respectively. The most significant differences between the results of the two subsamples concern the estimates of some shocks’ innovations. The volatility of most of the shocks
increases in the second sub-period. For example, the posterior mode and the standard deviation of the housing preference shock increase from 0.0005 to 0.0406 and from 0.0001 to 0.0064 respectively. Similarly, the posterior mode and the standard deviation of the labor supply shock dropped from 0.0141 to 0.0505 and from 0.0027 to 0.0146 respectively. However, the results indicate that the estimates of other structural parameters are not varied significantly to samples.

Table 4.1: Subsample Estimates.

<table>
<thead>
<tr>
<th>parameter</th>
<th>2000m1-2008m12</th>
<th>2009m1-2013m12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Posterior Mode</td>
<td>Posterior SD</td>
</tr>
<tr>
<td>$\gamma_c$</td>
<td>0.2746</td>
<td>0.0533</td>
</tr>
<tr>
<td>$\gamma'_c$</td>
<td>0.3128</td>
<td>0.0627</td>
</tr>
<tr>
<td>$\eta$</td>
<td>0.4616</td>
<td>0.0932</td>
</tr>
<tr>
<td>$\eta'$</td>
<td>0.4807</td>
<td>0.0981</td>
</tr>
<tr>
<td>$\psi_c$</td>
<td>14.5712</td>
<td>2.3497</td>
</tr>
<tr>
<td>$\psi_h$</td>
<td>9.7428</td>
<td>2.4546</td>
</tr>
<tr>
<td>$\iota_p$</td>
<td>0.4557</td>
<td>0.0833</td>
</tr>
<tr>
<td>$\iota_{wc}$</td>
<td>0.1872</td>
<td>0.0766</td>
</tr>
<tr>
<td>$\iota_{wh}$</td>
<td>0.3987</td>
<td>0.1597</td>
</tr>
<tr>
<td>$\xi$</td>
<td>-0.8472</td>
<td>0.1113</td>
</tr>
<tr>
<td>$\xi'$</td>
<td>-0.9946</td>
<td>0.1014</td>
</tr>
</tbody>
</table>

Notes: SD stands for standard deviation.
Table 4.1: (Continued).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2000m1-2008m12</th>
<th>2009m1-2013m12</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho_{ac}$</td>
<td>0.9045</td>
<td>0.9187</td>
</tr>
<tr>
<td>$\rho_{ah}$</td>
<td>0.9771</td>
<td>0.9543</td>
</tr>
<tr>
<td>$\rho_{g}$</td>
<td>0.845</td>
<td>0.9413</td>
</tr>
<tr>
<td>$\rho_{p}$</td>
<td>0.9515</td>
<td>0.9562</td>
</tr>
<tr>
<td>$\rho_{d}$</td>
<td>0.9712</td>
<td>0.8486</td>
</tr>
<tr>
<td>$\rho_{z}$</td>
<td>0.9648</td>
<td>0.8499</td>
</tr>
<tr>
<td>$\rho_{\pi}$</td>
<td>1.6181</td>
<td>1.4746</td>
</tr>
<tr>
<td>$\rho_{R}$</td>
<td>0.8222</td>
<td>0.7064</td>
</tr>
<tr>
<td>$\rho_{y}$</td>
<td>0.1813</td>
<td>0.2751</td>
</tr>
<tr>
<td>$\theta_{\pi}$</td>
<td>0.9611</td>
<td>0.874</td>
</tr>
<tr>
<td>$\theta_{wc}$</td>
<td>0.8066</td>
<td>0.8425</td>
</tr>
<tr>
<td>$\theta_{wh}$</td>
<td>0.8217</td>
<td>0.8973</td>
</tr>
<tr>
<td>$\rho_{\lambda a}$</td>
<td>-0.0121</td>
<td>-0.0128</td>
</tr>
<tr>
<td>$\varepsilon_{ac}$</td>
<td>0.0065</td>
<td>0.0119</td>
</tr>
<tr>
<td>$\varepsilon_{ah}$</td>
<td>0.0013</td>
<td>0.0032</td>
</tr>
<tr>
<td>$\varepsilon_{e}$</td>
<td>0.0128</td>
<td>0.0224</td>
</tr>
<tr>
<td>$\varepsilon_{d}$</td>
<td>0.0005</td>
<td>0.0406</td>
</tr>
<tr>
<td>$\varepsilon_{\phi}$</td>
<td>0.0116</td>
<td>0.0215</td>
</tr>
<tr>
<td>$\varepsilon_{p}$</td>
<td>0.0021</td>
<td>0.0043</td>
</tr>
<tr>
<td>$\varepsilon_{m}$</td>
<td>0.001</td>
<td>0.0005</td>
</tr>
<tr>
<td>$\varepsilon_{g}$</td>
<td>0.005</td>
<td>0.0005</td>
</tr>
<tr>
<td>$\varepsilon_{\psi}$</td>
<td>0.0141</td>
<td>0.0505</td>
</tr>
<tr>
<td>$\varepsilon_{m}$</td>
<td>0.0005</td>
<td>0.0174</td>
</tr>
<tr>
<td>$\varepsilon_{z}$</td>
<td>0.0162</td>
<td>0.0132</td>
</tr>
</tbody>
</table>

Notes: SD stands for standard deviation.
4.3 The Model Fit

There are various techniques\(^{43}\) that can be used to examine whether a Bayesian estimated DSGE model fit the data well. My research uses posterior odd comparison to assess the model fit. Researchers can place probabilities on competing models and assess alternative specifications based on their posterior odds (An and Schorfheide, 2007). One common approach is to compute the posterior odd ratio. The procedures can be summarized as follows\(^{44}\):

The posterior odd ratio is expressed in the form of

\[
R_{12} = \frac{p(M_1)p(y_T|M_1)}{p(M_2)p(y_T|M_2)}
\]

where \(M_1\) and \(M_2\) denote two model specifications, \(p(M_1)\) and \(p(M_2)\) are the prior distributions on these two competing models and which are the same for both models. Finally, \(p(y_T|M_1)\) and \(p(y_T|M_1)\) are the marginal densities of data conditional on the models. Here, we assume \(M_1\) is the baseline model, while \(M_2\) is the alternative model specification. \(R_{12}\) is the posterior odd ratio of Model 1 against Model 2. Usually, a higher \(R_{12}\) means Model 1 is the most favored. It is relatively

\(^{43}\) An and Schorfheide (2007) classify the methods into two categories: one is to evaluate the absolute fit, e.g. posterior predictive model check; another is to compare the performance of a DSGE model with other macro-econometric models, such as a VAR model or a BVAR model or to compute posterior odds of different model specifications. In general, the log marginal likelihood is considered as a good measurement to compare the one-step-ahead predictive performance across different models.

\(^{44}\) The theoretical procedures of computing the marginal density of data in this section are summarized based on the work of Geweke (1999), Kass and Raftery (1995) and Tommaso (2013).
easy to define the prior distributions \( p(M_1) \) and \( p(M_2) \). In the next step we need to determine \( p(y_T|M_1) \) and \( p(y_T|M_1) \) before we can compute the posterior odd ratio.

We have

\[
p(y_T|M_i) = \int p(\theta; y_T|M_i) d\theta = \int p(\theta|M_i)p(y_T|\theta, M_i)d\theta
\]

note that the items inside the integral sign in the last expression is actually the posterior kernel.

To obtain marginal density of the data, the posterior kernel was approximated by a functional form that can be integrated and is highly peaked at the posterior modes of the structural parameters. There are two alternative ways to do it: one is using the Laplace approximation approach and another is using the Modified Harmonic Mean Estimator. Kass and Raftery (1995) show that the most common and the best approximation, especially for large samples, is the Laplace approximation or Gaussian which is in the form as shown below

\[
\hat{p}(y_T|M_i) = (2\pi)^{k/2} |\Sigma_\theta|^{-1/2} p(\bar{\theta}|y_T, M_i) \ p(\bar{\theta}|M_i)
\]

where \( k \) is the dimension of deep parameter \( \theta \), \( |\Sigma_\theta| \) is the absolute value of the Hessian matrix of second derivatives of \( \log p(\theta|M_i)p(y_T|\theta, M_i) \) with respect to \( \theta \) at the posterior mode \( \bar{\theta} \).

The Modified Harmonic Mean Estimator is an approach that first simulates the marginal density of data with the aid of Metropolis-Hasting runs and then takes the average of the simulated values. Geweke (1999) shows that for any p.d.f. \( f(\theta) \) whose support is contained in \( \Theta \), there are
If $\theta$ is drawn $N$ times, it suggests from the expression above that the marginal density of data is approximately in the form of

$$E \left[ \frac{f(\theta)}{p(\theta|M)p(y_T|\theta,M)} \right] = \int_\Theta \frac{f(\theta)}{p(\theta|M)p(y_T|\theta,M)} P(\theta|y_T,M) d\theta$$

$$= \int_\Theta \frac{f(\theta)}{p(\theta|M)p(y_T|\theta,M)} \frac{P(\theta|M)P(y_T|\theta,M)}{\int_\Theta p(\theta|M)p(y_T|\theta,M) d\theta} d\theta$$

$$= \frac{\int_\Theta f(\theta) d\theta}{\int_\Theta p(\theta|M)p(y_T|\theta,M) d\theta} = p(y_T|M)^{-1}$$

The marginal density of data is also the predictive probability of data which is the calculated probability of observing the actual data before it is available (Kass and Raftery, 1995). The ratio of the logarithm of the marginal densities of one model over an alternative model may also be viewed as a predictive score to evaluate model performance in out-of-sample forecasting, in particular, the one-step-ahead forecasting, because of the following equation

$$log p(y_T|M) = \sum_{i=1}^{N} \log \frac{f(\theta^i)}{p(\theta^i|M)p(y_T|\theta^i,M)} = p(y_T|M)^{-1}$$

where $p(y_t|y_{t-1},\ldots,y_1,M_i)$ is the predictive probability distribution of $y_t$ given the data $\{y_1,\ldots,y_{t-1}\}$ and model specification $M_i$.

Hence, in order to evaluate the model performance, the marginal densities of the data for baseline model and any alternative models are calculated according to the two approaches mentioned above. The results are then compared across models.
Generally speaking, the higher the marginal density is, the better the model fits the data.

Table 4.2 summarizes the marginal density of the data based on the Laplace Approximation and the Modified Harmonic Mean methods for different model settings. The baseline model is a DSGE model with ten shocks and a rich set of frictions. The marginal densities of the baseline model computed using the two methods above are 4072.7 and 4057.7 respectively. A very low degree of price stickiness causes the marginal likelihoods to fall by 262 points and 168 points based on each method. Moreover, a more flexible wage setting leads to a sharp drop of the marginal likelihoods by 186 points and 188 points. In addition, a lower elasticity of consumption investment adjustment cost significantly decreases the marginal likelihoods to 3863.9 and 3840.1. Finally, when the three housing-related shocks are simultaneously shut off, marginal densities fall to 3992.6 and 3968.1, which implies that the model does not fit the data as well as the baseline model. Other alternative models have smaller marginal likelihoods than the baseline model as well. However, the size of these reductions is not significant. Overall, the marginal likelihood results verify that the baseline model fits the data relatively well in comparison to the alternative models. Moreover, they also imply that the housing-related shocks, price and wage stickiness and investment adjustment cost are of significance in terms of the model performance.
Table 4.2:  The Marginal Densities of the Data for Different Model Settings.

<table>
<thead>
<tr>
<th>Model</th>
<th>Laplace Approximation Method</th>
<th>Modified Harmonic Mean Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>baseline</td>
<td>4072.7</td>
<td>4057.7</td>
</tr>
<tr>
<td>price indexation ( t_p=0 )</td>
<td>4026.5</td>
<td>4013.6</td>
</tr>
<tr>
<td>wage indexation ( t_{wc}=0 )</td>
<td>4075.0</td>
<td>4055.7</td>
</tr>
<tr>
<td>wage indexation ( t_{wh}=0 )</td>
<td>4053.1</td>
<td>4037.1</td>
</tr>
<tr>
<td>price stickiness ( \theta_p=0.01 )</td>
<td>3810.1</td>
<td>3870.9</td>
</tr>
<tr>
<td>wage stickiness ( \theta_{wc}=0.3 )</td>
<td>3886.7</td>
<td>3868.6</td>
</tr>
<tr>
<td>wage stickiness ( \theta_{wh}=0.01 )</td>
<td>4071.2</td>
<td>3875.4</td>
</tr>
<tr>
<td>adjustment cost elasticity ( \psi_c=0 )</td>
<td>3863.9</td>
<td>3840.1</td>
</tr>
<tr>
<td>adjustment cost elasticity ( \psi_h=0 )</td>
<td>4066.0</td>
<td>4038.7</td>
</tr>
<tr>
<td>no housing bubble shock</td>
<td>4064.3</td>
<td>4049.0</td>
</tr>
<tr>
<td>no government policy shock</td>
<td>4063.1</td>
<td>4046.8</td>
</tr>
<tr>
<td>no credit shock</td>
<td>4060.8</td>
<td>4038.1</td>
</tr>
<tr>
<td>no three housing-related shocks</td>
<td>3992.6</td>
<td>3968.1</td>
</tr>
</tbody>
</table>

In addition, Table 4.3 presents the variances of selected variables under different model settings. It illustrates that the baseline model relatively better captures the volatility of the variables. When prices or wages are allowed to be flexible, the variances of consumption, investment and GDP become much higher. This implies excessive volatility. Similarly, consumption, non-housing investment and GDP appear to be more volatile than they really are if there is no investment
adjustment cost for consumption good production. However, investment adjustment cost for housing production is of no significance to the variables’ theoretical moments.
Table 4.3: Variances of Selected Variables under Different Models.

<table>
<thead>
<tr>
<th>Model</th>
<th>C</th>
<th>IK</th>
<th>IH</th>
<th>GDP</th>
<th>q</th>
<th>R</th>
<th>π</th>
</tr>
</thead>
<tbody>
<tr>
<td>raw data</td>
<td>0.0026</td>
<td>0.0178</td>
<td>0.0382</td>
<td>0.0035</td>
<td>0.0114</td>
<td>3.61e-05</td>
<td>3.14e-05</td>
</tr>
<tr>
<td>baseline</td>
<td>0.0026</td>
<td>0.0139</td>
<td>0.0264</td>
<td>0.0045</td>
<td>0.0063</td>
<td>3.35e-05</td>
<td>2.92e-05</td>
</tr>
<tr>
<td>( t_p=0 )</td>
<td>0.0047</td>
<td>0.0158</td>
<td>0.0275</td>
<td>0.0067</td>
<td>0.0055</td>
<td>5.40e-05</td>
<td>4.44e-05</td>
</tr>
<tr>
<td>( t_{wc}=0 )</td>
<td>0.0023</td>
<td>0.0134</td>
<td>0.0267</td>
<td>0.004</td>
<td>0.006</td>
<td>3.41e-05</td>
<td>3.30e-05</td>
</tr>
<tr>
<td>( t_{wh}=0 )</td>
<td>0.0023</td>
<td>0.0128</td>
<td>0.0236</td>
<td>0.0039</td>
<td>0.0056</td>
<td>3.94e-05</td>
<td>3.62e-05</td>
</tr>
<tr>
<td>( \theta_w=0.01 )</td>
<td>0.0018</td>
<td>0.0077</td>
<td>0.0761</td>
<td>0.0023</td>
<td>0.0312</td>
<td>0.0001</td>
<td>0.0003</td>
</tr>
<tr>
<td>( \theta_{wc}=0.3 )</td>
<td>0.0072</td>
<td>0.0075</td>
<td>0.0788</td>
<td>0.0041</td>
<td>0.0311</td>
<td>0.0002</td>
<td>0.0001</td>
</tr>
<tr>
<td>( \theta_{wh}=0.01 )</td>
<td>0.0024</td>
<td>0.0071</td>
<td>0.109</td>
<td>0.0023</td>
<td>0.0318</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>( \psi_c=0 )</td>
<td>0.0042</td>
<td>0.0407</td>
<td>0.0266</td>
<td>0.0086</td>
<td>0.0088</td>
<td>8.32e-05</td>
<td>4.14e-05</td>
</tr>
<tr>
<td>( \psi_h=0 )</td>
<td>0.0017</td>
<td>0.0109</td>
<td>0.0231</td>
<td>0.0031</td>
<td>0.0056</td>
<td>2.43e-05</td>
<td>2.40e-05</td>
</tr>
<tr>
<td>no bubble shock</td>
<td>0.0024</td>
<td>0.0171</td>
<td>0.0229</td>
<td>0.0045</td>
<td>0.0061</td>
<td>2.95e-05</td>
<td>2.95e-05</td>
</tr>
<tr>
<td>no policy shock</td>
<td>0.0015</td>
<td>0.0097</td>
<td>0.0231</td>
<td>0.0028</td>
<td>0.0048</td>
<td>2.22e-05</td>
<td>2.11e-05</td>
</tr>
<tr>
<td>no credit shock</td>
<td>0.0017</td>
<td>0.0109</td>
<td>0.0234</td>
<td>0.0029</td>
<td>0.0061</td>
<td>2.66e-05</td>
<td>2.56e-05</td>
</tr>
</tbody>
</table>

Notes: GDP, C, IK, IH, q, R and π represent the output, consumption, non-housing investment growth, housing investment, housing price, interest rate and inflation rate. The output, consumption, housing, non-housing refer to the growth rate of value added of industry, real consumption per capita, real housing investment per capita, real non-housing investment per capita. The raw data of growth rate for value added of industry are seasonally adjusted and demeaned. The raw data of consumption, housing investment and non-housing investment are divided by population, transformed into real terms, seasonally adjusted, and transformed again to log-differenced values. The monthly housing prices are computed as the housing sales volume divided by the housing sale area in the same period, and then transformed into real terms, seasonally adjusted and log-differenced. The variances of variables are calculated based the 2500 draws of the time series obtained by setting the structural parameters equal to their posterior modes.
4.4 The Spillover Effect from the Housing Market to the Overall Economy

According to the results of the impulse responses, forecast error variance decompositions and historical decompositions presented in section 5.1, we can conclude that the volatility in the housing market can be propagated to the whole economy. We have already seen that the aggregated variables, for example, output, consumption, investment and inflation immediately responds in varying degrees to a housing-related shock. The influences are also lasting.

To further explore the spillover effect of the housing market volatility on the whole economy, the three housing-related shocks (a housing bubble shock, a government policy shock and a credit shock) are shut down at the same time and the theoretical moments of variables before and after are recorded. Table 5.4 presents the simulated theoretical moments of selected variables in the baseline model as well as in the model without the three shocks. The outcomes indicate that after blocking the sources which cause the housing market to fluctuate, the simulated mean volatility of all selected variables are significantly reduced. In other words, the overall economy will be more stable if housing market is less volatile.
Table 4.4: Theoretical Moments of Models with/without Housing Related Shocks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>SD</th>
<th>Variance</th>
<th>Variable</th>
<th>SD</th>
<th>Variance</th>
<th>Variance Change in percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.0510</td>
<td>0.0026</td>
<td>C</td>
<td>0.0417</td>
<td>0.0017</td>
<td>34.62</td>
</tr>
<tr>
<td>π</td>
<td>0.0055</td>
<td>0.0000</td>
<td>Pi</td>
<td>0.0054</td>
<td>0.0000</td>
<td>0.00</td>
</tr>
<tr>
<td>IH</td>
<td>0.1625</td>
<td>0.0264</td>
<td>IH</td>
<td>0.1149</td>
<td>0.0132</td>
<td>50.00</td>
</tr>
<tr>
<td>IK</td>
<td>0.1179</td>
<td>0.0139</td>
<td>IK</td>
<td>0.0848</td>
<td>0.0072</td>
<td>48.20</td>
</tr>
<tr>
<td>q</td>
<td>0.0794</td>
<td>0.0063</td>
<td>q</td>
<td>0.0470</td>
<td>0.0022</td>
<td>65.08</td>
</tr>
<tr>
<td>GDP</td>
<td>0.0671</td>
<td>0.0045</td>
<td>GDP</td>
<td>0.0493</td>
<td>0.0024</td>
<td>46.67</td>
</tr>
<tr>
<td>nc</td>
<td>0.0547</td>
<td>0.0030</td>
<td>nc</td>
<td>0.0477</td>
<td>0.0023</td>
<td>23.33</td>
</tr>
<tr>
<td>nh</td>
<td>0.1812</td>
<td>0.0328</td>
<td>nh</td>
<td>0.1353</td>
<td>0.0183</td>
<td>44.21</td>
</tr>
<tr>
<td>wc</td>
<td>0.0285</td>
<td>0.0008</td>
<td>wc</td>
<td>0.0284</td>
<td>0.0008</td>
<td>0.00</td>
</tr>
<tr>
<td>wh</td>
<td>0.0498</td>
<td>0.0025</td>
<td>wh</td>
<td>0.0363</td>
<td>0.0013</td>
<td>48.00</td>
</tr>
</tbody>
</table>

Notes: SD stands for the standard deviation. The GDP, C, IK, IH, q and π represent the same observables as in the Table 4.3. nc and nh as well as wc and wh refer to the labor supply and wage rates in the non-housing and housing sector respectively, and they are theoretical values. The variances are calculated based on 2500 draws of the time series obtained by setting the structural parameters equal to their posterior modes.

4.5 Should Monetary Policy Respond to Housing Price Volatility?

We have already seen in the section 4.1 that the housing-related shocks affect the rest of the economy. Additionally, the outcome of the counterfactual experiment in the section 4.4 provides some evidence that the housing market volatility can be transmitted to the rest of the economy. These findings raise a concern whether monetary policy should respond to the housing price fluctuations. There are heated debates on this question. Regardless of the debates, the Chinese

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45 There is a growing literature which studies the role played by the housing market and the conduct of monetary policy. Those studies consider the scope for targeting house prices in a monetary policy rule using New Keynesian DSGE models in the presence of a multi-sector structured economy, nominal rigidities, and financial
government has already used a variety of monetary policies to interfere with the boom and bust of the housing market since 2004. For example, the government has adjusted the benchmark interest rate and required reserved ratio. In particular, the People’s Bank of China has continually raised the benchmark interest rates over different periods five times during the single year of 2007 in order to control rocketing housing prices. This resulted in an increase in the interest rate of 16.9 per cent on average in 2007.

Should monetary policy take into consideration the volatility in the housing market? To answer this question, the optimal monetary policy is evaluated and a comparison made between the loss functions of the Central Bank under the different policy regimes. Therefore, the following two Taylor rules are considered:

without response to the housing price volatility

\[ R_t = R_{t-1} + \rho_r \left( \pi_t \rho_n \left( \frac{GDP_t}{GDP_{t-1}} \right)^{\rho_y} \right)^{1-\rho_r} e_t^r \]

with response to the housing price volatility

\[ R_t = R_{t-1} + \rho_r \left( \pi_t \rho_n \left( \frac{GDP_t}{GDP_{t-1}} \right)^{\rho_y} \left( \frac{q_t}{q_{t-1}} \right)^{\rho_q} \right)^{1-\rho_r} e_t^r \]

46 I use the Dynare Optimal Simple Rule command to evaluate the loss function under different policy regimes. Dynare searches numerically the best value for the coefficients of some pre-specified policy rule. In Dynare the default objective function is a weighted sum of the variance of some variables in the model.
To evaluate optimal monetary policy, the loss function of Central Bank is assumed to be the weighted variances average of inflation rate and output:

$$LF = \varphi \text{var}(y_t) + (1 - \varphi)\text{var}(\pi_t),$$

where \( \varphi \) is the weight and \( \varphi \in [0, 1] \); \( \text{var}(y_t) \) and \( \text{var}(\pi_t) \) are the unconditional variances of output and inflation. The goal of the Central Bank is to minimize the loss function with respect to some structural parameters in the Taylor rule, subject to a linear law of motion implied by the first order conditions in the model. In my study, the law of motion is the Taylor rule. The linear quadratic problem is solved by \textit{csminwel}, an iterative optimization algorithm developed by Chris Sims. The initial values of parameters are set to be equal to their posterior modes. In particular, The initial value of the response coefficient to the housing price is 0.1076 following Wang et al., (2013).

A series of different values of weight \( \varphi \) is used to plot the efficiency frontier curves, and the variances of output and inflation rate under each \( \varphi \) are collected. Figure 4.13 displays the plots of the efficiency frontier curves under two different monetary policy regimes in. It shows that the curve pertaining to the policy with response to the housing price is under the curve pertaining to the policy without response to the housing price volatility. So it implies that with response to the housing price volatility, the monetary policy effectively reduces the fluctuations in output and inflation.
Figure 4.13: Efficiency Frontier Curves.

The marginal density of the data under different monetary policy regimes is also evaluated. The initial value of the response coefficient to the housing price is 0.1076 following Wang et al., (2013). The results indicate that when the model uses the Taylor rule with response to housing price volatility, the marginal densities of the model are 4087.76 and 4067.2 according to the Laplace Approximation method and the Modified Harmonic Mean approach respectively. In comparison to the baseline model, the alternative model performance is no worse which implies that the overall model performance is improved to some extent when the Taylor rule with response to the housing price volatility is included.

Hence, according to the results of frontier efficiency curves and the models’ marginal densities, the Chinese Central Bank should respond moderately to housing price fluctuations.
Chapter 5

CONCLUSIONS

5.1 The Summaries of Empirical Findings

This dissertation conducts an investigation of the Chinese housing sector development and the business cycles. Three issues are addressed: i) the driving forces behind movements in the housing sector and business cycle over the past few decades; ii) the spillover effects of the housing sector volatility on the broader economy; iii) the monetary policy response to fluctuations in the housing prices. To examine these issues, a Bayesian estimated dynamic stochastic general equilibrium model is used which includes a rich set of frictions and shocks from previous literature. In particular, the model features three housing-related shocks - a housing bubble shock, a government policy shock and a credit shock. These shocks capture some important characteristics of the Chinese economy.

First, the results from impulse responses, forecast error variance decompositions and historical decompositions show that government policy shocks are the dominant force that drives movements in the housing market followed by housing bubble shocks and housing preference shocks and monetary policy shocks. These findings are consistent with the common belief that government policies can generate significant effects on the housing sector. Investment-specific technology shocks and labor supply shocks account for most of the variation in the macroeconomic variables over the whole sample. Moreover, the housing-related
shocks have effects on the rest of the economy. In order to see the spillover effects of the housing sector on the overall economy, a counterfactual experiment is conducted in which the housing-related shocks are shut down. The simulation results show that without these shocks the variances of selected variables are reduced. This implies that the housing sector can generate considerable volatility on the economy through its effect on investments, consumption and labor supply. Finally, the optimal monetary policy is evaluated and comparisons made of the loss functions of the Central Bank under different policy regimes. The results of the frontier efficiency curves and the models’ marginal likelihoods suggest that the Chinese Central Bank should respond moderately to housing price fluctuations. In addition, the study also performs robustness analysis and model fitness analysis. In general, the estimated results are robust to changes in the structural parameters and model specifications, and the overall model performance is satisfied.

5.2 Future Work

There are some questions which I do not address in my research due to the limit of time and the lack of necessary data.

First, my study only considers the case in which the households face a collateral constraint and enterprises are assumed to not face this constraint. However, in the real world Chinese housing enterprises also face a collateral constraint. Throughout 2007 to 2012, the Chinese housing industry had an increasing rate of Return on Total Assets (ROA) and an even faster rising rate of Return on Common Stockholders in the meanwhile. Hence, the leverage ratio over the industry increased. This may imply that enterprises also face the collateral constraint. Nation-wide,
large-scaled listed companies have relatively strict requirements on the leverage level. Therefore, for them, the collateral constraint is not binding. However, for small and medium enterprises, the collateral constraint is binding. So in the future, it is necessary to study the case in which housing enterprises also face a collateral constraint.

Second, heterogeneity in the Chinese housing market is neglected in my research. As mentioned in Chapter 1, the Chinese cities are classified into six ranks based on their economic and political significance. We can imagine that the factors that lead to the volatility in the housing market could significantly vary by region. For example, in the first and second tier cities the housing demand volatility may primarily be caused by fundamental demand, while in the third and fourth tier cities the housing demand volatility may more likely be caused by excessive housing speculation activities. Hence, including housing market heterogeneity in the model can produce different conclusions and implications from the current ones. However, in my study this heterogeneity is abstracted mainly due to the fact that the data at the city-level in China are difficult to acquire. In the future, it is meaningful to make an improvement in this respect.

Third, money supply is excluded in my model due to the lack of data. The People’s Bank of China increased the money liquidity to stabilize and stimulate the economy since the breakout of the 2008 financial crisis. A large amount of money flowed into the housing market and became an important factor which increased the housing price. Therefore, it is necessary to further examine the effects of the money
supply on the housing market and the overall economy in any future when the data become available.

Fourth, due to the time limit, this dissertation does not compare the model performance of a DSGE model with other econometric models such as VAR, BVAR or DSGE-VAR models. Keep in mind that like all macroeconomic models, the DSGE model is a simplification of a real economy, so it does not necessarily outperform other econometric models, especially when doing forecasting and therefore could be misspecified. Other research suggests that these are not important criteria to evaluate the performance of a specific model. For example, Granger (1999), Clements and Hendry (2005) and Kai et al. (2010) emphasize that “forecast performance is not a good criteria to evaluate a model, unless the model is designed particularly for making forecasts”, and Sims (1980) notes that “though a model could be misspecified with some false restrictions, but these restrictions may not necessarily hurt the performance of model as long as the restrictions are not quite false.” However, there is still much work ahead in terms of both econometrics and modeling. For example, a DSGE-VAR model can be applied to examine the degree to which false restrictions matter which is not explored in my research or to further examine model fitness.

Finally, we need to consider whether it is proper to apply a model as the DSGE which is based on the equilibrium assumption to study an economy like China, because the Chinese economy is still in the structural transition and may not be at a steady state as defined in economics. My responses to this concern are: i) this research is not the first one to study the Chinese economy in the context of a DSGE
model. Most of the empirical results of this research make sense, which implies that the model can successfully explain the economic behavior to some extent. ii) I think by including a rich set of frictions and shocks the model can better correspond to the Chinese economic reality in the transition period. However, I am unable to take all possible frictions and shocks into consideration in one study. But future work will be done to make improvements on this aspect.
REFERENCES


Appendix A

DATA AND SOURCES

Consumption c_ob: the monthly Total Retail Sales of Consumption Goods from 2000 to 2013. Sources: National Bureau of Statistics of People’s Republic of China. Available at: http://data.stats.gov.cn/workspace/index;jsessionid=21A6428A273A8E7A98294C57005330AD?m=hgyd. Data are divided by population, transformed into real terms by being divided by the inflation rate, seasonally adjusted, and transformed again to log-differenced values. X-13 ARIMA method is applied to process the data.

Housing Investment ih_ob: the monthly Total Housing Fixed Investment from 2000 to 2013. Sources: National Bureau of Statistics of People’s Republic of China. Available at: http://data.stats.gov.cn/workspace/index?m=hgyd. Data are divided by population, transformed into real terms by being divided by the inflation rate, seasonally adjusted, and transformed again to log-differenced values. X-13 ARIMA method is applied to process the data. The National Bureau of Statistics of China also publishes the data of housing fixed investments under different subcategories. For example, it provides the data of residential housing fixed investment, business housing fixed investment and other related categories. However, in order to be consistent with the variable of “housing investment” defined in the model, the data of total housing fixed investment is selected to make estimations.
Business Investment $ik_{ob}$: the monthly difference between Total Fixed Investment and Housing Fixed Investment from 2000 to 2013. Source: National Bureau of Statistics of People’s Republic of China. Data of Total Fixed Investment and Residential Investment are available at: http://data.stats.gov.cn/workspace/index?m=hgyd. Data are divided by population, transformed into real terms by being divided by the inflation rate, seasonally adjusted, and transformed again to log-differenced values. X-13 ARIMA method is applied to process the data.


Housing Price $q_{ob}$: Based on author’s calculation using data from National Bureau of Statistics of People’s Republic of China. The national average housing price is calculated as the total housing sales volume divided by the total housing sale area in the same period, then transformed into real term by being divided by the inflation rate, seasonally adjusted and log-differenced. Data of the monthly housing sale volumes and housing sale areas from 2000 to 2013 are available at http://data.stats.gov.cn/workspace/index?m=hgyd. The Residential Housing Prices Indices are not used, because since 2011, the Residential Housing Price Indices are expanded to include 70 large and medium-sized major cities in China from previous 35 cities, but NBS no longer publishes national composites. In addition, according to
NBS, data after 2011 use a different methodology and are not directly comparable with the previous 35 metro price indices.

**Land Price** $R_{ob}$: Land Transaction Price Index. Source: Journal of China Monthly Economic Indicators 2000.1-2013.1. Chinese Land Transaction Price Index is defined as the actual price paid by developers or other construction units for land use rights. It covers transaction price for residential land, industrial land, commercial land and other land prices. It excludes follow-up of development costs, taxes, various handling charges and compensation for demolition. The land transaction mainly include auction, public bidding and so on. Data are log-differenced.

**Housing Sale Area** $H_{ob}$: the monthly housing sale areas from 2000 to 2013. Source: National Bureau of Statistics of People’s Republic of China. Available at: http://data.stats.gov.cn/workspace/index?m=hgyd. Data are seasonally adjusted and log-differenced. The National Bureau of Statistics of China also publishes the data of housing sale areas under different subcategories. For example, it provides the data of residential housing sale areas, business housing sale areas, and other related categories. However, in order to be consistent with the variable of “housing” defined in the model, the data of total housing sale areas is selected to make estimations.


**Output** $y_{ob}$: the Chinese statistics authority does not publish monthly GDP data, but it does publish monthly data of the value added of industry. Research shows that
there is a high positive correlation between the growth rate for the Chinese value added of industry and the growth rate of GDP in China. According to the investigation conducted by the State Information Center of China, the correlation coefficient over these two variables remains above 0.90 over the past few decades. Therefore, many studies of the Chinese economy use the growth rate for value added of industry as a substitute for the growth rate of GDP to do empirical analysis. Following the tradition of these studies, the growth rate for value added of industry is used as an approximation. The monthly data of the value added of industry growth rate is available at: http://data.stats.gov.cn/easyquery.htm?cn=A01. Data are seasonally adjusted and demeaned.

Note that the National Bureau of Statistics of China does not publish the data of consumption and growth rate of value added of industry in January and February of each year. It does not publish the data of housing fixed investment, total fixed investment and housing sale areas in January of each year neither. The reason provided by the National Bureau of Statistics of China for why it does not publish the data during these periods is because of a large seasonal disturbance of data caused by the Chinese Spring Festival holidays. In my research, these intermediate missing values in each of the data series are given values using the spline interpolation method executed by the Eviews 8.

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47 Value added of industry is defined as value added in mining, manufacturing, construction, electricity, water and gas in the reference period and only includes those enterprises whose annual business avenues are above 5 million RMB, or approximately 0.81 million US dollars. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources.
Appendix B

A TIMELINE OF KEY CHINESE HOUSING POLICIES

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>“Circular of the State Council on Further Deepening the Urban Housing System Reform and Accelerating Housing Construction” unveils the blueprint for commercializing urban housing: Families with the lowest incomes rent the low-rent housing provided by the government or the work unit; families with medium to low incomes purchase economically affordable houses, and families with high incomes purchase and rent commodity houses at market prices.</td>
</tr>
<tr>
<td>1999</td>
<td>The “Guideline for Personal Consumption Credit Operations” marks the beginning of personal loans, including mortgages.</td>
</tr>
<tr>
<td>2000</td>
<td>The end of housing allocation in China.</td>
</tr>
<tr>
<td>2002</td>
<td>Land Public Bidding System is enacted.</td>
</tr>
<tr>
<td>2003</td>
<td>“Circular of the State Council on Promoting the Continuous and Healthy Development of the Real Estate Markets” acknowledges that the real estate industry is a pillar of the economy.</td>
</tr>
<tr>
<td>2004</td>
<td>Starting August 31, all lands are publicly bid and auctioned. Home prices soar.</td>
</tr>
<tr>
<td>2005</td>
<td>The “Eight Rules,” the “New Eight Rules,” and “Opinion of Such Departments as the Ministry of Construction on Effectively Stabilizing House Prices” signal the central government’s first efforts to rein in home prices.</td>
</tr>
<tr>
<td>2006</td>
<td>“Opinions of the Ministry of Construction and other Departments on Adjusting the Housing Supply Structure as Well as Stabilizing Housing Prices” requests municipal governments to produce detailed development plans on residential housing. It is required that 70% of...</td>
</tr>
<tr>
<td>Year</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td>2007</td>
<td>The government says it will increase taxes to discourage sales of large homes and start taxing the appreciation of property values based on actual market prices. “Certain Opinions About Solving the Housing Hardships of Urban Low-Income Households” confirms that affordable urban housing is a top policy priority. The down payment requirement for first-time homeowners is increased to 20%. Required down payments for second homes are raised to 40% from 30%, and requirements for commercial properties increase to 50% from 40%. The government bans foreign investors in Chinese real estate from borrowing offshore. Monthly payment-to-increase ratio is capped at 50%. Property Right Law is enacted.</td>
</tr>
<tr>
<td>2009</td>
<td>A series of policy change is announced to support the property markets: lower mortgage rates, reduced down payments, lower transaction taxes. In December, further measures are announced to support the property market, including cuts in business and transaction taxes for real estate sales and policies to make it easier for developers to obtain credit. Also in December, China announces that individuals must own their homes for five years to be eligible for sales tax exemption, up from the previous minimum of two years. It also says it will increase the supply of lower-cost housing.</td>
</tr>
<tr>
<td>2010</td>
<td>In March, China orders 78 state companies whose core business is not property to submit plans to divest form the sector within 15 working days. In April, “Notice of the State Council on Resolutely Curbing the Soaring of Housing Prices in Some Cities” is issued. China announces a rise in down payments required on second homes to 50% from 40%.</td>
</tr>
</tbody>
</table>
The government says banks must charge a minimum mortgage rate on second homes of 1.1 times the benchmark interest rate and increases down payments on first homes larger than 90 square meters to 30% from 20%.

In August, regulators order lenders to test the impact of a fall in house prices of up to 60% in key cities and instruct banks to stop extending mortgages to people buying their third homes in some cities.

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>In January, “National Eight” Regulations increase minimum down payment for second mortgages to 60%. Some cities, including Beijing, put new restrictions on home purchases by non-residents. Other tightening measures involving taxes and land transactions are enacted throughout the year.</td>
</tr>
<tr>
<td>2012</td>
<td>Provident funds in some regions ease loan policies for first-time homebuyers.</td>
</tr>
</tbody>
</table>

*Source: cited in Barth, Lea and Li (2012).*
Appendix C

EQUILIBRIUM EQUATIONS

Let $u_c$ denote marginal utility of consumption, $u_{nc}$ and $u_{nh}$ the marginal disutility of labor in each sector, and $u_h$ the marginal utility of housing.

The first order conditions for patient households are:

$$\lambda_{c,t} = z_t \left[ \frac{1}{C_t - Y_c C_{t-1}} - E_t \frac{\beta Y_c}{C_{t+1} - Y_c C_t} (1 + \lambda_{z,t+1}) \right] \text{ w.r.t } C_t \quad (C.1)$$

$$\frac{z_t \theta_t}{h_t} = \lambda_{c,t}\mu_t q_t + \beta E_t \left( \lambda_{c,t+1} q_{t+1} (1 - \delta_h) \right) \text{ w.r.t } h_t \quad (C.2)$$

$$w_{c,t} = \frac{z_t}{\lambda_{c,t}} \frac{\phi_t}{1+\xi} \left( n_{c,t}^{1+\xi} + n_{h,t}^{1+\xi} \right) \frac{n_c^\xi}{1+\xi} n_{c,t}^{\xi} \text{ w.r.t } n_{c,t} \quad (C.3)$$

$$w_{h,t} = \frac{z_t}{\mu_t} \frac{\phi_t}{1+\xi} \left( n_{c,t}^{1+\xi} + n_{h,t}^{1+\xi} \right) \frac{n_h^\xi}{1+\xi} n_{h,t}^{\xi} \text{ w.r.t } n_{h,t} \quad (C.4)$$

$$q_{ck,t} = \frac{\lambda_{ck,t}}{\lambda_{c,t}} \quad (C.5)$$

$$q_{hk,t} = \frac{\lambda_{hk,t}}{\lambda_{c,t}} \quad (C.6)$$

$$r_{c,t} u_{c,t} - a(u_{c,t}) + q_{ck,t} = \beta(1-\delta) E_t \frac{\lambda_{c,t+1}}{\lambda_{c,t}} q_{ck,t+1} \text{ w.r.t } k_{c,t} \quad (C.7)$$

$$r_{h,t} u_{h,t} - a(u_{h,t}) + q_{hk,t} = \beta(1-\delta) E_t \frac{\lambda_{c,t+1}}{\lambda_{c,t}} q_{hk,t+1} \text{ w.r.t } k_{h,t} \quad (C.8)$$

$$1 = q_{ck,t} \left[ 1 + \frac{\Omega_c + \phi_t}{2} \left( \frac{I_{c,t}}{I_{c,t-1}} - \frac{\lambda_c}{1} \right)^2 \right] = (\Omega_c + \phi_t) \left( \frac{I_{c,t}}{I_{c,t-1}} - \frac{\lambda_c}{1} \right) \frac{I_{c,t}}{I_{c,t-1}}$$

$$+ \beta(\Omega_c + \phi_t) E_t \frac{\lambda_{c,t+1}}{\lambda_{c,t}} q_{k,t+1} \left( \frac{I_{c,t+1}}{I_{c,t}} - \frac{\lambda_c}{1} \right) \frac{I_{c,t+1}}{I_{c,t}} \text{ w.r.t } I_{c,t} \quad (C.9)$$
The first order conditions for impatient households are:

\[
\lambda_{c,t} = z_t \left( \frac{1}{C_t' - Y_c C_{t-1}'} - \frac{E_t}{C_{t+1}' - Y_c C_t'} (1 + \lambda_{x,t+1}) \right) \quad \text{w. r. t } C_t' \quad (C.14)
\]

\[
\frac{z_t \lambda_{c,t}}{R_t} h_t = \lambda_{c,t} \psi_t q_t + \beta E_t \left( \lambda_{c,t+1} q_{t+1} (1 - \delta) \right) - \lambda_{c,t} m t q_{t+1} \pi_{t+1} R_t \quad \text{w. r. t } h_t' \quad (C.15)
\]

\[
w_{c,t} = \frac{z_t}{\lambda_{c,t}} \frac{\psi_{t}}{1 + \xi} \left( n_{c,t}^{1+\xi} \right)^{\eta-\xi} n_{c,t}^{\xi} \quad \text{w. r. t } n_{c,t}' \quad (C.16)
\]

\[
w_{h,t} = \frac{z_t}{\lambda_{c,t}} \frac{\psi_{t}}{1 + \xi} \left( n_{h,t}^{1+\xi} \right)^{\eta-\xi} n_{h,t}^{\xi} \quad \text{w. r. t } n_{h,t}' \quad (C.17)
\]

\[
\frac{1}{R_t} = \beta E_t \left( \frac{\lambda_{c,t+1}}{\pi_{t+1}} \frac{1}{\lambda_{c,t} + \lambda_t} \right) \quad \text{w. r. t } B_t' \quad (C.18)
\]

The first order conditions for firm are

\[
w_{c,t} = \frac{(1 - \alpha) Y_t}{N_{c,t}} \quad (C.19)
\]
\[ w_{h,t} = \frac{(1 - \alpha')IH_t}{N_{ht}} \] (C.20)

\[ \frac{\alpha Y_t}{k_{ct}} = r_{c,t}u_{ct} \] (C.21)

\[ \frac{\alpha'(1 - \phi)q_tIH_t}{k_{ht}} = r_{h,t}u_{ht} \] (C.22)

\[ \frac{\alpha'\phi q_tIH_t}{l_t} = R_{l,t} \] (C.23)

where \( \lambda_{ct} \) and \( \lambda'_{ct} \) are the Lagrangian multiplier for the budget constraint for each type of household, \( \lambda_c \) is the Lagrangian multiplier for the borrowing constraint for impatient households, \( \lambda_{ck,t} \) and \( \lambda_{hk,t} \) are the multipliers for the law of motion of capital for each sector. \( q_{ck,t} \) and \( q_{hk,t} \) is interpreted as the shadow price of capital.

The Phillips curve is

\[ \ln p_t - \tau_t \ln p_{t-1} = \beta (E_t \ln p_{t+1} - \tau_t \ln p_t) - \kappa_t \ln \mu_t^p + \lambda_{pt} \] (C.24)

The Taylor rule is

\[ R_t = R_{t-1}^{\rho_r} \left( \pi_t^{\rho_x} \left( \frac{GDP_t}{GDP_{t-1}} \right)^{\rho_y} \right)^{1-\rho_r} e_t^r \] (C.25)

where GDP is the sum of the value added of the two sectors, that is GDP = \( Y_t + q_tIH_t \).

Four market clear conditions are

\[ C_t + \sum_{i=0}^{h} \left[ 1 + \frac{\Omega_i}{2} \left( \frac{I_{t,t}}{I_{t-1,t}} - \frac{\lambda_{i,t}}{\lambda_{i,t-1}} \right) \right] I_{t,i} = Y_t \] (C.26)

\[ h_t - (1 - \delta_h)h_{t-1} = IH_t \] (C.27)

\[ n_{i,t} + n'_{i,t} = N_{i,t} \] (C.28)

\[ l=1 \] (C.29)

By Walras’ law, bond market has
To study the fluctuation around the balanced growth path, the variables are detrended at and then linearized. The resulting system is around the stationary steady state.

\[ B_t + B'_t = 0 \quad (C.30) \]
Appendix D

STEADY STATES

To get steady state value, we assume that the investment adjustment cost function and its first order at steady state are both equal to zero, \( \bar{s} = \bar{s}' = 0 \), the utilization rates are both equal to one at steady state, and the adjustment cost functions of utilization rate are both equal to zero at steady state.

Based on the first order conditions, resource constraints and other conditions which define the equilibrium, we obtain the following expressions that sketch the relations across variables at their steady state values. Note that all the variables in this section are steady state values.

The law of motion of capital implies
\[
\delta_c k_c = i_c \quad (D.1)
\]
\[
\delta_l k_l = i_l \quad (D.2)
\]

The technology production function of intermediate good producer implies
\[
y = k_c^\alpha n_c^{1-\alpha} \quad (D.3)
\]

The first order conditions with respect to capital and labor imply
\[
(1-\alpha)y/k_c = r_c \quad (D.4)
\]
\[
(1-\alpha)y/n_c = w_c \quad (D.5)
\]

The above conditions yields
\[
1 = \left( \frac{1-\alpha}{w_c} \right)^{1-\alpha} \left( \frac{\alpha}{r_c} \right)^\alpha \quad (D.6)
\]
The first order conditions with respect to capital and labor in the cost minimization problem of intermediate good producer imply

\[ k_c = \frac{\alpha}{1 - \alpha} \frac{w_c}{r_c} n_c \quad (D.7) \]

\[ \mu_t^p = \left( \frac{-1}{\varepsilon + 1} \right) (1 - \alpha) \alpha^{-1} \alpha^{-\alpha} r_c \alpha w_c \alpha^{1-\alpha} \quad (D.8) \]

where \( \varepsilon \) is the price elasticity of demand for consumption good and is fixed at -0.2 in steady state.

The Calvo pricing equation yields

\[ P = 1 \quad (D.9) \]

The housing production technology function yields

\[ IH = k_h^{\mu_h} n_h \mu_h - \mu_l \quad (D.10) \]

Resource constraint of consumption good implies

\[ y = c + ih + ic \quad (D.11) \]

Resource constraint of housing implies

\[ IH = \delta_{ih} h \quad (D.12) \]

First order conditions of the households yields

\[ \lambda_c = \frac{1}{c} \quad (D.13) \]

\[ \lambda_c q = \frac{1}{h} + \beta \lambda_c q (1 - \delta_{ih}) \quad (D.15) \]

\[ w_c = \frac{\left( n_c^{1+\xi} + n_h^{1+\xi} \right) \frac{\eta - \xi}{1+\xi} n_c^{\xi}}{\lambda_c} \quad (D.16) \]

\[ w_h = \frac{\left( n_c^{1+\xi} + n_h^{1+\xi} \right) \frac{\eta - \xi}{1+\xi} n_h^{\xi}}{\lambda_c} \quad (D.17) \]
\[ \beta \lambda_c r_c = \lambda_{ck} (1 - \beta (1 - \delta_c)) \quad (D.18) \]
\[ \beta \lambda_c r_h = \lambda_{hk} (1 - \beta (1 - \delta_h)) \quad (D.19) \]
\[ \beta \frac{R}{\pi} = 1 \quad (D.20) \]
\[ \beta (R^l + p_t) = p_t \quad (D.21) \]
\[ r_c = a' (1) \quad (D.22) \]
\[ r_c = a' (1) \quad (D.23) \]
\[ \lambda_c = \lambda_{ck} \quad (D.24) \]
\[ \lambda_c = \lambda_{hk} \quad (D.25) \]

The first order conditions of housing producer imply
\[ \frac{\mu_h qIH}{k_h} = r_h \quad (D.26) \]
\[ \mu_t qIH = R_t \quad (D.27) \]
\[ \frac{(1 - \mu_h - \mu_t)qIH}{n_h} = w_h \quad (D.28) \]

Equations D.26 – D.28 imply
\[ r_c = \frac{1 - \beta (1 - \delta_c)}{\beta} \quad (D.29) \]
\[ r_h = (1 - \frac{\beta (1 - \delta_h)}{\beta} \quad (D.30) \]

The steady state value of inflation is assumed to be equal to 3.5 based on the inflation target of the Chinese government, then
\[ R = \frac{3}{\beta} \quad (D.31) \]
\[ w_c^{1-\alpha} = (1 - \alpha) a^{\frac{\alpha}{1-\alpha}} r_c^{\frac{-\alpha}{1-\alpha}} \quad (D.32) \]
\[ IH = \delta_{ih} h \quad (D.33) \]
\[
\lambda_c = \frac{1}{c} \quad (D.34)
\]

\[
\lambda_c q(1 - \beta(1 - \delta_{ih})) = \frac{1}{\bar{h}} \quad (D.35)
\]

\[
\frac{qIh(1 - \beta(1 - \delta_{ih}))}{\delta_{ih}} = c \quad (D.36)
\]

\[
\frac{ic}{y} = \frac{\delta_{c}k_c}{\bar{c}} = \frac{\alpha}{r_c} \delta_c \quad (D.37)
\]

\[
\frac{ih}{y} = \frac{\delta_{h}k_h}{\bar{h}} = \frac{\mu_hqIh}{r_hy} \quad (D.35)
\]

\[
1 = \frac{c}{y} + \frac{ic}{y} + \frac{ih}{y} \quad (D.36)
\]

\[
1 = \frac{qIh(1 - \beta(1 - \delta_{ih}))}{\delta_{ih}y} + \frac{\alpha}{r_c} \delta_c + \frac{\mu_hqIh}{r_hy} \quad (D.36)
\]

\[
\left(1 - \frac{\alpha}{r_c} \delta_c \right) = \frac{qIh}{y} \left(1 - \frac{\beta(1 - \delta_{ih})}{\delta_{ih}} + \frac{\mu_h}{r_h} \right) \quad (D.37)
\]

Let \(1 - \frac{\alpha}{r_c} \delta_c\) = A and \(\frac{1 - \beta(1 - \delta_{ih})}{\delta_{ih}} + \frac{\mu_h}{r_h}\) = B

\[
\left(\frac{n_c}{n_h}\right)^{1+\xi} = \frac{1 - \alpha}{1 - \mu_h - \mu_l} \frac{y}{qIh} \quad (D.38)
\]

Let \(\frac{1 - \alpha}{1 - \mu_h - \mu_l}\) = C and \(\frac{CB}{A} = D\)

So \(n_c = n_hD^{1+\xi}\) \( (D.38)\)

\[
\left(\frac{w_c \lambda_c}{\eta^{\xi}}\right)^{1+\xi} = n_c \quad (D.39)
\]

\[
y = \frac{w_c n_c}{1 - \alpha} \quad (D.40)
\]

\[
\frac{qIh}{y} = \frac{A}{B} \quad (D.41)
\]

\[
\lambda_c = \lambda_{ck} = \lambda_{hk} = c = \frac{qIh(1 - \beta(1 - \delta_{ih}))}{\delta_{h}} = \frac{w_c n_c A (1 - \beta(1 - \delta_{ih}))}{1 - \alpha B \delta_{h}} \quad (D.42)
\]
After setting land supply equal to 1, we have

\[ R_l = \mu_l q H \quad (D.43) \text{ and } \quad p_l = \frac{\beta}{1-\beta} R_l \quad (D.44) \]
Appendix E

LOG-LINEARIZED SYSTEM

Note, variables in this sector are all percentage deviations from their steady state values.

Law of capital motion for consumption production

\[ k_{c,t} = (1 - \delta_c)k_{c,t-1} + \delta_c i_{c,t} + \delta_h \mu_t \quad (E.1) \]

Law of capital motion for housing production

\[ k_{h,t} = (1 - \delta_h)k_{h,t-1} + \delta_h i_{h,t} \quad (E.2) \]

Production function consumption sector

\[ y_t = A_{c,t} + \alpha u_{c,t} + a k_{c,t-1} + (1 - \alpha) n_{c,t} \quad (E.3) \]

Cost minimization problem of intermediate good producer

\[ X_t = \alpha r_{c,t} + (1 - \alpha) w_{c,t} - A_{c,t} - u_{c,t} \quad (E.4) \]

New Keynesian Phillips Curve

\[ \pi_t = \frac{t_\pi}{1 + \beta t_\pi} \pi_{t-1} + \frac{\beta}{1 + \beta t_\pi} E_t \pi_{t+1} + \frac{(1 + \theta_\pi \beta)(1 - \theta_\pi)}{\theta_\pi(1 + \beta \theta_\pi)} X_t - \lambda_{p,t} \quad (E.5) \]

Housing production function

\[ i h_t = g_t + \mu_h u_{h,t} + \mu_h k_{h,t-1} + (1 - \mu_h - \mu_i) n_{h,t} \quad (E.6) \]

Monetary policy

\[ R_t = \rho_r R_{t-1} + (1 - \rho_r) \rho_\pi \pi_t + (1 - \rho_r) \rho_y y_t - (1 - \rho_r) \rho_y y_{t-1} + \omega_{r,t} - s_t \quad (E.7) \]

Resource constraint
\[ y_t = \frac{\bar{c}}{y^*} c_t + \frac{\bar{h}}{y^*} h_t + \frac{\bar{c}}{y^*} i_t + \alpha u_{c,t} \quad (E.8) \]

Housing market equilibrium

\[ IH_t = \delta h_t - (1 - \delta h_t) h_{t-1} \quad (E.9) \]

Patient Household first order conditions

\[ \lambda_{c,t} = z_t + \frac{1 + \gamma^2}{(1 - \gamma)^2} c_t + \frac{\gamma}{(1 - \gamma)^2} c_{t+1} + \frac{\gamma}{(1 - \gamma)^2} c_{t-1} \quad (E.10) \]

\[ z_t + \theta_t = \frac{\lambda_{c,t}}{\delta_{ih} q_{IIH}} (\lambda_t + q_t + \mu_t + h_t) - \frac{\beta (1 - \delta_{ih})}{\delta_{ih} q_{IIH}} \lambda_{c,t} q_{IIH} (\lambda_{c,t} + q_{t+1} + h_t) \quad (E.11) \]

\[ w_{c,t} = z_t + \psi_t - \lambda_{c,t} + \xi n_{c,t} + (\eta - \xi) \left( \frac{n_{c,t+1} + \xi}{n_{c,t} + \xi} \right) \frac{\eta - 2\xi - 1}{1 + \xi} \lambda_{c,t} q_{IIH} (\lambda_{c,t} + q_{t+1} + h_t) \quad (E.12) \]

\[ w_{h,t} = z_t + \psi_t - \lambda_{c,t} + \xi n_{h,t} + (\eta - \xi) \left( \frac{n_{h,t+1} + \xi}{n_{h,t} + \xi} \right) \frac{\eta - 2\xi - 1}{1 + \xi} \lambda_{c,t} q_{IIH} (\lambda_{c,t} + q_{t+1} + h_t) \quad (E.13) \]

\[ \bar{r}_c (\lambda_{c,t+1} + r_{c,t+1} + u_{c,t+1}) - \bar{r}_c u_{c,t+1} = \lambda_{ck,t} - \beta (1 - \delta_c) \lambda_{ck,t+1} \quad (E.14) \]

\[ \bar{r}_h (\lambda_{h,t+1} + r_{h,t+1} + u_{h,t+1}) - \bar{r}_h u_{h,t+1} = \lambda_{hk,t} - \beta (1 - \delta_h) \lambda_{hk,t+1} \quad (E.15) \]

\[ \lambda_{c,t} = \lambda_{c,t+1} + R_t - \pi_{t+1} \quad (E.16) \]

\[ p_t (\lambda_{c,t} + p_{t,t}) = \beta \bar{R}_t R_{t+1} + \beta \bar{p}_t p_{t,t+1} \quad (E.17) \]

\[ r_{c,t} = \frac{a''(u_{c})}{a'(u_{c})} u_{c,t} \quad (E.18) \]

\[ r_{h,t} = \frac{a''(u_{h})}{a'(u_{h})} u_{h,t} \quad (E.19) \]

\[ \lambda_{c,t} = \lambda_{ck,t} + s''(1)i_{c,t-1} - (1 + \beta) s''(1)i_{c,t} + \beta s''(1)i_{c,t+1} \quad (E.20) \]
\[ \lambda_{h,t} = \lambda_{h,t} + s''(1)i_{h,t-1} - (1 + \beta)s''(1)i_{h,t} + \beta s''(1)i_{h,t+1} \quad (E.21) \]

Housing firm’s first order conditions

\[ q_t + IH_t - k_{h,t-1} = r_{h,t} + u_{h,t} \quad (E.22) \]

\[ q_t + IH_t = R_{t,t} \quad (E.23) \]

\[ q_t + IH_t - n_{h,t} = w_{h,t} \quad (E.24) \]
Appendix F

THE VOLATILITY OF SELECTED VARIABLES

Figure F.1: Approximated GDP Volatility, 2000m1-2013m12.

Notes: There is no monthly GDP data available. This graph simulates the monthly GDP growth volatility using the quarterly GDP data. The quarterly GDP is published by the National Bureau of Statistics of China. The raw data of GDP is divided by population, transformed into real terms by being divided by the inflation rate, seasonally adjusted, and transformed again to log-differenced values. To obtain the monthly GDP growth volatility, a spline interpolation method executed by Eviews 8 is applied. The vertical axis measures the absolute deviation from the trend and the horizontal axis indicates the time horizon.
Figure F.2  Real Consumption Volatility, 2000m1-2013m12.
Notes: The raw data of consumption are divided by population, transformed into real terms by being divided by the inflation rate, seasonally adjusted, and transformed again to log-differenced values. The vertical axis measures the absolute deviation from the trend and the horizontal axis indicates the time horizon.

Figure F.3:  Real Housing Investment Volatility, 2000m1-2013m12.
Notes: The raw data of housing fixed investment are divided by population, transformed into real terms by being divided by the inflation rate, seasonally adjusted, and transformed again to log-differenced values. The vertical axis measures the absolute deviation from the trend and the horizontal axis indicates the time horizon.
Figure F.4: Real Non-housing Investment Volatility, 2000m1-2013m12.  
*Notes:* The raw data of non-housing fixed investment are divided by population, transformed into real terms by being divided by the inflation rate, seasonally adjusted, and transformed again to log-differenced values. The vertical axis measures the absolute deviation from the trend and the horizontal axis indicates the time horizon.

Figure F.5: Real Inflation Volatility, 2000-2013.  
*Notes:* The data of inflation are demeaned. The vertical axis measures the absolute deviation from the trend and the horizontal axis indicates the time horizon.
Figure F.6: GDP, Housing Investment, Non-housing Investment and Housing Price Volatility, 2000m1-2013m12.

Notes: The data series used to generate this figure are the same ones used for Figure F.1, F.3, F.4 and Figure 1.3. The vertical axis measures the absolute deviation from the trend and the horizontal axis indicates the time horizon.
Appendix G

SIMULATIONS OF THE POSTERIOR WITH THE METROPOLIS-HASTING ALGORITHM

The following graphs report the prior and posterior distributions of selected structural parameters in the study. The posterior densities are based on the 5000 draws from Metropolis-Hasting algorithm. Grey lines indicate the prior distributions while bold lines the posterior distributions.

Figure G.1: Simulations of Structural Parameters.
Figure G.1 Continued
Figure G.1 Continued
Appendix H

PRIOR AND POSTERIOR DISTRIBUTIONS OF STRUCTURAL PARAMETERS

Table H.1: Prior and Posterior Distribution of the Structural Parameters.

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<th>Prior SD</th>
<th>Posterior Mean</th>
<th>Posterior SD</th>
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**Note:** 90% Highest Posterior Density interval is the one with the smallest interval width among all credible intervals that contain 90 per cent of posterior probability mass.
Table H.2: Prior and Posterior Distribution of the Shock Processes.

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Note: p-value of a chi squared test for equality of means in the beginning and the end of MCMC chain. For example, a value above 0.05 indicates the null hypothesis of equal means of parameters and thus convergence cannot be rejected at the 5 per cent level.
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<td>AR coefficient for investment-specific technology shock</td>
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Note: p-value of a chi squared test for equality of means in the beginning and the end of MCMC chain. For example, a value above 0.05 indicates the null hypothesis of equal means of parameters and thus convergence cannot be rejected at the 5 per cent level.
Appendix I

IMPULSE REPONSES OF SELECTED VARIABLES TO OTHOGONALIZED SHOCKS

Figure I.1: Impulse responses to a Consumption Good Productivity Shock.

*Notes:* The vertical axis measures absolute deviation from the steady state. The shaded areas are the 95 per cent error bands.
Figure I.2: Impulse Response to a Housing Preference Shock.  
*Notes:* The vertical axis measures absolute deviation from the steady state. The shaded areas are the 95 per cent error bands.

Figure I.3: Impulse Response to an Investment-Specific Technology Shock to the Capital in Consumption Production Sector.  
*Notes:* The vertical axis measures absolute deviation from the steady state. The shaded areas are the 95 per cent error bands.
Figure I.4: Impulse Response to a Housing Bubble Shock. 
*Notes:* The vertical axis measures absolute deviation from the steady state. The shaded areas are the 95 per cent error bands.

Figure I.5: Impulse Response to a Labor Supply Shock. 
*Notes:* The vertical axis measures absolute deviation from the steady state. The shaded areas are the 95 per cent error bands.
Figure I.6: Impulse Response to a Monetary Policy Shock.
*Notes:* The vertical axis measures absolute deviation from the steady state. The shaded areas are the 95 per cent error bands.

Figure I.7: Impulse Response to a Mark-up Shock.
*Notes:* The vertical axis measures absolute deviation from the steady state. The shaded areas are the 95 per cent error bands.
Figure I.8: Impulse Response to an Inter-temporal Preference Shock.
*Notes:* The vertical axis measures absolute deviation from the steady state. The shaded areas are the 95 per cent error bands.

Figure I.9: Impulse Response to a Credit Shock.
*Notes:* The vertical axis measures absolute deviation from the steady state. The shaded areas are the 95 per cent error bands.
Figure I.10: Impulse Response to a Government Policy Shock to Housing Supply. 
Notes: The vertical axis measures absolute deviation from the steady state. The 
shaded areas are the 95 per cent error bands.
### MODEL ROBUSTNESS ANALYSIS

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Notes: The table summarizes the posterior modes of structural parameters under different model settings.
Appendix K

THE YEAR-TO-YEAR GROWTH RATE OF HOUSING INVESTMENT IN THE DIFFERENT SOURCE CATEGORIES

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