The impact of monetary policy on China’s house prices

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Abstract

This paper constructs two Dynamic Stochastic General Equilibrium (DSGE) models: a New Keynesian model and a model that incorporates Chinese characteristic monetary policy. The latter includes multiple tools, adjustments to the benchmark interest rates, changes to the reserve requirement ratios, and the imposition of lending rate floors and deposit ceilings by the central bank. The fitness of these models is evaluated and estimated using the indirect inference method. This analysis examines transmission mechanisms, effectiveness, and impact of monetary policies on the housing market. Additionally, the primary causes of housing dynamics are explored. The results indicate that the model with specific Chinese monetary policies fits the data better. Both models reveal that housing demand shocks dominate housing price dynamics. A comparative analysis shows the inclusion of specific monetary policies provides more effective regulation of house prices. Welfare analysis reveals that the system of restriction on interest rates leads to economic instability. Maintaining control over housing prices comes at the expense of economic stability.

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1. Chapter 1

Introduction

1.1 Background

Economists and government authorities have consistently been very interested in the housing market in China. It has a significant impact on the country's economy. Furthermore, property prices are a major concern for Chinese citizens. In contrast to the well-established housing markets in Western countries, China's housing market has developed over a much shorter timeframe. China's initiation into the real estate market came later than that of other developed countries. In the centrally planned economy in China, from 1949 to 1978, there was no housing market. The state entirely owns real estate and land, and houses are distributed by Work Unite, which is a state-owned company or government sector where households work, and households have no housing property rights. The government played a major role in building houses and distributing houses. The work unit allocates the housing to the employees, who only pay a small amount of rent. Housing construction funds are 90% borne by the government and a small amount by the work units. Following the Reform and Opening-Up of 1978, China has undergone a transition from a planned economy to a market economy. In 1980, there was a small-sized housing market, and commercial housing construction began in some cities. This was the first time that houses were defined as commodities. In 1998, the welfare housing distribution system was abolished, heralding the full initiation of the housing market in China.

The period from 1980 to 1998 witnessed a transformation from a planned housing allocation to a liberalization of home buying. The central banking system also saw gradual enhancements during this period. Prior to the Reform and Opening-Up, the People's Bank of China (PBoC) acted as the central bank while also operating as the only commercial bank. Its responsibilities include formulating and implementing monetary policy and managing a range of banking activities, like lending and saving. Since 1979, the four major state-owned banks have been successively reinstated and operationalized. The State Council of China stated in 1983 that the People's Bank of China would be dedicated exclusively to the role of the national central bank. Starting in 1994, four major state-owned banks transitioned into purely commercial banks, contributing to the evolution of a multi-level banking system.

The People's Bank of China was legally designated as the central bank in 1995. Under the leadership of the State Council, PBoC possesses the authority to formulate and execute monetary policy, ensure financial stability, and offer financial services. Additionally, PBoC fulfils its regulatory and supervisory responsibilities. China's banking system is structured with the central bank as the primary regulator, while commercial banks directly engage in transactions with enterprises and households. The People's Bank of China does not offer deposit or loan services; its primary role is macroeconomic management. PBoC has been tasked with policymaking, banking regulation, and supervision in alignment with economic targets set by the State Council. The establishment of a comprehensive banking framework provides the groundwork for managing the economy and controlling the housing market.

The housing market is vital to China’s economy. The real estate sector has emerged as a crucial pillar of the national economy. There has been rapid development in the real estate sector since the cancellation of the welfare housing distribution. The contribution of the real estate industry to GDP, measured by its value-added, has risen from 4.1% in 2000 to 7.3% in

2020. This proportion exceeds 20% when considering industries closely connected to real estate. Besides directly contributing to GDP, the real estate sector also stimulates the development of related industries such as construction, furniture, decoration, and finance, playing an important role in driving economic growth. Han et al. (2021) indicate that a wide range of industries can be positively influenced by the growth momentum of the housing sector, especially financial industries. Besides, as Ren et al. (2014) mention, the development of the housing sector increases job opportunities, thereby stimulating housing purchases.

Another factor contributing to the significance of the housing market is its impact on social stability. In traditional Chinese society, owning a house is the true meaning of having a home. This idea has been passed down over thousands of years and still influences the way the Chinese view houses nowadays. For most Chinese people, a house can give them a sense of security. For many individuals, owning a house has become indispensable for starting a family. Besides, with the growing migration of households from rural to urban areas, there is an increasing demand for housing. Therefore, housing prices have become a prominent topic in society. Many individuals see owning a house as an essential requirement, particularly those who are getting married or migrating to urban areas, especially low-income families concerned about their ability to afford a home amidst increasing house prices. Moreover, the rapid development of the housing market has attracted numerous investors who are worried about potential decreases in housing prices. The study of Wrenn, Yi and Zhang (2019) demonstrate that a 1 per cent rise in house prices is accompanied by a 0.31 per cent decrease in initial marriage rates. It is also supported by Su et al. (2020), who added that homeownership is a significant factor in marriage in China, and marriage is considered incomplete without housing. Therefore, ensuring the healthy and stable growth of the real estate industry is a longstanding goal in China.

China's housing market, due to its rapid expansion, has faced issues including an overheated market and fluctuating house prices. In response, the government has consistently implemented regulatory policies aimed at stabilizing the market and mitigating the risks of bubbles and financial instability. House prices are a direct reflection of housing supply and demand, economic conditions, and policy instruments, making them an important indicator for analyzing the housing market. Figure 1.1 displays the Real Residential Commercial Property Prices Index in China from 2000 to 2020. Over this period, house prices have generally risen, with some fluctuations. The period from 2000 to 2003 experienced relative stability in housing prices, with minor fluctuations. Prices then increased between 2004 and 2007, followed by a sharp drop in 2008. A rebound occurred in 2009, exceeding the levels recorded in 2008. Between 2010 and 2011, housing prices exhibited a downward trend. From 2012 to 2015, prices exhibited repeated ups and downs, with the peak in 2013 slightly higher than in 2009. After 2015, prices continued to rise. The impact of COVID-19 caused a decline in 2019, but prices returned to an upward trend at the end of 2020.

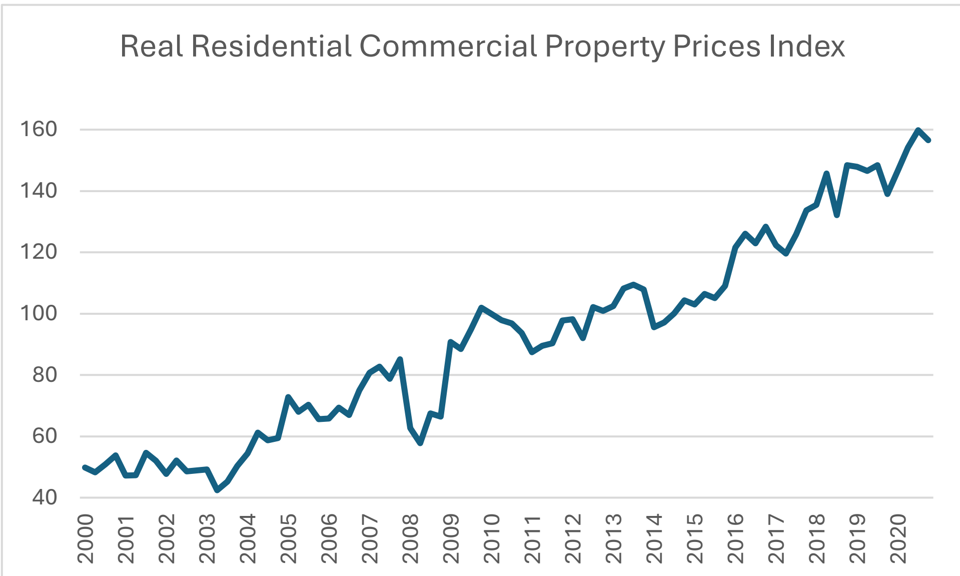


Figure 1.1 Real sales price index of residential commercial properties

Source: National Bureau of statistics of China

Deflation-adjusted housing prices. Baseline adjustment to 2010Q1=100

Many policies have been implemented to regulate the housing market, such as adjustments to the down payment ratio, mortgage ratio, and monetary policy. Monetary policies are key instruments that affect the housing market. The main monetary policy tools that the government used to intervene in the housing market are fine-tuning the reserve requirement ratio, benchmark interest rates and loan quantity. There has been a close correlation between monetary policies and house prices from 2003 to 2021. The reserve requirement ratio defines the minimum proportion of deposits that a commercial bank is required to hold as reserves. Figure 1.2 displays that this ratio has been adjusted very frequently.

Figure 1.2 shows residential commercial properties prices index and reserve requirement ratio. We can see that the change in the reserve requirement ratio highly affected house prices. More specifically, the reserve requirement ratio decreased in 2008 and 2009, which corresponded to an increase in house prices. An increase in the ratio was accompanied by a decrease in housing prices between 2010 and 2011. After 2015, a continuous decrease in the reserve ratio was accompanied by an increase in housing prices. Similar to the reserve requirement ratio, the data on benchmark interest rates also show a strong correlation with house prices. The benchmark lending rate decreased in 2008 and remained low in 2009, during which there was an increase in house prices. A rising lending rate in 2010 corresponded to a decline in house prices. In 2015, a decline in the lending rate was accompanied by continued rising house prices (Figure 1.3).

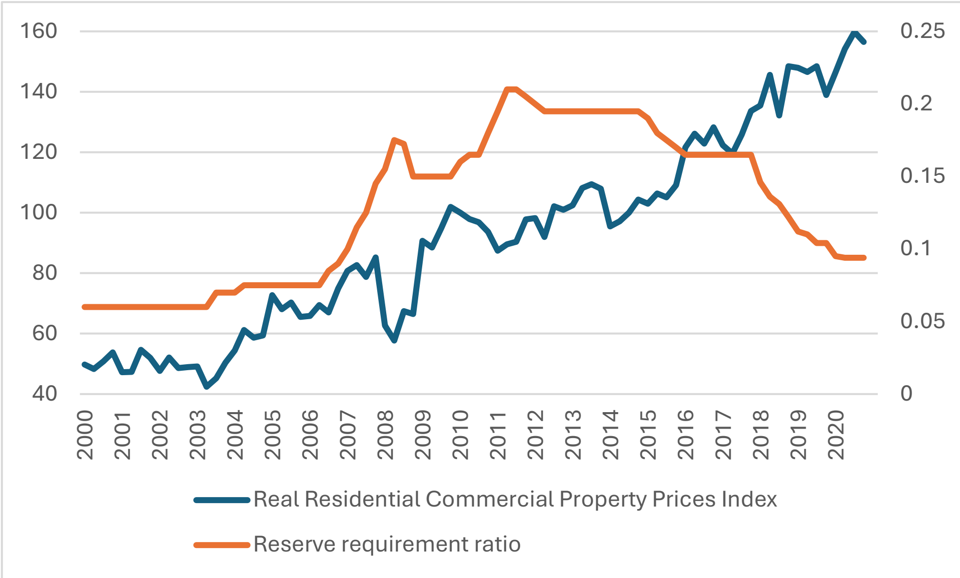


Figure 1.2 Reserve requirement ratio

Source: The Center for Quantitative Economic Research (CQER) of the Federal Reserve Bank of Atlanta and National Bureau of statistics of China

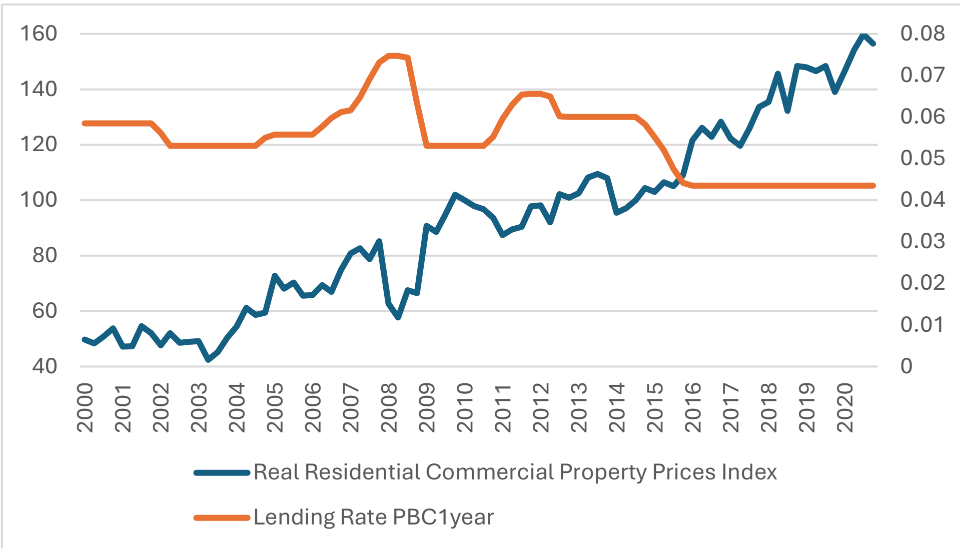


Figure 1.3 Benchmark lending interest rate

Source: The Center for Quantitative Economic Research (CQER) of the Federal Reserve Bank of Atlanta and National Bureau of statistics of China

Another distinctive feature of China's monetary policy is its ‘semi-market’ interest rate system. The PBoC sets the benchmark deposit rate and the benchmark lending rate, which serve as guidelines for commercial banks to adjust their own lending and deposit rates. Figure 1.4 displays the benchmark lending rate and deposit rates. Specifically, commercial banks can adjust their interest rates by floating them relative to benchmark rates, but the central bank imposes restrictions on the range of this floating. The restrictions on the maximum lending rates and minimum deposit rates, which were tied to the benchmark lending rate, were removed in 2004. However, restrictions on the lower limit for lending rates and the upper limit for deposit rates remained. Commercial banks are not allowed to lend at below 90% of the benchmark lending rate or offer deposit rates above the benchmark deposit rate. In 2013 and 2015, the central bank announced the removal of these remaining restrictions. Even without official restrictions, these constraints persisted in the regulation of interest rates, continuing to influence the behaviour of commercial banks. Tan et al. 2016 indicate that the removal of the last restriction on interest rates is not the end of the liberation of interest rates. Implicit regulations still exist on the lower limit of lending rates and the upper limit of deposit rates.

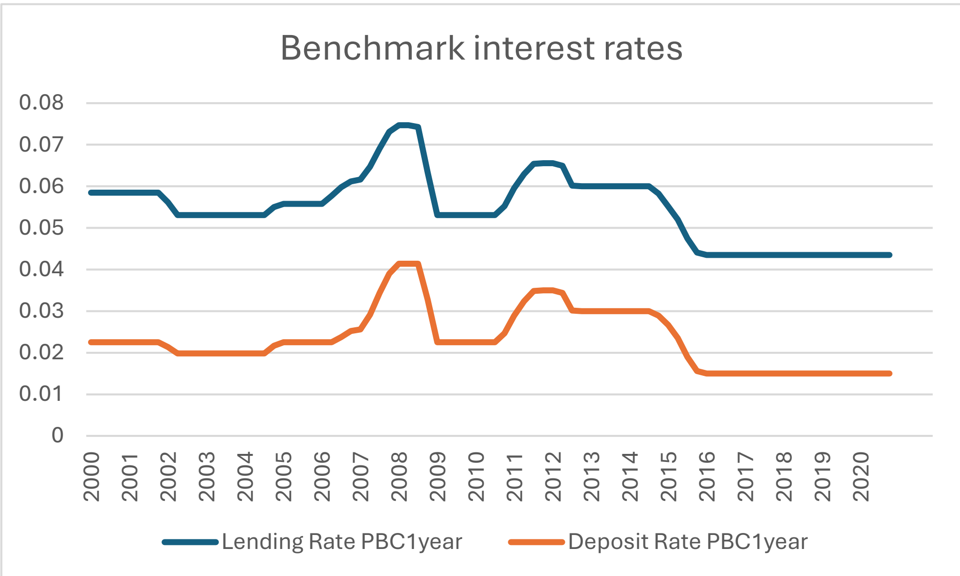


Figure 1.4 Benchmark interest rates

Source: The Center for Quantitative Economic Research (CQER) of the Federal Reserve Bank of Atlanta

The housing market's development in China has been characterized by a delayed start, rapid but unstable growth, and frequent government intervention. The real estate industry significantly contributes to the economy, and house prices have garnered considerable attention. Therefore, achieving healthy and stable growth in the housing market is crucial for maintaining a stable society and a healthy economic environment. Enhancing the banking system aids in regulating the housing market. Monetary policy is one of the instruments used to influence the housing market, particularly through frequent adjustments of the reserve requirement ratio and benchmark interest rates. Additionally, the benchmark interest rates, combined with the allowable range of fluctuation, determine the retail lending and deposit rates. The central bank's long-term goal is interest rate liberalization, starting from a regulated interest rate framework. Throughout this process, restrictions on lending and deposit rates have been gradually eliminated. The longest period was marked by the enforcement of a ceiling on deposit rates and a floor on lending rates.

1.2 Motivation

The housing market has become an increasingly significant contributor to China's economic growth and a pillar industry of the national economy. The sharp rise and fall in housing prices have had a negative impact on financial and economic development. Ensuring the healthy development of the housing market is crucial for both the national economy and social stability. Property prices, as a key indicator of the housing market, have received widespread attention across various sectors of society. There is also a high level of concern about house prices for society. Both high and low house prices will cause social anxiety. Higher property prices are affecting people's marriage and birth rates in China. Yin and Su (2021) suggest that the government should regulate the housing market to reduce the family burden of excessive residential property prices, which negatively impact fertility behaviour. Additionally, Clark et al. (2020), using data from 2013 and 2017 in China, find that a 1 per cent rise in house prices results in about a 0.94 percentage point decline in the probability of having a child.

One of my purposes is to analyze the transmission, effectiveness and impact of specific monetary policies on house prices. From the database, it shows that monetary policies affect housing prices, but there is a gap in how monetary policy influences housing prices. Knowing the inner transmission mechanism is helpful for further monetary policymaking and better controlling future housing prices. As an emerging market economy, China has experienced rapid economic growth and dynamic financial markets. Compared to mature economies, its monetary policy tends to be relatively conservative. The main monetary policy instruments are the reserve requirement ratio, and benchmark interest rate and restrictions on the interest rates. The restrictions on the interest rates are the ceiling on deposit rate and floor on lending rate, named 'semi-market' interest rate system in this thesis. These monetary policy instruments make the Chinese characteristic monetary policy. In the thesis, these monetary policies will be considered. Historical data on residential property prices individually show a close relationship between these monetary policies and housing prices.

Secondly, I'm interested in making a theoretical economic model that includes those Chinese characteristic monetary policies and the housing sector. There are many kinds of literature that study monetary policy and housing prices. Those studies mainly focus on the different types of monetary policy, quantity-based monetary policy type or price-based monetary policy. Few papers mentioned specific monetary policy instruments. The ability of the models to fit the data is also a key focus of this thesis. Two models are analyzed: the first employs a general Taylor rule monetary policy and serves as the benchmark model, while the second builds on this benchmark by incorporating

Chinese-specific monetary instruments. In the second model, a banking sector will be incorporated to simulate the behavior of commercial banks in China in response to adjustments in the reserve requirement ratio and restrictions on interest rates imposed by the PBoC. The thesis will compare the capacity of the two models to fit the data behaviour. It will also discuss and compare the transmission mechanism and impact of monetary policy based on these models.

This thesis also applies welfare analysis to examine the impact of different monetary policies on the economy. Specifically, the analysis compares the standard Taylor rule monetary policy with a monetary policy incorporating Chinese characteristics. The welfare effects of these two monetary policies are compared to assess their relative impact.

In summary, this thesis addresses two primary objectives: constructing an economic model that incorporates specific monetary policies and investigating the impact of monetary policy on China's housing market. It compares the fitness of two models: one based on the Taylor rule and the other integrating a 'semi-market' interest rate system and reserve requirement ratio. The welfare effects of these two models are also compared.

1.3 Methodology

To solve the questions described above, this thesis builds Dynamic Stochastic Equilibrium (DSGE) models and uses the indirect inference method to estimate and evaluate the structural model. In the specific model building, two models are constructed. The first is a benchmark model, which is a New Keynesian DSGE model. The second model enriches the benchmark by incorporating a private banking sector. These two models are both based on Iacoviello (2005) and Iacoviello and Neri (2010), which include the housing sector. This thesis removes collateral constraints from the DSGE model in contrast to Iacoviello's approach. This adjustment is based on the finding that a model incorporating housing collateral fails to explain the economic conditions in China, as supported by the analysis of Gai, Minford, and Ou (2020). In the second DSGE model, the structure of the banking system incorporates unique Chinese characteristics, following the model proposed by Chen, Funke, and Paetz (2012). Specifically, the model of the banking system in China is based on the work of He and Wang (2012) and Chen et al. (2013). The implementation of the banking sector in the DSGE model adheres to the framework established by Gerali et al. (2010). To align with the objectives of this thesis, factors such as the reserve requirement ratio, lending rate floor, and deposit rate ceiling are integrated into the banking sector.

To evaluate the fitness of models with respect to real data, the indirect inference evaluation has been applied. The indirect inference evaluation used in this thesis is introduced by Minford et al. (2009). The fundamental principle of indirect inference is that the simulated data generated by a data-fitted theoretical model should replicate the performance characteristics of the real data. The performance of data is evaluated using coefficients from an auxiliary model. The VAR model is utilized as the auxiliary model, following the approach by Meenagh et al. (2012), which operates independently of the theoretical model.

The criterion used is the Wald statistic, which compares whether the joint set of coefficients derived from real data aligns with those obtained from simulated data generated by the theoretical model. A higher Wald statistic indicates greater discrepancies between the performances of real and simulated data from the DSGE model. Additionally, the indirect inference method is employed for model estimation. The primary objective is to search for the structural model parameters that best minimize the criterion. The Indirect estimation approach has been widely utilized in estimating structural models, as demonstrated in studies such as Gourieroux et al. (1993) and Gourieroux and Monfort (1997). Both the benchmark model and the model incorporating specific monetary policies will undergo testing and estimation using this indirect inference method.

1.4 Finding and contribution

For the data fitness, the calibrated benchmark model and the model with the Chinese characteristic monetary policy are rejected by the data. After estimating, these two models all pass the test, but the model has lending interest floor and deposit interest rate ceilings and considering the reserve requirement ratio explains the data better.

Both historical decomposition and variance decomposition analysis in two models show the main cause of the fluctuations in housing prices is housing demand shock. The other finding is that the model with ‘semi-market’ can help cool down the housing market. The ‘semi-market’ interest rate system allows the model to set higher lending rates. Increased housing demand leads to more house construction, resulting in higher bank loans. This raises housing production costs, driving up housing prices, which effectively cools the housing market. The welfare analysis shows that the model with a ‘semi-market’ interest rate system exhibits greater instability than the benchmark model.

As for the contribution of this thesis, aside from constructing a New Keynesian dynamic stochastic general equilibrium (DSGE) model with Chinese-specific monetary policy and a housing sector, several new findings are also presented. Firstly, the model with Chinese-specific monetary policy fits the data better and can better control house prices under high housing demand. The second one is that welfare increases a lot when the Chinese-specific monetary policy is replaced with the standard Taylor rule, for the output is much more stable. The trade-off for controlling house prices is instability in the economy.

1.5 Thesis Structure

The following is the structure of the rest of this. Chapter 2 describes the literature review. Chapter 3 explores the impact of monetary policy on housing prices by building a New Keynesian model, where Taylor's rule controls the behavior of interest rates. This chapter also details the method of indirect inference evaluation and estimation, with the model tested and estimated before the analysis. Chapter 4 focuses on the construction of a DSGE model that incorporates China's characteristic monetary policy. The model's capacity for fitting data has also been tested and estimated. The comparison of the two models is also in Chapter 4. The welfare analysis is in Chapter 5. Chapter 6 concludes all the research findings and suggests further research on this topic.

2. Chapter 2

Literature review

2.1 Introduction

The contribution of the real estate industry makes up a significant proportion of China's GDP. The development of other industries, such as the construction industry, service industry, and financial sector, relies highly on the real estate industry. Over the past few decades, housing prices have experienced several rapid increases. Housing prices attract a lot of attention in China, and the sharp change in house prices may lead to a social disability. The Chinese government has intervened in the housing market using various instruments. The government in China frequently introduces monetary and non-monetary policies to intervene in house prices, like fine-tuning loan interest rates, lending quantity and down payment ratio, and carrying out home-buying restrictions. The monetary policy, as one of the important tools in macroeconomic regulation, directly affects the behaviour of agents in the economy. The non-monetary factors of down payment ratio and home buying restrictions will not be considered in the thesis.

The impact of monetary policy on housing prices is the focus of this thesis. The conduct of monetary policy in China is more complicated than in developed economies. There are more restrictions and constraints, like the regulated interest rates. The fluctuation in interest rates may lead to turbulence in the housing market by influencing the decisions of households and firms. This chapter reviews the literature on the housing market, focusing on housing price fluctuations and the interplay between housing prices and monetary policy. The literature on model construction related to Chinese characteristic monetary policy will also be discussed.

The structure of this chapter shows the following: section 2.2 reviews the different features of monetary policy in advanced economies and China. Section 2.3 focuses on the literature review in both empirical and theoretical analyses of various economies. Section 2.4 explores the model construction of Chinese characteristic monetary policy. Section 2.5 concludes.

2.2 Review of different features of Monetary Policy in advanced economy and China

For monetary policy, both advanced and emerging economies like China affect the interest rate to adjust the economy's behaviour. The Federal Reserve decreases or increases fund rates by purchasing or selling bonds, which affects the amount of money in the economy. The European Central Bank (ECB) adjusts the loan and deposit rates between the ECB and banks to affect the financial cost of banks and further affect the behaviour of the economy. Compared to the advanced economies, the monetary policy in China has its specific features, which combine the traditional monetary policy tools like open market operation and unconventional ones like the restriction of interest rates due to its unique economic structure and developmental stage. Specifically, the benchmark interest rates set by the central bank are guidelines for commercial banks' deposit and lending interest operations. Commercial banks set their lending rate and deposit rates based on the benchmark interest rates, and there are some restrictions on their lending rate and deposit rate, like the ceiling on deposit rate and floor on lending rate. For the open market operation, the main purpose is to ensure that interbank interest rates remain within a range deemed reasonable by the central bank. In this way, the market interest rates fluctuate around the benchmark rates, further supporting the transmission of the benchmark interest rates. The other feature is the frequent adjustment of the reserve requirement ratio. These adjustments directly affect the liquidity in the banking system.

As shown above, we can see the different properties of monetary policy between advanced economies and China. Monetary policy in advanced economies is based on market-based instruments like open market operations or ECB interest rates. The central bank, like the Federal Reserve and the ECB, adjusts the federal funds rates and main refinancing rates to affect the interest rate in the economy, but they do not directly set the interest rate for various deposits and loans. The monetary policy in China is the combination of market-based tools like open market operation and unconventional tools like the direct restriction of retail lending rate and deposit rate, as well as adjustment of reserve ratio, which is not used in advanced economies. The monetary policy in China is more regulated, and the main reason is that, as a developing economy, there are huge differences in economic structure, financial market maturity, and institutional environment compared to those in an advanced economies. Besides, the financial market is less market-driven compared to the US and Europe. The PBoC tends to exercise more direct control over interest rates and credit growth to prevent market volatility from adversely affecting the economy. The regulation of interest rates has transitioned from strict administrative controls to partly market-based pricing. In the 1990s, China’s deposit and lending rates were set directly by the PBOC. In 1996, the lending rates were allowed to float within prescribed limits. From 2000 to now, the limits have gradually been opened to the remaining ceiling of the deposit rate and floor of the lending rate. Even though the final limits of lending rate (the floor) and deposit rate (the ceiling) were officially removed in 2013 and 2015, respectively, some degree of “implicit floor” and “implicit ceiling” still exists in practice. These implicit constraints are mainly manifested through market mechanisms, guidance from regulators, and banks’ risk management strategies.

Monetary Policy and the Real Estate Market

Monetary policy influences the housing market in both advanced economies and China. In advanced economies, the main monetary policy is to influence the market interest rate, which affects the housing market. In 2008, following the financial crisis, the Federal Reserve purchased a large number of mortgage-backed securities (MBS) through massive quantitative easing, helping to stabilize and drive the recovery of the housing market. During the COVID period, from 2020 to 2021, the Federal Reserve lowered the funds rate near zero and initiated quantitative easing, which helped keep mortgage rates low and contributed to a booming housing market. The housing prices in the eurozone countries have also been affected by the low interest rate policy. Since 2014, the ECB's negative interest rate policy has helped to lower mortgage rates, particularly in countries such as the Netherlands, which has driven up house prices. While the policy has stimulated the property market overall, the impact has varied across countries and regions. The empirical study of Nocera and Roma (2018) finds that housing prices play a crucial role in the monetary policy transmission and emphasize the heterogenous responses of house prices in the eurozone. Monetary policy has significantly contributed to the increase in house prices in Ireland and Spain. The effects of monetary policy differ from 0.4% in Germany to 3% in Spain, according to the historical decomposition analysis.

In China, the interest rates have also been influenced to affect the housing market. The adjustment of benchmark interest rates was frequent during the financial crisis in 2008. There were five times decreases in benchmark interest rates in 2008, leading to a decrease in lending rates. The reserve ratio was decreased five times between September 2008 and the beginning of 2009. The total decreased volume was 3 per cent. The decrease in lending rate and reserve ratios increases the liquidity in the market, resulting in a rapid rebound in the housing market and a rapid rise in property prices. During the Covid 19, from 2020 to 2023, the reserve ratios were decreased by 2.1 percentage points overall across six occasions. These adjustments have helped to stabilize the housing market, especially during the recovery stage after the pandemic.

In summarizing the monetary policy affecting the housing market in the US and European zones, the interest rate is the main tool. In China, the interest rate also plays a major role, but there are other tools, such as the reserve requirement ratio adjustment. Additionally, the regulation of interest rates may also affect the housing market. We now know the different features of monetary policy in advanced economies and China. The following is a review of domestic and foreign research on the influence of monetary policy on the real estate market.

2.3 Review of existing literature

2.31 Empirical

International Studies on Housing Markets

The housing market in developed countries is more mature than that in China, and there is a lot of literature that studies the sources of fluctuations in residential property prices in advanced economies. McDonald and Stokes (2015) use a factor-augmented vector autoregressive model to investigate the effect of monetary policy and fiscal policy on housing prices in the United States. The results show that the interest rate on adjustable-rate mortgages is the main cause of the housing price dynamics. McDonald and Stokes (2013) investigate the origin of the housing bubble in the aspect of monetary policy. They found that the housing price bubble is attributable to the low federal funds rate, which comes from the interest rate policy carried out by the Federal Reserve between 2001 and 2004. Caraiani et al. (2022) find that market sentiment has an impact on monetary transmission in the US. They use the Quantile Structural Vector Autoregressive (QSVAR) model, and the results display that under an optimistic market, there is a strong effect on reducing house price growth rate with a contractionary monetary policy.

The study of Fischer et al. (2021) focuses on finding the heterogeneous response of monetary policy in different regions using a factor-augmented vector autoregressive model. They found that there are regional variations in the housing market's sensitivity to interest rates. Regulatory environments and the elasticity of housing supply across different regions contribute to the heterogeneous responses. The research on the impact of monetary policy on house prices in several advanced countries has been investigated by Seyfried (2010), which indicates that monetary policy in the United States, Ireland and Spain was too loose. The policy conducted by the European Central Bank was appropriate for Germany and France but quite loose for Spain and Ireland. They also found that expansionary monetary policy has a significant effect on housing prices in the United States, Ireland, and Spain.

In other developing countries, the relationship between monetary policy and the housing market also has been investigated. Umar et al. (2019), applying the VAR model, collected data from 2011 to 2016 and found that tight monetary policy leads to a decline in housing prices in Pakistan. It is unidirectional for the relationship between house prices and monetary policy. The relationship between monetary policy and house prices has also been investigated in India. Naikoo, Ahmed and Ishtiaq (2021) apply the Autoregressive Distributive Lag (ARDL) model, using data from 2009 and 2018 found that about 13 per cent of the housing price fluctuation can be explained by monetary policy in ten months. Mallick (2011) uses the same method to find the causes of the growth of construction sector activities in India. The results show that commercial bank credit and gross income have a positive effect on construction activity in the long run.

Housing Bubble Evidence in China

Research has shown that a low federal funds rate contributed to housing price bubbles prior to the 2008 financial crisis in the United States (McDonald and Stokes, 2013). In China, concerns have arisen that the rapid growth in housing prices may be driven by speculative bubbles. Several studies investigate the existence of housing price bubbles across Chinese cities. Zhi et al. (2019) conduct a bubble diagnostic analysis across 35 cities using the Log-Periodic-Power-Law-Singularity (LPPLS) model and find that 10 cities exhibit positive bubble signals. They also suggest that the restriction policy in housing sales has proven effective in limiting excessive speculation since 2017. Li, Wei and Chiang (2020) use a recursive forward looking method, revealing that the number of cities with reported housing bubbles has risen continuously since 2013, starting to decline in 2017. Their results also suggest that tier 1 and tier 1.5 cities have a higher probability of housing bubbles. Lan (2014), applying cointegration analysis, finds no evidence of a housing price bubble at the national level but emphasises the important role of monetary policy on housing prices. Chen, Phillips and Shi (2023) employ the PSY procedure, which was originally developed by Phillips and coauthors (Phillips, Wu and Yu (2011); Phillips, Shi and Yu (2015)), to test housing price bubbles in 89 cities in China from 2005 to 2008 and find a common bubble in tier 1 and tier 2 cities from June 2007 to February 2008.

In addition to bubble detection, several studies investigate the mechanisms underlying the formation and propagation of speculative bubbles in China's housing market. Wang (2012) suggests that the Chinese government's policies have been the primary force behind the speculative behaviours in the housing market. Believing that low housing prices are detrimental to real estate development, the government accelerates urbanization, deliberately creates an aggregate supply gap and eases mortgage lending, thereby boosting the housing market. The rapid increase in housing prices subsequently attracts many speculative investors to enter the market, further pushing housing prices upward. Wang (2012) also notes that the persistence of speculative behaviour requires the housing price growth rate to remain above a minimum boundary. Shih, Li and Qin (2014) find that there are bubbles and affordability issues in most of the provinces in China, particularly in Beijing and Shanghai. These two cities are core areas for housing price spillovers in China, significantly affecting housing prices in neighbouring provinces. Yang et al. (2017) also mention that there is a significant spatial correlation between housing prices in different regions, particularly in eastern coastal provinces. Zhang et al. (2017) distinguish the rational and irrational bubbles, finding those irrational expectations play a key role in driving the housing bubble. They argue that government intervention effectively mitigates speculative behaviour. These two findings are also supported by Yu (2011). The empirical analysis of Arestis and Zhang (2020) shows that the housing market in Shanghai had an irrational bubble issue and monetary factors such as money supply and interest rates are the key elements for housing prices.

Marriage and Housing Markets in China

Some social factors closely link the housing market and marriage market. In Chinese tradition, it is customary for families to prepare 'must - have items' in anticipation of marriage (Wrenn, Yi and Zhang (2019)), which have transitioned from basic home appliances in earlier decades to cars and houses today. Moreover, in China, owning a house is essential for obtaining access to urban social welfare and public services, such as education and healthcare (Wen and Wallace (2019); Montgomery (2012)). Housing acts more like a status good in the Chinese marriage market. As Wei and Zhang (2011) argue, the current sex ratio imbalance has intensified competition in the marriage market, leading Chinese parents to increase their savings in preparation for purchasing houses to improve their sons' relative attractiveness. Wei, Zhang and Liu (2017) also find that families with a son in cities exhibiting greater sex ratio imbalance prefer more expensive and larger houses to increase competition in marriage market, which drives up housing prices.

Meanwhile, the fluctuations in the housing market influence marriage market dynamics. Wrenn, Yi and Zhang (2019) find that the increase in housing prices leads to a decrease in the initial marriage rate. Chang et al. (2024) indicate that the home purchase restriction policy, which primarily aims at reducing housing prices, inadvertently delays marriage entry among younger age groups for their ineligibility to buy homes. Cheng et al. (2025) suggest that higher housing prices contribute to delayed marriage for men due to financial pressure of homeownership, increasing the spousal age gap. Social factors and speculative bubbles significantly affect housing markets; however, this thesis specifically concentrates on monetary policy.

Monetary Policy and Housing Price

Similar to the findings in advanced economies, the empirical analysis in China also finds a close connection between house prices and monetary policy. Zhang, Hua and Zhao (2012) find the determinants of housing prices from many macroeconomic variables using the Nonlinear Auto-Regressive Moving Average with exogenous inputs (NARMAX) method combined with the Vector Error Correction Model (VECM). The results show that producer price, real effective exchange rate, mortgage rate and broad money supply explain the movement of housing prices in China from 1999 to 2010. Chen, Wei and Huang (2019) applied the VAR model with Granger causality tests, impulse response functions, and variance decompositions and found that there was a decline in the housing price growth rate due to the implementation of tight monetary policy in China. They also indicate that market-based short-term interest rates, namely the 7-day interbank offered rate in the thesis, are useful information for PBoC making monetary policy in controlling housing prices.

To investigate the effect of monetary policy on the house price growth rate in China, Xu and Chen (2012) consider the long-term benchmark loan rate, monetary supply (M2) and mortgage credit policy indicator in their regression model. The results show that easing monetary policy accelerates house price growth, while tight policy generally slows it down. Hot money flow has an impact on the money supply but no impact on house prices. They also suggest that the monetary policy is the main factor that changes the real house prices. Tan and Chen (2013) find that monetary policy can effectively regulate house prices. House prices occupy an important place in the transmission mechanism of Chinese monetary policy. They also emphasise that the house price index can be used to measure the effect of monetary policy, which provides a new perspective for policymakers to better understand and predict the effects of monetary policy.

Except for the monetary policy element, Zhang et al. (2011) also include other factors like income and demand, inflation or user cost, land price … seven factors in total and use the Nonlinear Auto Regressive Moving Average with Exogenous inputs model (NARMAX) on exploring the fluctuation of house prices. The factor of monetary policy they consider is monetary supply (M2) and an average of medium- and long-term mortgage rates. The NARMAX model can automatically identify the linear and nonlinear forms and appropriate lags of variables based on their statistical characteristics. They find that monetary policy is the key factor, and the other factors are producer price and real effective exchange rates in both linear and non-linear estimation. However, income is not significant, contrary to the conventional economic expectations. They also found that the NARMAX method has a very powerful performance in predicting future house prices.

Some articles consider monetary policy alongside other aspects, such as policy uncertainty and heterogeneity in different regions. Wang et al. (2020) also agree that the volatility of house prices stems from the monetary policy, but they further consider the factor of policy uncertainty using a logistic smooth transition vector autoregressive model. The empirical results indicate an asymmetric influence; specifically, easing monetary policy boosts the housing market, increasing house prices under a high policy uncertainty. However, a tight monetary policy makes it difficult to decrease house prices. The proxy of monetary policy in their model is the growth rate of money supply (M2) and benchmark interest rate.

Yang, Wu and Shen (2017) explore the effect of monetary policy on consumption and house prices from the perspective of a nation and region using the panel VAR model. There are five regional groups: tier-1, northern, eastern, middle, southern and western. The house prices in tier-1 cities are much higher. The house prices in each group are similar. They find that the impact of monetary policy differs in different groups. Specifically, monetary policy has a significant effect on consumption in the cities of the Middle South and West, while the impact on house prices is minimal. However, in tier-1 cities and eastern cities, house prices play an important role in the transmission of monetary policy, which is accompanied by less of an effect of monetary policy on consumption. The monetary policy in the model is 7-day CHIBOR or money supply (M2). Yu and Zhang (2019) also explore the heterogeneous characteristics of the housing market in China, grouping 101 cities into three tiers and analysing the effect of monetary policy on house prices in the level and volatility effect. The results indicate that house prices are more sensitive to the monetary policy in tier 1 cities. They also mention that housing demand in Tier 1 cities is more speculative, and monetary policy has a limited influence on investors’ behaviour.

Yin et al. (2020) use the continuous wavelet transform method to compare the impact of money supply (M2) and interest rates on house prices. The empirical results show a co-movement between housing prices and M2, with changes in M2 preceding those in housing prices. However, the movement between house prices and interest rates is not significant. The interest rate has a limited effect on house prices. The high interest rate has not been effective in cooling the housing market.

The majority of the research talks about the money supply and interest rate on house prices, and a small part considers the reserve requirement ratio. Yu and Zhang (2019) investigate how monetary policy influences both the level and volatility of housing prices in China. The proxies of monetary policy are commercial bank lending rate growth rate, benchmark lending rate, money supply (M2) and reserve requirement. They find that there is a positive relationship between house prices and banking lending growth, inflation and money supply and a negative relationship with reserve ratio and benchmark lending rate in the long run. For the volatility effect, the results indicate that money supply, reserve ratio and bank lending rate have a negative effect on house price volatility.

The VAR model or the extended VAR models are widely used in exploring the housing market movements. However, Liu and Ou (2021) indicate that these pure econometric models can capture the effects of gender imbalance and avoid endogeneity issues, but they are limited in their applicability to policy analysis. These models cannot include the factors of other agents' decisions, which may affect the housing prices. Monetary policy analysis is the key element in the thesis; therefore, a micro-founded theoretical model is applied in this thesis to investigate the effects of monetary policy on the housing market. It has the ability to illustrate the links of economic variables because of the interactions between different agents making their optimal choices.

2.32 Theoretical

This section reviews the housing market exploration based on a theoretical economic model: A micro-founded Dynamic Stochastic General Equilibrium (DSGE) model. The housing price fluctuation and the influence of monetary policy will also be discussed in this section. The models of Iacoviello (2005) and Iacoviello and Neri (2010) have been widely studied and used to investigate the dynamics of the housing market. The key features of the Iacoviello (2005) model include nominal debt contracts and the addition of collateral constraints on the household and firm sectors. The transmission of aggregate demand to housing price shocks has been modified by adding collateral constraints. The slow transmission from output to inflation can also be improved by containing nominal debt. Iacoviello and Neri (2010) update the model of Iacoviello (2005) to investigate the sources of housing market dynamics in the United States. The results show that monetary factors, housing technology shocks and housing demand have an impact on housing prices.

The model has also been widely used in investigating the housing market in China. Applying the spirit of Iacoviello's (2005) and Iacoviello and Neri's (2010) model, Tan, Tang and Meng (2022) construct a DSGE model to study the impact of monetary policy on residential property prices in China. The dynamic analysis displays that a continuous tight monetary policy performs better than a discontinuous tight monetary policy in controlling housing prices. The period structure of the tightening policy also has a significant influence on policy performance. The longer the period of austerity, the more effective the regulation. Gai, Minford and Ou (2020) study the behaviours of the business cycle in China by comparing the models with and without housing collateral. The result show that the model without housing collateral passed the Indirect Inference test, which measures the compatibility of the model with data. The model with housing collateral rejects that. This indicates that the model without housing collateral is in line with China's economic situation. By extending the Iacoviello (2005) model by adding government spending and government investment, Liu and Ou (2019) investigate the function of fiscal policy in the housing market in China. There is a weak effect of increasing government spending in lowering housing prices. The increase in government investment raises housing prices, and the increase in wealth pushes up housing demand. Housing demand shock is the key factor for house price movements.

Some authors consider the specific situation of the housing market in China and expand upon Iacoviello's (2005) model. In addition to the factor of monetary policy, Deng et al. (2023) extend the Iacoviello (2005) model by incorporating down payment ratio and property taxes on houses. A Taylor-type rule governs the down payment ratio, using lagged values of the ratio itself, the loan-to-value ratio, and housing price growth, as a macroprudential policy instrument. The mechanism of this rule is that when house prices increase, the down payment ratio will increase to decrease the loan-to-value ratio, which curbs further escalation in house prices. The finding is that the combination of macro-prudential policy and monetary policy can effectively stabilize housing price movements. Ng (2015) modified the model of Iacoviello and Neri (2010) by including a loan-to-value ratio in the borrowing constraints. They found that housing preference shock dominates the volatility of housing prices in China, and the second factor is the shock in monetary policy. The further simple regression of housing preference shock found that there is a positive relationship between the housing preference shock and the sex ratio of men to females.

Some studies use the DSGE model, which is not based on that of Iacoviello (2005) and Iacoviello and Neri (2010). Calza, Monacelli and Stracca (2013) constructed a two-sector DSGE model to investigate the impact of housing finance on monetary policy transmission, using 19 industrialized countries' samples. The research demonstrates that monetary policy shocks affect housing prices and residential investment more in countries with more flexible mortgage markets. Kuang and Liu (2015) apply a four-sector general equilibrium model using data from 35 cities in China from 1996 to 2010. They conclude that both household income and interest rates have an impact on housing prices. Uncommon increasing housing prices may aggravate inflation.

Compared with the effect of inflation on housing prices, the effect of the money supply on that is much greater. Wen and He (2015) built a DSGE model where the Money supply rule follows an augmented McCallum rule to explore the underlying causes of the housing price dynamics. They found the main cause is housing supply for the fluctuation of housing prices rather than monetary supply. They also suggest that the central bank should apply the money supply rule, taking into account the movement of real housing prices, which can effectively stabilize the economy in China.

Some specific instruments regarding the intervention of the housing market can also be discussed by using the DSGE model. He (2019) added an element of down payment in the household sector of a DSGE model to investigate the influence of down payment policy on the economy. The results show that the increase in the down payment ratio reduces the speculative activities and the housing demand of households, cooling down the housing market. Wang and Hou (2021), considering government-imposed land price discrimination in a DSGE model, found the discrimination combined with loose monetary policy results in an increase in housing prices and a fall in inflation of prices of consumer goods.

Similar to the advanced economy, speculative activity in the housing market is also an important factor that leads to the movement of housing prices. He and Xia (2020) consider speculative behaviour by dividing households into fundamental traders and speculators. The behaviour of the speculators' housing purchases refers to Cutler et al. (1990), involving dynamic learning based on past prices. When population growth is taken into account in a DSGE model, the results show limited effects of population shocks on housing prices (Ding,2019). Liu and Ou (2021) construct an economic DSGE model which includes commercial and shadow banks to find drivers for housing price dynamics. There is strong evidence to show that housing demand shocks are a fundamental factor in the occurrence of housing price 'bubbles'.

2.4 Model with Chinese Characteristics in Monetary Policies

Some research has been conducted on the characteristics of Chinese monetary policy. A theoretical model of the banking system in China has been developed. He and Wang (2012) investigate monetary policy in China by constructing a theoretical model of the banking system, focusing on the transmission from specific monetary policy instruments to market interest rates. The model contains a dual-track interest rate system where interest rates are regulated (the lending interest rate floor and the deposit interest ceiling), reserve requirements and open market operations. The results indicate that changes in benchmark interest rates have the greatest impact on market interest rates, followed by significant effects from reserve requirements. In contrast, the influence of open market operations is less pronounced. Chen, Chen and Gerlach (2013) built a model of bank behaviours, showing how the retail lending rate and interbank rate are determined under the regulation on deposit and lending rates and credit, as well as the change in reserve requirement ratio. The finding indicates that the use of multiple monetary policy instruments efficiently brings the growth of money and credit to its target level in a short period. They also find that the impact of monetary policy instruments through inter-bank lending depends on whether the restrictions (lending rate floor and deposit rate ceiling) have been hit.

Some literature explores the impact of different monetary policy instruments based on statistics. Kim and Chen (2022) construct a structural VAR model to investigate the impact of different monetary policies, like benchmark interest rates, reserve requirement ratio and short-term interest rates on the economy in China and discover the interactions of these monetary policy instruments. They find that the benchmark lending rate and short-term interest rate have more impact on output compared to the others.

In terms of a structural theoretical model, considering the complexity of implementing monetary policy, some literature does not describe the monetary policy rule as a simple Taylor-type rule. Taking into account multiple monetary instruments, such as benchmark interest rates, reserve requirement ratios, and other factors, Liu and Zhang (2010) apply the New Keynesian model to evaluate the adequacy of China's monetary policy framework. They utilize a hybrid rule incorporating both quantity of money and interest rate regulations. The simulation results indicate that the framework with the interest rate and money quantity rule performs better than that with any single rule. There are some authors who no longer insist on choosing conventional monetary policy rule but combine Taylor's rule and non-conventional monetary policy to discuss China's economy. Chen, Funke, and Paetz (2012) develop a New Keynesian DSGE model that contains specific monetary policies, like window guidance, lending and deposit rates, and required reserve ratio, by adding a commercial bank sector to the model. The result displays that the roles of control for credit supply and the interest rate corridor are complementary. They also emphasize that the choice of monetary policy is determined by the shock sources.

2.5 Conclusion

This chapter first reviews the difference in monetary policy between advanced economies and China and then reviews the existing empirical and theoretical research on the monetary policy and house price dynamics. Finally, it reviews the model building related to the housing market and Chinese-specific monetary policy instruments.

The monetary policy tools in the advanced economies are market-based and have no direct restriction on the interest rates. The PBoC directly sets the guidelines for interest rates and restrictions on retail interest rates. Besides, they frequently adjust the benchmark interest rate and reserve requirement ratio to affect the housing market in China. Monetary policy explains the dynamics of housing prices in both advanced economies and developing countries. Some developing countries, like China and Pakistan, utilize monetary policy as one of the instruments that are frequently used to control housing prices. The review of the monetary policy and property prices in theoretical models reveals that the Iacoviello (2005) model has been extensively utilized to investigate the housing market. This model has also found widespread application in the context of China. There are two types of models for the review of model construction related to Chinese characteristic monetary policies. One model simulates the behavior of a commercial bank, considering the multiple monetary instruments to see how a commercial bank determines the market interest rate. The other one is a structural economic model, in which the commercial bank sector is one of the key agents in the model. Within this sector, Chinese characteristic monetary instruments are incorporated.

The methods used in the above literature can generally be divided into data-based and theoretical-based approaches. The commonly used data-based models are VAR and VECM. In terms of the theoretical models, Iacoviello's (2005) model, which incorporates a housing sector, has been broadly applied to investigate the housing dynamics, including the analysis related to China. Chen, Funke and Paetz's (2012) embed a banking sector into their DSGE model and demonstrate how China's characteristic monetary policy influences the economy. This thesis fills the gap by combining these two models to investigate the impact of specific monetary policy on housing prices.

To explore the impact of specific monetary policy on housing prices in China, this study employs models developed by Iacoviello and Neri (2010) and Chen, Funke and Paetz (2012) to construct a model of the Chinese economy that includes a banking sector and specific monetary policies. The thesis constructs two models: a benchmark model and an extended model with a more complex monetary policy system. The benchmark model encompasses households, firms, retailers, and a central bank that adjusts the interest rate following a

Taylor-type rule. In the extended model, based on Chen, Funke and Paetz (2012), a commercial banking sector is incorporated into the benchmark model to create a ‘semi-market’ system. The collateral borrowing constraint from the Iacoviello models is not incorporated because a model without this constraint better fits the data from China, as supported by Gai, Minford, and Ou (2020). While many studies investigate the impact of interest rates and general monetary policy on housing prices, few examine the effects of specific monetary policies. This thesis fills this gap by adopting the model proposed by Chen, Funke and Paetz (2012), which simulates the behavior of the private banking sector. This includes implementing restrictions on deposit and lending interest rates and adjusting the reserve requirement ratio to influence the economy.

3. Chapter 3

Benchmark model

3.1 Introduction

As a newly developing economy, China relies heavily on the real estate market, which is characterized by its late start, rapid growth, and significant government intervention. The real estate market plays a major role in economic output. In 2017, the value of housing sales was equivalent to 16.4% of GDP (Liu and Xiong (2018)). However, rapid economic growth is not the primary target of the Chinese government due to its potential issues. A stable housing market is crucial for ensuring social stability. For many Chinese, owning a house is seen as an important factor in achieving happiness and future security. This connection between housing prices and birth or marriage rates has been investigated by Clark et al. (2020), Wrenn, Yi and Zhang (2019), Yin and Su (2021) and Su et al. (2020). Furthermore, the high homeownership rate in China underscores the importance of owning houses in the minds of the Chinese. According to Clark, Huang and Yi (2021), homeownership in China exceeds 90%, with 96% in rural areas and 87% in urban areas. Therefore, the Chinese government frequently intervenes in the housing market to ensure stable growth and development. Monetary policy is one of the crucial tools.

A theoretical model provides a more reliable framework for analyzing monetary policy within an economy. Such models have a structural framework that enables the examination of the inner mechanisms and connections among agents in the economy. In China, the housing market is characterized by highly dynamic house prices. A micro-founded dynamic stochastic general equilibrium (DSGE) model is particularly suitable for investigating these housing dynamics. The housing market has attracted increasing attention from economists, especially regarding the exploration of housing dynamics (Wen and He (2015), Ng (2015) and Gai Minford, and Ou (2020)) and identifying the drivers of housing price movements (Liu and Ma (2021), Liu and Ou (2019), Wen and he (2015), and Gai, Minford, and Ou (2020)). House preferences and monetary policy are primary factors influencing housing market dynamics. Other specific factors reviewed in the literature include the down payment ratio (He (2019)), fiscal policy (Liu and Ou (2019)), population growth (Ding (2019)), real estate tax (Deng et al. (2023)), and government-imposed land price discrimination (Wang and Hou (2021)).

This chapter constructs a New Keynesian DSGE model based on the model by Iacoviello and Neri (2010), excluding the collateral constraint, as it does not fit Chinese data (Gai, Minford, and Ou 2020). The model serves two purposes: as a benchmark model and to identify the causes of housing price dynamics. This study contributes by using the indirect inference method to evaluate and estimate the model based on updated data from 2000 to 2020. Most studies estimate models using the Bayesian method. However, indirect inference relies more on actual data, whereas the Bayesian method is influenced by prior parameter settings. The ability of the theoretical model to explain real data behaviour is the key concern of economists. Additionally, using the same criterion of indirect inference makes the model's data-fitting capacity comparable, even across models based on different theories.

The model includes eight shocks, two of which are non-stationary technology shocks. Although identifying the determinants of housing price movements is an established topic, it remains valuable to explore it using an estimated model based on relatively recent data.

The structure of this chapter is organized as follows: the model setting is in section 3.2. Section 3.3 covers the principles of indirect inference evaluation and estimation. Section 3.4 discusses the empirical results, including the data description and findings from the indirect inference evaluation and estimation. Section 3.5 concludes this chapter.

3.2 Model

There are four sectors in the benchmark model: households, entrepreneurs, retailers and monetary policy. On the demand side, households maximize their lifetime utility by consuming general goods and housing, supplying labor to both the general and housing sectors, and making savings. On the supply side, the economy has two sectors: the general goods sector, which produces consumption goods, and the housing sector, which produces houses. In the consumption sector, price rigidity is introduced, while the housing sector exhibits flexible pricing. Retailers collect the intermediate goods and differentiate them without cost and sell the differentiated goods. The monetary policy follows the Taylor-type rule. Each agent solves the problem by corresponding optimality conditions, which, combined with market-clearing conditions, determine the behavior of the economy. Eight shocks are introduced to perturb these conditions.

3.21 Households

A continuum of households, with measure one, consume goods c_t and houses h_t and savings in regular time deposits b_t, which yield regular return r_{t-1}, meanwhile, offer labor $n_{c,t}$ and $n_{h,t}$. The households choose sequences for houses h_t, consumptions c_t, deposits b_t, and labor supply $n_{c,t}$ and $n_{h,t}$ to maximize Life-time Utility function equation (3.1) subject to budget constraint equation (3.5). The constant relative risk aversion (CRRA) utility function is widely used in DSEG models, like the macroeconomic model of Smets and Wouters (2003,2007) and the housing-market DSGE models of Iacoviello and Neri (2010) and Ng (2015). The CRRA utility is a standard assumption in DSGE models, allowing for tractable modelling of agents' intertemporal preferences and responses to uncertainty. The risk aversion parameter plays an important role in determining the responsiveness of consumption and housing demand to shocks. It can be expressed as:

$$E_0 \sum_{t=0}^{\infty} \beta^t \varepsilon_{p,t} \left[\frac{c_t^{1-\iota}}{1-\iota} - \varepsilon_{l,t} \left[\frac{\left({n_{c,t}}^{1+\vartheta} + {n_{h,t}}^{1+\vartheta}\right)^{\frac{1+\aleph}{1+\vartheta}}}{1+\aleph} \right] + \varepsilon_{h,t} \frac{(h_t)^{1-\psi}}{1-\psi} \right] \tag{3.1}$$

The household derives utility from consuming consumption goods c_t and houses h_t, and experience disutility from supplying labor $n_{c,t}$ and $n_{h,t}$. E_0 is the expectation factor at period 0. β is the discount factor. ι and ψ are the inverse of the intertemporal elasticity of substitution of consumption and housing. $\aleph$ is the inverse of the elasticity of labor supply for goods and house production. ϑ denotes the substitutability of labor for goods and for house production. $n_{c,t}$ is labor for goods, $n_{h,t}$ is labor for house. h_t is housing stock.

The utility function contains three shocks,$\varepsilon_{p,t}$ $\varepsilon_{l,t}$ $\varepsilon_{h,t}$. Where $\varepsilon_{l,t}$ captures labor supply shock. $\varepsilon_{p,t}$ represents the shock to intertemporal preference shock. $\varepsilon_{h,t}$ is housing demand shock, otherwise referred to as housing preference shock. As Iacoviello and Neri (2010) explained, this shock captures changes in the resources available for purchasing housing as economic conditions fluctuate, which shifts households' preferences in purchasing houses. All three shocks follow the AR(1) process.

$$ln\varepsilon_{p,t} = \rho_p ln\varepsilon_{p,t-1} + u_{p,t} \tag{3.2}$$

$$ln\varepsilon_{l,t} = \rho_l ln\varepsilon_{l,t-1} + u_{l,t} \tag{3.3}$$

$$ln\varepsilon_{h,t} = \rho_h ln\varepsilon_{h,t-1} + u_{h,t} \tag{3.4}$$

Where $u_{p,t}$, $u_{l,t}$, and $u_{h,t}$ are independent and identically distributed (i.i.d.), each with its own variance σ_p^2, σ_l^2 and σ_h^2.

Households face the following budget constraint in real terms:

$$c_t + b_t + q_{h,t}[h_t - (1-\delta_h)h_{t-1}] = w_{c,t}n_{c,t} + w_{h,t}n_{h,t} + b_{t-1}(1+r_{t-1}) + F_t^F - t_t \tag{3.5}$$

Where $q_{h,t}$ represents the price of houses, δ_h denotes the depreciation rate of houses. The real wages for producing goods and houses are denoted by $w_{c,t}$ and $w_{h,t}$, respectively. F_t^F denotes the lump-sum profit transfers from retail firms to households assumed to possess ownership of retail firms. t_t is lump-sum tax. $1 + r_{t-1}$ is the gross interest rate on deposits. All the variables are in the real term. Expenses on the left-hand side of equation (3.5) are funded by resources on the right-hand side. Specifically, equation (3.5) implies that the wealth household used to buy consumption goods, pay lump-sum tax, accumulate houses, and make deposits comes from wages for producing consumption goods and houses, interest rate gain and lump-sum profit transfers from retail firms.

Households maximize the utility function (3.1) by choosing c_t, b_t, h_t, $n_{c,t}$ $n_{h,t}$, subject to budget constraint (3.5). The following display Lagrange and first order conditions.

$$L = \sum_{t=0}^{\infty} \beta^t \varepsilon_{p,t} \left[\frac{c_t^{1-\iota}}{1-\iota} - \varepsilon_{l,t} \left[\frac{\left({n_{c,t}}^{1+\vartheta} + {n_{h,t}}^{1+\vartheta}\right)^{\frac{1+\aleph}{1+\vartheta}}}{1+\aleph} \right] + \varepsilon_{h,t} \frac{(h_t)^{1-\psi}}{1-\psi} \right] +$$
$$\lambda_t \left[w_{c,t}n_{c,t} + w_{h,t}n_{h,t} + b_{t-1}(1+r_{t-1}) + F_t^F - t_t - c_t - b_t - q_{h,t}[h_t - (1 - \delta_h)h_{t-1}] \right] \tag{3.6}$$

First order conditions:

$$\frac{\partial L}{\partial c_t} : \frac{\varepsilon_{p,t}}{c_t^{\iota}} = \lambda_t \tag{3.7}$$

$$\frac{\partial L}{\partial b_t} : \beta E_t \lambda_{t+1}(1 + r_t) = \lambda_t \tag{3.8}$$

$$\frac{\partial L}{\partial h_t} : \varepsilon_{p,t}\varepsilon_{h,t}(h_t)^{-\psi} + \beta E_t \lambda_{t+1} q_{h,t+1}(1 - \delta_h) = \lambda_t q_{h,t} \tag{3.9}$$

$$\frac{\partial L}{\partial n_{c,t}}: \varepsilon_{p,t}\varepsilon_{l,t}\left({n_{c,t}}^{1+\vartheta} + {n_{h,t}}^{1+\vartheta}\right)^{\frac{\aleph-\vartheta}{1+\vartheta}}{n_{c,t}}^{\vartheta} = \lambda_t w_{c,t} \tag{3.10}$$

$$\frac{\partial L}{\partial n_{h,t}}: \varepsilon_{p,t}\varepsilon_{l,t}\left({n_{c,t}}^{1+\vartheta} + {n_{h,t}}^{1+\vartheta}\right)^{\frac{\aleph-\vartheta}{1+\vartheta}}{n_{h,t}}^{\vartheta} = \lambda_t w_{h,t} \tag{3.11}$$

The equations in the left-hand side (3.7) - (3.11) illustrate the marginal utility loss associated with selecting pertinent allocations, whereas the right-hand side represents the marginal utility gain.

Equations (2.12) and (3.13) show the optimal intra-temporal substitution between labor and consumption for combining equations (3.7) and (3.10) and equations (3.7) and (3.11). These equations determine the optimal decisions of households regarding labor supply in two sectors and consumption.

$$\varepsilon_{l,t}\left({n_{c,t}}^{1+\vartheta} + {n_{h,t}}^{1+\vartheta}\right)^{\frac{\aleph-\vartheta}{1+\vartheta}}{n_{c,t}}^{\vartheta} = \frac{w_{c,t}}{c_t^l} \tag{3.12}$$

$$\varepsilon_{l,t}\left({n_{c,t}}^{1+\vartheta} + {n_{h,t}}^{1+\vartheta}\right)^{\frac{\aleph-\vartheta}{1+\vartheta}}{n_{h,t}}^{\vartheta} = \frac{w_{h,t}}{c_t^l} \tag{3.13}$$

Combining equations (3.7) and (3.9), we have equation (3.14). It displays optimal intra-temporal substitution between housing and consumption.

$$\varepsilon_{p,t}\varepsilon_{h,t}(h_t)^{-\psi} + \beta E_t \frac{\varepsilon_{p,t+1}}{c_{t+1}^l} q_{h,t+1}(1-\delta_h) = \frac{\varepsilon_{p,t}}{c_t^l} q_{h,t} \tag{3.14}$$

Combining equations (3.7) and (3.8), we get the Euler equation (3.15), which shows a dynamic optimal decision for consumption today and tomorrow.

$$\frac{\varepsilon_{p,t}}{c_t^l} = \beta E_t \frac{\varepsilon_{p,t+1}}{c_{t+1}^l}(1+r_t) \tag{3.15}$$

In general, the problem provides optimal conditions that indicate how future consumption, housing, and labor trade off against current consumption in terms of marginal rates of substitution. This set of equations (3.12) - (3.15) determines the supply of labor in the consumption goods sector and housing sector, demand for houses and general goods of households.

3.22 Firms

On the supply side, a continuum of measure one of the representative entrepreneurs produces houses $Y_{h,t}$ and intermediate goods Y_t by using capital $k_{h,t}$, $k_{c,t}$, and labor $n_{c,t}$, $n_{h,t}$. The technologies are different in two sectors, $A_{c,t}$, $A_{h,t}$. Their business profits are used to support consumption, the sole factor affecting their utility function. Entrepreneurs borrow b_t . A representative entrepreneur chooses consumption c_t^e , capital $k_{h,t}$, $k_{c,t}$, labor demand $n_{c,t}$, $n_{h,t}$, borrowing $b_{c,t}$ and investments $i_{c,t}$ $i_{h,t}$ to maximize utility function equation (3.16). Similar to the household, the utility function of firms assumes a constant relative risk aversion (CRRA), which can be written as:

$$E_0 \sum_{t=0}^{\infty} \beta^t \varepsilon_{p,t} \left[\log \left(\frac{c_t^{e\,1-\varsigma}}{1-\varsigma} \right) \right] \tag{3.16}$$

Where c_t^e denotes consumption for entrepreneurs, entrepreneurs choose c_t^e subject to equations (3.17), (3.18), (3.19), (3.22), (3.23). ς denotes the inverse of the intertemporal elasticity of substitution of consumption. Similar to households, β^t and $\varepsilon_{p,t}$ are the discount factor and preference shock.

Entrepreneurs have the Budget constraint:

$$c_t^e + w_{c,t} n_{c,t} + w_{h,t} n_{h,t} + \frac{k}{2}(\Delta k_{c,t})^2 + \frac{k}{2}(\Delta k_{h,t})^2 + i_{c,t} + i_{h,t} + b_{t-1}(1 + r_{t-1}) = \frac{Y_t}{X_t} + q_{h,t} Y_{h,t} + b_t \tag{3.17}$$

Where X_t denotes the mark-up price to the intermediate goods. Empirical research indicates that there is not much change in capital across periods. Economists typically justify this by positing the existence of adjustment costs. Therefore, in the firm sector, capital adjustment is included to curb excessive investment volatility. $\frac{k}{2}(\Delta k_{c,t})^2$ and $\frac{k}{2}(\Delta k_{h,t})^2$ are capital adjustments cost, assuming in a quadratic form, which prevents firms from making rapid changes to their capital stock. For the whole budget constraint, the costs on the left side of equation (4) are covered by resources on the right side. Specifically, the inflow stems from the sale of intermediate goods Y_t, houses $Y_{h,t}$, and loans b_t, which are then distributed among consumption, wage disbursements in two sectors, investments in two sectors, capital adjustment costs, as well as principal and interest repayments.

Production function Cobb-Douglas:

$$Y_t = A_{c,t} {n_{c,t}}^{1-\alpha} {k_{c,t-1}}^{\alpha} \quad (3.18)$$

$$Y_{h,t} = A_{h,t} {n_{h,t}}^{1-\omega} {k_{h,t-1}}^{\omega} \quad (3.19)$$

For the production function, Cobb-Douglas, a constant-return-to-scale production function, has been used. The inputs for producing consumption goods and houses are labor and capital. α and $1-\alpha$ are the share of capital input and labor input in producing intermediate goods. ω and $1-\omega$ are the share of capital input and labor input in producing houses. α and ω measure how output reacts to changes in capital. $A_{c,t}$ and $A_{h,t}$ measure technologies for producing normal goods and houses individually. The stationarity tests on residuals in Section 3.43 indicate that the two technology shocks exhibit stochastic non-stationarity. Based on this empirical finding, the productivity shock process is specified as an AR(1) in first differences, implying that productivity shocks have a permanent influence. This specification is also consistent with several DSGE models applied to the Chinese economy (Le et al. (2014), Le et al. (2021), Gai, Minford, and Ou (2020)). It can be written as:

$$\Delta lnA_{c,t} = \rho_{Ac}\Delta lnA_{c,t-1} + u_{ac,t} \tag{3.20}$$

$$\Delta lnA_{h,t} = \rho_{Ah}\Delta lnA_{h,t-1} + u_{ah,t} \tag{3.21}$$

Where $u_{ac,t}$ and $u_{ah,t}$ follow the independently and identically distributed processes, with variance σ_{ac}^2 and σ_{ah}^2. $u_{ac,t}$ and $u_{ah,t}$ will have lasting impacts on the $A_{c,t}$ and $A_{h,t}$.

The Capital accumulation follows:

$$k_{c,t} = \left(1 - \delta_{k,c}\right)k_{c,t-1} + i_{c,t} \tag{3.22}$$

$$k_{h,t} = \left(1 - \delta_{k,h}\right)k_{h,t-1} + i_{h,t} \tag{3.23}$$

$i_{c,t}, i_{h,t}$ are investments in intermediates goods sector and housing sector. $\delta_{k,h}$, $\delta_{k,c}$ are depreciation rates.

A representative entrepreneur maximizes utility function subject to the budget constraint (3.17), production functions(3.18), (3.19) and capital accumulations (3.22), (3.23) by choosing consumption c_t^e, capital $k_{h,t}$, $k_{c,t}$, labor demand $n_{c,t}$, $n_{h,t}$, and borrowing $b_{c,t}$ via Lagrange.

To solve entrepreneurs' problems, we have Lagrange and first order conditions.

$$L = E_0 \sum_{t=0}^{\infty} \beta_e^t \varepsilon_{p,t}\left[\frac{c_t^{e\,1-\varsigma}}{1-\varsigma}\right] + \lambda_{e,t}\left[\frac{A_{c,t}{n_{c,t}}^{1-\alpha}{k_{c,t-1}}^{\alpha}}{X_t} + q_{h,t}A_{h,t}{n_{h,t}}^{1-\omega}{k_{h,t-1}}^{\omega} + b_t - c_t^e - w_{c,t}n_{c,t} - w_{h,t}n_{h,t} - k_{c,t} + \left(1-\delta_{k,c}\right)k_{c,t-1} + (1 + r_{t-1}^l)b_{t-1} - k_{h,t} + \left(1-\delta_{k,h}\right)k_{h,t-1} - \frac{k}{2}(k_{c,t} - k_{c,t-1})^2 - \frac{k}{2}(k_{h,t} - k_{h,t-1})^2\right] \tag{3.24}$$

First order conditions:

$$\frac{\partial L}{\partial c_t^e}: \frac{\varepsilon_{p,t}}{c_t^{e\varsigma}} = \lambda_{e,t} \tag{3.25}$$

$$\frac{\partial L}{\partial b_t^e}: \lambda_{e,t} = \beta \lambda_{e,t+1}(1 + r_t) \tag{3.26}$$

$$\frac{\partial L}{\partial k_{c,t}}: \beta \lambda_{e,t+1} \left[\alpha * \frac{Y_{t+1}}{X_{t+1} k_{c,t}} + (1 - \delta_{k,c}) + k(k_{c,t+1} - k_{c,t}) \right] = \lambda_{e,t}[1 + k(k_{c,t} - k_{c,t-1})] \tag{3.27}$$

$$\frac{\partial L}{\partial k_{h,t}}: \beta \lambda_{e,t+1} \left[\omega \frac{q_{h,t+1} Y_{h,t+1}}{k_{h,t}} + (1 - \delta_{k,h}) + k(k_{h,t+1} - k_{h,t}) \right] = \lambda_{e,t}[1 + k(k_{h,t} - k_{h,t-1})] \tag{3.28}$$

$$\frac{\partial L}{\partial n_{c,t}}: (1 - \alpha) \frac{Y_t}{X_t n_{c,t}} = w_{c,t} \tag{3.29}$$

$$\frac{\partial L}{\partial n_{h,t}}: (1 - \omega) q_{h,t} \frac{Y_{h,t}}{n_{h,t}} = w_{h,t} \tag{3.30}$$

Equations (3.29) and (3.30) display the firm’s labor demand in the general consumption sector and housing sector individually. The marginal productivity of labor equals the cost of labor, which is the wage.

Combining (3.25) and (3.26), we get the Euler equation (3.31). From equation (3.31), the consumption dynamics of firms adhere to a similar Euler equation pattern as observed in households' consumption behavior.

$$\frac{\varepsilon_{p,t}}{c_t^{e\varsigma}} = \beta \frac{\varepsilon_{p,t+1}}{c_{t+1}^{e\ \varsigma}} (1 + r_t) \tag{3.31}$$

Combining equation (3.25) and equation (3.27), we have capital demand for general goods, equation (3.32). It also can be written as equation (3.33) by combining equation (3.32) and equation (3.31). According to equation (3.33), the firm has the option to either get a gross return by lending, which is shown on the right-hand side of the equation or allocate resources to generate output in subsequent periods corresponding to the marginal product of capital, as illustrated on the left-hand side of the equation.

$$\beta \frac{\varepsilon_{p,t+1}}{c_{t+1}^{e\ \varsigma}}\left[\alpha * \frac{Y_{t+1}}{X_{t+1}k_{c,t}} + \left(1-\delta_{k,c}\right) + k\left(k_{c,t+1}-k_{c,t}\right)\right] = \frac{\varepsilon_{p,t}}{c_t^{e\varsigma}}\left[1 + k\left(k_{c,t}-k_{c,t-1}\right)\right]$$

(3.32)

$$\alpha * \frac{Y_{t+1}}{X_{t+1}k_{c,t}} + \left(1-\delta_{k,c}\right) + k\left(k_{c,t+1}-k_{c,t}\right) = (1+r_t)\left[1 + k\left(k_{c,t}-k_{c,t-1}\right)\right]$$

(3.33)

Combining equation (3.25) and equation (3.28), we have capital demand for houses, equation (3.34). Similar to the general goods sector, the capital demand function in the housing sector can be expressed as equation (3.35). The interpretation remains consistent within the general goods sector. Firms can either choose to make loans or to produce houses.

$$\beta \frac{\varepsilon_{p,t+1}}{c_{t+1}^{e\ \varsigma}}\left[\omega \frac{q_{h,t+1}Y_{h,t+1}}{k_{h,t}} + \left(1-\delta_{k,h}\right) + k(k_{h,t+1}-k_{h,t})\right] = \frac{\varepsilon_{p,t}}{c_t^{e\varsigma}}\left[1 + k(k_{h,t}-k_{h,t-1})\right]$$

(3.34)

$$\omega \frac{q_{h,t+1}Y_{h,t+1}}{k_{h,t}} + \left(1-\delta_{k,h}\right) + k(k_{h,t+1}-k_{h,t}) = (1+r_t)\left[1 + k(k_{h,t}-k_{h,t-1})\right]$$

(3.35)

The above set of conditions determines the behaviour of a firm in two sectors. Specifically, Equations (3.29) and (3.30) define the labor demand for normal goods and household production. Equations (3.32 or 3.33) and (3.34 or 3.35) elucidate the optimal balance between capital and goods, showcasing the trade-offs involved in their allocation in two sectors. Production functions equation (3.18) and equation (3.19) determine the supply of houses and intermediate goods. The consumption behavior of firms is governed by the Euler equation (3.31). In equilibrium, the relationship of consumption, labor demand, investment and capital are determined by equations (3.29), (3.30), (3.31), (3.33) and (3.35) and (3.17), (3.18), (3.19), (3.22), (3.23). And dynamic behavior will be affected by the permanent technology shocks, equations (3.20) and (3.21).

3.23 Retailers

In the retailers' sector, a continuum of measure one of retailers aggregates intermediate goods into a final good and sells it at price P_t. Sticky prices in the general sector are applied through monopolistic competition assumption and Calvo-style contracts, whereas the housing sector features flexible pricing. Final goods firms operate in a perfectly competitive market and produce final goods by aggregating differentiated intermediate goods through CES technology, following the Dixit-Stiglitz framework.

$$Y_t = \left[\int_0^1 Y_{t(i)}^{\frac{\epsilon-1}{\epsilon}} d_i\right]^{\frac{\epsilon}{\epsilon-1}} ; \epsilon > 0 \tag{3.36}$$

Where Y_t is final goods. $Y_{t(i)}$ are intermediate goods, $i \in [0,1]$. ϵ is the elasticity of substitution among intermediate goods, and $\epsilon > 0$. Taking power $\frac{\epsilon}{\epsilon-1}$ of the integral, we can make the production function constant returns to scale.

The profit maximization problem of the final good firm is equation (3.37). Π_t denotes the profit of final goods.

$$\Pi_t = \max_{Y_{t(i)}} P_t\, Y_t - \int_0^1 P_{t(i)} Y_{t(i)} d_{(i)} \tag{3.37}$$

Inserting equation (3.36) into equation (3.37) yields equation (3.38). Where P_t is the price of the final good.

$$\Pi_t = \max_{Y_{t(i)}} P_t \left[\int_0^1 Y_{t(i)}^{\frac{\epsilon-1}{\epsilon}} d_i\right]^{\frac{\epsilon}{\epsilon-1}} - \int_0^1 P_{t(i)} Y_{t(i)} d_{(i)} \tag{3.38}$$

Maximizing profit Π_t with respect to $Y_{t(i)}$, then we have equation (3.39).

$$\frac{\epsilon}{\epsilon-1} P_t \left[\int_0^1 Y_{t(i)}^{\frac{\epsilon-1}{\epsilon}} d_i\right]^{\frac{\epsilon}{\epsilon-1}-1} \frac{\epsilon-1}{\epsilon} Y_{t(i)}^{\frac{\epsilon-1}{\epsilon}-1} = P_{t(i)} \qquad (3.39)$$

Rearranging equation (3.39) yields the relative demand function for ith intermediate good, as shown in equation (3.40).

$$\Rightarrow Y_{t(i)} = \left[\frac{P_{t(i)}}{P_t}\right]^{-\epsilon} Y_t \qquad (3.40)$$

The demand function for intermediate goods displays that the intermediates' price to final foods price ratio negatively affects demand for intermediate goods. There is a positive relationship between demand for intermediate goods and final goods production.

By substituting equation (3.40) into (3.36), we get equation (3.41).

$$Y_t = \left[\int_0^1 (\left[\frac{P_{t(i)}}{P_t}\right]^{-\epsilon} Y_t)^{\frac{\epsilon-1}{\epsilon}} d_i\right]^{\frac{\epsilon}{\epsilon-1}}; \epsilon > 0 \qquad (3.41)$$

Rearranging it, we get the aggregate price level equation (3.42).

$$P_t = \left[\int_0^1 P_{t(i)}{}^{1-\epsilon} d_i\right]^{\frac{1}{1-\epsilon}} \qquad (3.42)$$

From the firm sector, we know an intermediate producer using constant return to scale technology in labor and capital produces output, which is expressed as equation (3.18). This is a monopolistically competitive intermediate goods market. Firms minimize the cost of production by choosing $n_{c,t}$ and $k_{c,t}$. The cost of production is $TC_t = w_{c,t}n_{c,t} + r_t k_{c,t-1}$. Firms maximize their profit each period by minimizing costs. To solve this problem, we get the real marginal cost $mc_t = \frac{1}{A_{c,t}}\left(\frac{1}{\alpha}\right)^{\alpha}\left(\frac{1}{1-\alpha}\right)^{1-\alpha} w_{c,t}^{1-\alpha} r_t^{\alpha}$.

The real flow profit for intermediate producer i is equation (3.43).

$$F_t^F(i) = \frac{P_{t(i)}}{P_t} Y_{t(i)} - mc_t Y_{t(i)} \qquad (3.43)$$

Price rigidity is introduced by following Calvo (1983). The Calvo (1983) contract presents only a fraction of firms that can change prices freely in each period. We denote $1-\varphi$ in this thesis. The rest fraction φ of firms should stick to the price chosen in the last period. The probability of a firm not changing a price for one period is φ, for two periods φ^2, etc. The Price adjustment rule aims to maximize the expected discounted profit value. The firm will apply the adjusted prices for more than one period. There are two parts to the discounted factor: the usual stochastic discount factor $(\beta^F)^s \frac{u'(C_{t+s})}{u'(C_t)}$ and the probability φ that the firm cannot adjust prices. Firms discount profits s periods into the future by the stochastic discount factor β^F multiplied by the probability that a price chosen in t will still be in period t + s. β^F is the discount factor in the firm sector.

The intermediate firms maximize the discounted profit.

$$\max_{P_{t(i)}} E_t \sum_{s=0}^{\infty} (\beta^F \varphi)^s \frac{u'(C_{t+s})}{u'(C_t)} \left(\frac{P_{t(i)}}{P_{t+s}} Y_{t+s(i)} - mc_{t+s} Y_{t+s(i)}\right) \qquad (3.44)$$

Substituting equation (3.40) into equation (3.44), we have equation (3.45). Equation (45) displays the problem of intermediate entrepreneurs, where they should choose the price in a period to maximize the discounted profits.

$$\max_{P_{t(i)}} E_t \sum_{s=0}^{\infty} (\beta^F \varphi)^s \frac{u'(C_{t+s})}{u'(C_t)} \left(\frac{P_{t(i)}}{P_{t+s}} \left(\frac{P_{t(i)}}{P_{t+s}}\right)^{-\epsilon} Y_{t+s} - mc_{t+s} \left[\frac{P_{t(i)}}{P_{t+s}}\right]^{-\epsilon} Y_{t+s}\right) \qquad (3.45)$$

The optimal price of intermediate goods is shown by equation (3.45). Intermediate firms adjust prices according to the rule equation (3.45). Then, we can investigate the price dynamics in the model. Taking the first order condition of equation (3.45) with respect to $P_{t(i)}$, then we have equation (3.46)

$$E_t \sum_{s=0}^{\infty} (\beta^F \varphi)^s u'(C_{t+s}) \, (1-\epsilon) P_{t(i)}^{-\epsilon} P_{t+s}^{\epsilon-1} Y_{t+s} +$$

$$E_t \sum_{s=0}^{\infty} (\beta^F \varphi)^s u'(C_{t+s}) \epsilon P_{t(i)}^{-\epsilon-1} P_{t+s}^{\epsilon} Y_{t+s} mc_{t+s} = 0 \tag{3.46}$$

Each firm updates the price following the same rule. Rearranging equation (3.46), we have the optimal reset price p_t^*.

$$p_t^* = \frac{\epsilon}{(\epsilon-1)} \frac{E_t \sum_{s=0}^{\infty} (\beta^F \varphi)^s u'(C_{t+s}) P_{t+s}^{\epsilon} Y_{t+s} mc_{t+s}}{E_t \sum_{s=0}^{\infty} (\beta^F \varphi)^s u'(C_{t+s}) P_{t+s}^{\epsilon-1} Y_{t+s}} \tag{3.47}$$

A fraction of $1-\varphi$ intermediate firms can change their price to the optimal price, and a fraction of φ firms should keep the last period prices. The general price level can be expressed as equation (3.48).

$$P_t = \left[(1-\varphi) p_t^{*1-\epsilon} + \varphi P_{t-1}^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}} \tag{3.48}$$

Log-linearizing equation (3.47) around zero inflation steady state, we get:

$$\widehat{P_t^*} = (1-\beta^F \varphi) E_t \sum_{s=0}^{\infty} (\beta^F \varphi)^s \left(\widehat{mc_{t+s}} + \widehat{P_{t+s}} \right) \tag{3.49}$$

Log-linearizing equation (3.48) and combining $\widehat{\pi_t} = \widehat{P_t} - \widehat{P_{t-1}}$, we get:

$$\widehat{\pi_t} = (1-\varphi)(\widehat{P_t^*} - \widehat{P_{t-1}}) \tag{3.50}$$

We got a forward-looking New Keynesian Phillips curve (equation 3.51) by substituting equation (3.49) into equation (3.50).

$$\widehat{\pi_t} = \beta^F E_t \widehat{\pi_{t+1}} + \frac{(1-\varphi)(1-\beta^F\varphi)}{\varphi}\widehat{mc}_t + \widehat{\varepsilon_{\pi,t}} \tag{3.51}$$

Equation (3.51) displays that inflation is affected by expected inflation and real marginal cost. Equation (3.52) displays the retailers' profit, which will be transferred into the household sector as lump-sum profits.

$$F_t^F = (1 - \widehat{mc}_t)Y_t \tag{3.52}$$

3.24 Monetary policy

The monetary policy is determined by a Taylor rule, which captures how the official nominal interest rate R_t responds to inflation φ_π, the growth of GDP φ_x and policy inertia also been included ρ_R.

In the equation, R_t is the official nominal interest rate. π_t denotes inflation rates measured by the GDP deflator. r^{ss} is the steady state value of interest rate ε_t^{MP} is monetary policy shock. ρ_R captures the policy inertia. φ_π and φ_x are the elasticity of inflation and the elasticity of economic growth, respectively.

$$1 + R_t = (1 + R_{t-1})^{\rho_R}(1 + \pi_t)^{(1-\rho_R)\varphi_\pi}\left({GDP_t}/{GDP_{t-1}}\right)^{(1-\rho_R)\varphi_x}[1 + r^{ss}]^{1-\rho_R}\varepsilon_t^{MP} \tag{3.53}$$

According to Iacoviello and Neri (2010), GDP_t includes the value of normal goods Y_t and houses $\overline{q_{h,t}}Y_{h,t}$. $\overline{q_{h,t}}$ denotes real housing prices in steady state.

$$GDP_t = Y_t + \overline{q_{h,t}} Y_{h,t} \tag{3.54}$$

The interest rate determined in this sector is equal to the deposit rate mentioned in the household sector and the lending rate mentioned in the firm sector. In the benchmark model setting, there is no difference between deposit interest rate and loan interest.

Nominal and real interest rates are related through the Fisher equation (3.55).

$$R_t = r_t + E_t \pi_{t+1} \tag{3.55}$$

Here r_t is real interest rate.

Market clearing conditions

By making supply equal to demand, market-clearing conditions balance the economy. These conditions link the agents in the economy, such as the production side and the consumption side, ensuring coherent interactions among them. The non-housing and housing market clearing requires:

$$Y_t = C_t + I_t + \frac{k}{2}(\Delta k_{c,t})^2 + g_t \tag{3.56}$$

$$C_t = c_t + c_t^e \tag{3.57}$$

$$I_t = i_{c,t} + i_{h,t} \tag{3.58}$$

$$h_t - (1 - \delta_h) h_{t-1} = Y_{h,t} \tag{3.59}$$

3.25 Shocks

lng_t: Government shock

$$lng_t = \rho_g l\, ng_{t-1} + u_{g,t} \tag{3.60}$$

$\varepsilon_{p,t}$: Intertemporal preference shock

$$ln\varepsilon_{p,t} = \rho_p ln\varepsilon_{p,t-1} + u_{p,t} \tag{3.61}$$

$\varepsilon_{l,t}$: Labor supply shock

$$ln\varepsilon_{l,t} = \rho_l ln\varepsilon_{l,t-1} + u_{l,t} \tag{3.62}$$

$\varepsilon_{h,t}$: Housing demand shock

$$ln\varepsilon_{h,t} = \rho_h ln\varepsilon_{h,t-1} + u_{h,t} \tag{3.63}$$

$\varepsilon_{\pi,t}$: Inflation shock

$$ln\varepsilon_{\pi,t} = \rho_\pi ln\varepsilon_{\pi,t-1} + u_{\pi,t} \tag{3.64}$$

$\varepsilon_{MP,t}$: Monetary policy shock:

$$ln\varepsilon_{MP,t} = \rho_{MP} ln\varepsilon_{MP,t-1} + u_{MP,t} \tag{3.65}$$

$A_{c,t}$: Technology shock (good production)

$$lnA_{c,t} = lnA_{c,t-1} + \rho_{A_c}(lnA_{c,t-1} - lnA_{c,t-2}) + u_{Ac,t} \tag{3.66}$$

$A_{h,t}$: Technology shock (house production)

$$lnA_{h,t} = lnA_{h,t-1} + \rho_{A_h}(lnA_{h,t-1} - lnA_{h,t-2}) + u_{Ah,t} \tag{3.67}$$

Where $u_{g,t}, u_{p,t}, u_{l,t}, u_{Ac,t}, u_{h,t}, u_{\pi,t}, u_{MP,t}$ $u_{Ah,t}$ are all i. i. d.

3.3 Indirect inference method

Confronting the model with data: can model fit the facts?

Model evaluation is crucial for determining whether the DSGE model accurately captures the key features and dynamic behaviors of the economy. This process is essential for evaluating how well the model explains economic variables like GDP, inflation, and interest rates. The evaluation process ensures the dependability of the theoretical model for predictive purposes and policy analysis. Several methods can be used to evaluate a DSGE model, including Maximum Likelihood Estimation, the Generalized Method of Moments, the Bayesian method, and the indirect inference method. Both models in this thesis will be evaluated and estimated. This section will introduce and discuss the indirect inference method for evaluation and estimation.

Bayesian and indirect inference methods have been widely utilized for evaluating DSGE models in recent years. Bayesian estimation has gained popularity compared to classical Maximum Likelihood (ML) estimation. The Bayesian approach utilizes a likelihood function generated by the model to systematically fit the solved DSGE model to time series data. Bayesian methods offer flexibility by allowing researchers to specify prior beliefs about parameters in DSGE models and incorporating data to refine estimates. However, the reliability of Bayesian estimation is influenced by the choice of priors, which are often derived from previous literature. Both Blanchard (2016) and Hansen and Heckman (1996) indicate that the justification for these priors is often weak. According to Le et al. (2016), the indirect inference method generally exhibits greater statistical power than the likelihood ratio test when dealing with small samples.

The indirect inference method employed in this thesis was first introduced by Minford et al. (2009) and further developed by Le et al. (2011, 2012, 2016). Le et al. (2011) refine the procedure of bootstrap by applying Monte Carlo simulation to the indirect inference method and compare the results obtained between the original and refined procedures, finding that the conclusions have not changed substantially. Le et al. (2011) use the indirect inference method to evaluate the Smets-Wouters New Keynesian model. They also employ a Monte Carlo experiment to verify that the bootstrap distribution can achieve the correct size of the test, thereby proving the reliability of the bootstrap. In a later study, Le et al. (2016) compare the test power of indirect inference and direct inference (likelihood ratio), finding that both methods are powerful, but the indirect inference method has greater power than direct inference (LR). The mechanisms of direct and indirect inference methods differ in key ways. The former focuses on forecasting current data, while the latter focuses on replicating properties of the auxiliary model estimated from real-world data. The indirect inference method evaluates a theoretical model's ability to replicate real-world data behaviour, particularly its dynamic properties. This method involves positing an auxiliary model that is independent of the theoretical model. The performance of both actual data and simulated data from the theoretical model is quantified by estimating the same auxiliary model separately. Then, the Wald test is used to measure the differences between the actual data and the simulated data. Additionally, the indirect inference method can be used for model estimation. This involves repeatedly applying the indirect inference testing process to find the set of coefficients that minimize the Wald statistic. To effectively search for the optimal set of coefficients, the Simulated Annealing algorithm is utilized to implement the process of minimizing the Wald statistic.

In summary, the indirect inference method demonstrates superior testing power compared to likelihood ratio estimation in small sample sizes. Asymptotically, in large samples, they are the same. China's transition from its longstanding welfare housing system to full housing commercialization began in 1998. The data sample is small. Furthermore, unlike the Bayesian method, this approach heavily relies on actual data, thus more accurately reflecting comparisons with real-world data. The search system employed in indirect inference estimation aligns the theoretical model more closely with real-world data, thereby enhancing the reliability of subsequent analyses. As a result, this thesis undertakes indirect inference evaluation and estimation. The following will introduce the theory of indirect inference, the operational mechanics of indirect inference, and the choice of an auxiliary model.

3.31 Introduction of Indirect inference.

Indirect inference is a method created by Smith (1993) and developed in various ways by Minford et al. (2009), which is applied to evaluate the fitness of the full economy model by comparing moments obtained from simulated data from the model and collected data in the real world. There exists a classical statistical inference framework in which an auxiliary model is employed as a tool to test and estimate the full model. This auxiliary model is entirely independent of the theoretical model and is used to provide a description of the data. The theory's performance is then evaluated indirectly based on this description. This description of data can be encapsulated by parameters of the auxiliary model or by functions derived from these parameters. The descriptions of data obtained from real data and simulated data generated by the theoretical model are compared to evaluate the theoretical model's fit.

The main idea of the indirect inference method in model evaluation is to treat the calibrated model as the 'true model', or null hypothesis, representing the true description of the data. The auxiliary model's performance, estimated with simulated data from the 'true model', is subsequently compared to its performance when applied to actual data. To make the comparison, the distributions of two sets of parameter estimates for the auxiliary model, or functions based on these estimates, will be examined. A descriptive model such as VAR is commonly chosen for the auxiliary model due to its succinct and accurate representation of the data. The auxiliary model is independent of the full model. The Wald test is used as the evaluation criterion, which is utilized to determine whether the distribution of VAR coefficients obtained from the calibrated DSGE model covers the VAR coefficients derived from the actual data at a certain significance level. The performance of simulated data derived from the 'true theoretical model' should resemble that of the actual data. In other words, the VAR coefficients obtained from the simulated data should not differ significantly from those derived from the actual data.

The Wald statistic is computed as follows:

$$W = \left(\beta^a - \bar{\beta}\right)'\Omega^{-1}\left(\beta^a - \bar{\beta}\right) \tag{3.68}$$

Where β^a : VAR coefficients derived from the actual data. β^i : VAR coefficients derived from the simulated data.

$\bar{\beta}$: $\bar{\beta} = E\left(\beta^i\right) = \frac{\sum_{i=1}^{N} \beta^i}{N}$ $\quad i \in (1, N)$, which is the number of simulations, for each simulation there is a related VAR coefficient. $\Omega = \mathrm{cov}\left(\beta^i - \bar{\beta}\right) = \frac{\sum_{i=1}^{N}(\beta^i - \bar{\beta})\prime(\beta^i - \bar{\beta})}{N}$.

Essentially, we are gauging the difference between the actual VAR parameters and the average of the simulated VAR parameters. This difference serves to reflect how closely or differently the model aligns with the real data. The Wald test is quite rigorous, and increasing either the number of lags in the auxiliary model or the number of endogenous variables makes it even more stringent.

To determine if the model is directly rejected by the data, the Wald statistic is converted into a t-statistic using the formula (equation 3.69), denoted as the transformed distance. The Wald statistic computed from equation (3.68) follows a Chi-square distribution. This statistic is then converted to a normal distribution to obtain the t-statistic. For the model to be considered a good fit to the data at the 95% confidence level, the Wald statistic derived from the actual data should be less than the 95th percentile of Wald statistics obtained from simulated data. From the (3.69) equation, if the Wald statistic obtained from the actual data, w^a, is exactly equivalent to the 95th percentile of that obtained from simulated data, $w^{0.95}$, the transformed statistic, T, will be 1.645. Therefore, using the transformed Wald statistic simplifies determining whether the model is rejected. If the transformed Wald statistic exceeds 1.645, the model is rejected. Conversely, if the statistic falls below this value, the model passes the test.

$$T = \left(\frac{\sqrt{2w^a} - \sqrt{2k-1}}{\sqrt{2w^{0.95}} - \sqrt{2k-1}}\right) 1.645 \tag{3.69}$$

Where w^a represents the Wald statistic calculated from the actual data. $w^{0.95}$ denotes the Wald statistic corresponding to the 95th percentile of the simulation data. k indicates the number of parameters, and $k-1$ is the degrees of freedom.

The testing procedure consists of three main steps: First, errors are collected from the calibrated structural model and the real-world data. Next, simulated data is generated through bootstrapping. Finally, the Wald statistic is calculated. The theoretical model, assumed to be the 'true model', generates 'true errors', which are then used to bootstrap a large number of sample replications. Typically, a descriptive time-series model like VAR is selected as an auxiliary model. The implications of the DSGE model for the VAR are examined by estimating the same VAR on each set of replicated data (Minford et al. (2009)), thereby generating a distribution of VAR coefficients.

The Wald test is applied to evaluate the performance of the VAR model estimated on replicated data against that estimated on real data. Specifically, it assesses whether coefficients derived from actual data fall within the distribution of coefficients obtained from replicated data at a specified confidence level. If the coefficients derived from the actual data fall within the distribution of the coefficients obtained from the replicated data, it indicates that the characteristics of the replicated data resemble those obtained from the actual data. Conversely, if the model fails the Wald test, it suggests an inability to explain real-world economic behaviour.

In essence, this approach evaluates whether simulated data from a calibrated DSGE model aligns with observed real-world data, leveraging an auxiliary model to illustrate both.

3.32 Indirect inference estimation

The indirect inference test evaluates whether the created model can generate data with similar performance to real data. If the disparity between real data and simulated data exceeds the criterion, it indicates the model's rejection. Models with different sets of parameters can generate different data, which have different performances. Different parameter sets in models can produce varying data performances; thus, while one calibrated model might fail the test, alternative parameter sets could pass. Exploring multiple parameter sets helps identify the optimal parameters that align the theoretical model closest to real-world behavior. If even the best set of parameters fails to pass the test, the model self has been rejected. This model requires further adjustment. The calibrated model may pass the test without requiring any adjustments to its parameters or equations. The indirect inference estimation method entails selecting several parameters sets for the structural model and conducting tests to search for parameters that minimise the differences in VAR coefficients between the simulated and real data. Namely, using the same auxiliary model, the optimal set of coefficients minimises the differences between the coefficients estimated from simulated and real data. The Wald statistic quantifies these differences.

Simulated annealing is utilized to find the set of parameters that have minimum value in Wald statistics. The inputs of indirect inference estimation are initial parameters, the maximum and minimum bounds of the parameters and the number of iterations. Normally, the calibrated parameter is taken as an initial value. According to the algorithm of Simulated Annealing, many different parameter sets will be chosen within the preset bound, and the corresponding Wald test statistic value will be calculated. The output is the set of parameters that minimize the value of the Wald test. The initial value is the starting point for the search, and the distance to the next trial point from the current point is determined randomly according to a probability distribution where the current temperature determines the scale. The algorithm accepts all new points, whether they increase or decrease the Wald statistic value. Namely, each point will be a new point, and this new point is the base point to generate the next point. Accepting all the points avoids the trap of local minima. This approach ensures a comprehensive search within the bounds. An annealing schedule is implemented to gradually lower the temperature throughout the algorithm's execution. With the reduction in temperature, the algorithm narrows its search scope to achieve convergence at a minimum. The best point will be stored during the search process.

In summary, indirect inference testing is a useful method for verifying that the model fits the actual data. The testing highly relies on the actual data. Besides, the uniform testing criterion allows the comparison of different models related to data fitness. Checking which model fits the data better is one of the purposes of this thesis. This estimation method has been utilized to find the optimal set of parameters.

3.33 The choice of auxiliary model

Following Meenagh et al. (2012), a VARX model is used as an auxiliary. The first reason for choosing the VARX model is that a reduced form of a log-linearized DSGE model can often be approximately expressed as a VAR. Meenagh et al. (2009) have employed this characteristic. Le et al. (2016) indicate that the reduced form of the Smets-Wouters (2007) DSGE model is approximately represented as a 7VAR(4) model. The use of a level VAR requires stationary shocks. If any non-stationary shock exists in a DSGE model, a VECM (Vector Error Correction Model) will be used, which can be approximately represented as a VARX model. In this thesis, there are two non-stationary shocks, specifically two technology shocks. Therefore, the VARX model is required as an auxiliary model. The following explanation of choosing the VARX model, derived by Meenagh et al. (2012), supports this approach.

The equation (3.70) displayed the solution of a log-linear DSGE model.

$$A(L)y_t = B(L)E_t y_{t+1} + C(L)x_t + D(L)e_t \tag{3.70}$$

Where e_t is iid with zero mean. y_t and x_t are vectors of ρ endogenous variables and q exogenous variables, individually. Equation (3.70) displays the dynamic relationship between endogenous variables y_t and the expected value of these endogenous variables $E_t y_{t+1}$, the exogenous variables x_t ,and shocks e_t.

x_t is assumed to follow equation (3.71).

$$\Delta x_t = a(L)\Delta x_t + d + c(L)\varepsilon_t \quad (3.71)$$

Where d is a vector of constant term and e_t is iid with zero mean. The exogenous variables can be stationary or non-stationary. Therefore, y_t also can be non-stationary. The symbol L represents the lag operator. $A(L), B(L), C(L) \ldots$ in equation (3.70) and (3.71) are polynomial functions with roots that are not within the unit circle.

The general solution of y_t can be expressed as (3.72)

$$y_t = G(L)y_{t-1} + H(L)x_t + f + M\,(L)e_t + N(L)\varepsilon_t \quad (3.72)$$

Where f is a vector of constant term, and ε_t is iid with zero mean. Same to $A(L), B(L), C(L) \ldots, G(L), H(L)$ ... in equation (3.72) have roots that are not within the unit circle. Because y_t and x_t are non-stationary, the solution exhibits ρ cointegration relationships.

$$y_t = [I - G(1)]^{-1}[H(1)x_t + f] = \Pi x_t + g \quad (3.73)$$

In the long run, the model solution is provided by equations (3.74), (3.75) and (3.76).

$$\overline{y_t} = \Pi \overline{x_t} + g \quad (3.74)$$

$$\overline{x_t} = [I - a(1)]^{-1}[d_t \; + c(1)\xi_t] \quad (3.75)$$

$$\xi_t = \sum_{i=0}^{t-1} \varepsilon_{t-s} \quad (3.76)$$

Equation (3.74) shows how the long-run value of the endogenous variables $\overline{y_t}$ depends on the long-run values of the exogenous variables $\overline{x_t}$ and the constant vector term g. From equation (3.75), $\overline{x_t}$ incorporates the effects of deterministic components and stochastic shock. Where $\bar{x}_t^D$ denotes deterministic trend which is $[I - a(1)]^{-1} d_t$. Where $\bar{x}_t^D$ represents a stochastic trend is $[I - a(1)]^{-1} c(1) \xi_t$. ξ_t has the cumulative sum of the past shocks ε_t.

Equation (3.77) displays the solution for y_t, which can be expressed as VECM.

$$\begin{aligned} \Delta y_t &= -[I - G(1)](y_{t-1} - \Pi x_{t-1}) + P(L)\Delta y_{t-1} + Q(L)\Delta x_{t-1} + f + M(L)e_t \\ &\quad + N(L)\varepsilon_t \\ &= -[I - G(1)](y_{t-1} - \Pi x_{t-1}) + P(L)\Delta y_{t-1} + Q(L)\Delta x_{t-1} + f + \omega_t \end{aligned} \quad (3.77)$$

$$\omega_t = M(L)e_t + N(L)\varepsilon_t \quad (3.78)$$

ω_t is a mixed moving average process, (3.77) can be written as VARX seen equation (3.79).

$$\Delta y_t = K(y_{t-1} - \Pi x_{t-1}) + R(L)\Delta y_{t-1} + S(L)\Delta x_{t-1} + g + \zeta_t \quad (3.79)$$

ζ_t is iid zero mean process.

For $\overline{y_t} - \Pi \overline{x_t} - g = 0$, Another way to represent VECM is (3.80):

$$\Delta y_t = K(y_{t-1} - \overline{y_{t-1}} - \Pi(x_{t-1} - \overline{x_{t-1}})) + R(L)\Delta y_{t-1} + S(L)\Delta x_{t-1} + h + \zeta_t \quad (3.80)$$

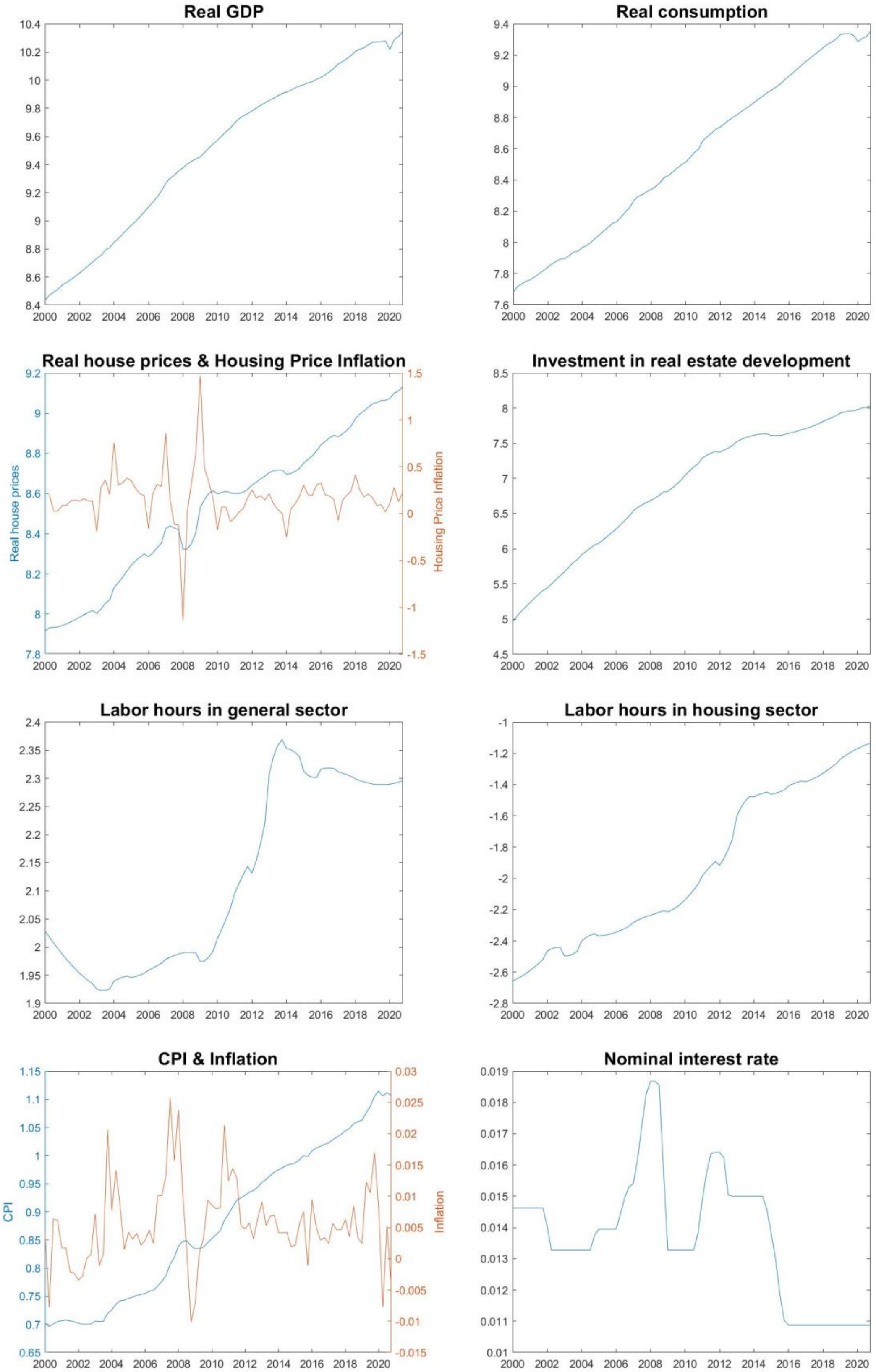
Both equations (3.79) and (3.80) can serve as the auxiliary model. The equation (3.80) distinguishes between the influence of trend factors on x_t and temporary deviations from its trend. These two factors have varying impacts on the model; therefore, it is necessary to distinguish them in the data. Equation (3.80) can also be estimated using the OLS method. In this thesis, equation (3.80) will be used as an auxiliary model.

3.4 Empirical Results

3.41 Data and Calibration

Description of Data

Data spanning from 2000Q1 to 2020Q4 are collected for various variables, including household consumption, housing prices, wages in the regular and real estate sectors, labor inputs for these sectors, interest rates, real estate investments, housing output, total consumption, total investment, Consumer Price Index (CPI), and working-age population (pop). Yearly data were transformed into quarterly intervals using EViews by the quadratic sum method or the quadratic average method. Seasonal adjustments were applied using the U.S. Department of Commerce X-12 quarterly seasonal adjustment method, whenever applicable. All variables, where applicable, are adjusted by the CPI and working population and are expressed in natural logarithms. Interest rates are quarterly interest rates. The housing price index was derived from the quarter-on-quarter growth of housing prices in real terms, while inflation was computed based on the quarter-on-quarter growth of CPI. These datasets were subsequently utilized for estimation and evaluation. The following Figure 3.1 displays the real-term per capita data in natural logarithms. Appendix B displays information on data sources and processing procedures in detail and a statistical summary of data.


Real GDP
Real consumption
Real house prices & Housing Price Inflation
Real house prices
Housing Price Inflation
Investment in real estate development
Labor hours in general sector
Labor hours in housing sector
CPI & Inflation
CPI
Inflation
Nominal interest rate

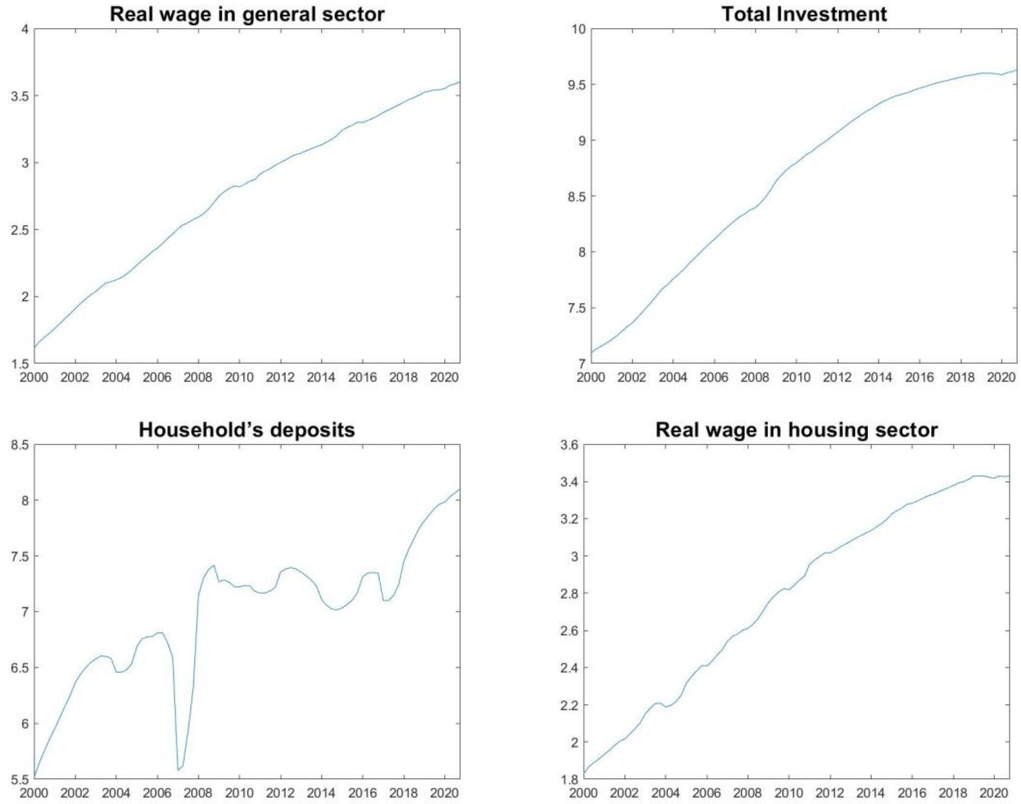


Figure 3.1 Chinese macroeconomic data: 2000Q1 to 2020Q4

The housing price inflation figure shows a short increase in the housing price rate around 2003, followed by a sharp increase from 2005 to 2006. The upward trend was interrupted by the financial crisis, resulting in a temporary drop in 2008, followed by a rebound to higher levels in 2009. After 2009, the rate seems to be controlled well, with no unexpected significant decrease or increase.

Calibration

This section presents the calibrated coefficients of the Benchmark DSGE model before estimation. Some coefficients are derived from existing literature, while others are based on data specific to China. Overall, all the coefficient values are set according to theory or data in China. Specifically, Table 3.1 shows the values of coefficients setting based on literature. Table 3.2 presents coefficients determined by steady-state ratios derived from Chinese data. The model will undergo testing using these calibrated parameters; if the model fails the tests, adjustments will be made using indirect inference estimation.

Regarding the value based on the literature, the household discount factor is set at 0.985, following Liu and Ou (2021) and Gai, Minford, and Ou (2020), which implies a steady-state annual real interest rate of around 6%. In the benchmark model, the discount factors for households and firms are assumed to be the same.

The coefficients ι and ψ represent the relative risk aversion of households in the general goods market and the housing market, respectively. The values $1/\iota$ and $1/\psi$ correspond to the elasticity of intertemporal substitution, indicating how responsive the growth rate of consumption is to the real interest rate. We set ι to 2 and ψ to 1, in line with Walsh (2003) and Iacoviello (2005). The higher value of ι (2) compared to ψ (1) suggests that the elasticity of intertemporal substitution in the general goods market (0.5) is lower than in the housing market (1). Consequently, household consumption growth in the housing market is more sensitive to changes in the interest rate than in the general goods sector, reflecting real-life household behavior.

For the parameters of the disutility of labor, $\aleph$ and ϑ, the first one describes the inverse elasticity of labor supply, and the second one describes the inverse elasticity of substitution across hours in two sectors, the normal good sector and housing sector. We select the value of the inverse of the elasticity of labor supply $\aleph$ at 0.5, based on findings from Iacoviello and Neri (2010) and Liu and Ou (2021). This value implies an elasticity of labor supply of 2, indicating the responsiveness of labor supply to changes in wages. Regarding the parameter ϑ, Horvath (2000) indicates that ϑ equals zero, implying perfect substitutability of hours between the two sectors. Positive values of ϑ indicate varying degrees of sector specificity, suggesting that relative labor hours are less responsive to differences in sectoral wages, as noted by Horvath (2000). He calibrated this parameter to approximately one. Based on the empirical analysis by Liu and Ou (2021), We set the value of ϑ at 0.5.

As for the parameters related to firms, we set the intertemporal elasticity of substitution to 2 (ς=2), which is the same as that in the household sector. Following Liu and Ou (2021), we set the quarterly depreciation rates δ_h, $\delta_{k,c}$, $\delta_{k,h}$.The depreciation rate of housing δ_h is 0.015. The depreciation rates of productive capital in the general good sector and in the housing sector equal 0.03, $(\delta_{k,c} = 0.03)$ and 0.04 $(\delta_{k,h} = 0.04)$, respectively, which is in line with the previous literature. The capital share in normal goods production is 0.34, and in house production, it is 0.2, according to Liu and Ou (2021). Assuming constant returns to scale (CRS), the labor share in general goods production is 66%, in house production, it is 80%

We set the Calvo stickiness parameter φ to 0.75, based on Chen, Funke, and Paetz (2012). This parameter represents the probability that firms are unable to adjust prices in each period. A higher φ indicates longer intervals between price adjustments. The monetary policy parameters are calibrated following Taylor (1993) and Liu and Ou (2021), setting $\rho_R = 0.75$, $\varphi_\pi = 1.5$ and $\varphi_x = 0.125$. The interest rate responds more to inflation than to output growth or the previous period's interest rate, which reflects the standard Taylor rule principle. For the capital equation, we follow Meenagh et al. (2010). The detailed values of these calibrated parameters are provided in Table 3.1.

For the final section, we establish the steady-state ratios. Table 3.2 presents the steady-state ratios, including Non-residential output, Residential output, Consumption, Total investment, Household consumption, Firm consumption, non-housing sector investment, and Housing sector investment. These ratios are derived from quarterly data collected in China from 2000Q1 to 2020Q4.

Table 3.1 Calibrated Parameters – Benchmark model

Definition	Parameter	Calibration
Households		
discount factor of household	β	0.985
elasticity of household consumption	ι	2
elasticity for housing	ψ	1
inverse elasticity of labor supply	$\aleph$	0.5
labor substitutability	ϑ	0.5
Firms		
elasticity of firm consumption	ς	2
depreciation rate of housing	δ_h	0.015
depreciation rate of capital in goods sector	$\delta_{k,c}$	0.03
depreciation rate of capital in housing sector	$\delta_{k,h}$	0.04
Capital share (normal goods production)	α	0.34
Capital share (house production)	ω	0.2
Calvo contract non-resetting probability	φ	0.67
Monetary policy		
monetary policy inertia	ρ_R	0.75
interest-rate response to inflation	φ_π	1.5
interest-rate response to output growth	φ_x	0.125
Capital demand coefficient	k_{c1}	0.51
Capital demand coefficient	k_{c2}	0.47
Capital demand coefficient	k_{c3}	0.02
Capital demand coefficient	k_{c4}	0.25
Capital demand coefficient	k_{h1}	0.51
Capital demand coefficient	k_{h2}	0.47
Capital demand coefficient	k_{h3}	0.02
Capital demand coefficient	k_{h4}	0.25

Table 3.2 Steady state ratios – Benchmark Model

Definition	Parameter	Data
Non-residential output ratio	Y/GDP	0.925
Residential output ratio	Y_h/GDP	0.075
Consumption ratio	C/Y	0.5891
Investment ratio	I/Y	0.4108
Household consumption ratio	c/C	0.70
Firm consumption ratio	c_e/C	0.30
Investment ratio for non-housing sector	i_c/I	0.83
Investment ratio for housing sector	i_h/I	0.17

3.42 Evaluation and estimation

Model fit

The indirect inference method will be applied to estimate and evaluate the model in this sector. We have a calibrated benchmark model, and we need to choose an auxiliary model. We choose VARX as an auxiliary model, which has been discussed in section 3.33. The output, nominal interest rate and housing prices have been chosen as endogenous variables in an auxiliary model. In terms of the output, the output is one of the important variables of a macro model. Besides, one of the targets of monetary policy in China is to promote economic growth. The output can directly reflect the economic growth situation. Hence, it is essential for the model to provide a reasonable explanation for output behavior. Interest rates are included because the government adjusts benchmark rates to influence the housing market. We talked about the close relationship between housing prices and the adjustment of the benchmark interest rates, in Chapter 1.1. For the last variables, the essential element in the thesis is housing prices; we are exploring how monetary policy affects housing prices. So, the variable of housing prices should also be included in an auxiliary model. The model should effectively explain housing price behavior. In summary, output, nominal interest rate, and housing prices are three endogenous variables chosen for the auxiliary model. There are 12 VARX coefficients considered in the Wald test, to be specific, nine coefficients of lagged endogenous variables and three variances of the disturbances.

During the estimation process, if the macroeconomic model does not pass the test, the calibrated parameters will serve as initial values for the indirect inference estimation. Table 3.3 presents the calibrated and estimated parameters in each column, along with the test statistics and P-values for the macroeconomic model with these parameters. This section will discuss the empirical results based on the indirect inference method.

Table 3.3 Model Coefficients

Definition	Parameter	Calibration	Estimation
Household			
discount factor of household	β	0.985	Fixed
elasticity of consumption	ι	2	2.246098
elasticity of consumption in houses	ψ	1	1.114649
Inverse elasticity of labor supply	$\aleph$	0.5	0.595277
Elasticity of labor substitution	ϑ	0.5	0.437682
Firm			
elasticity of firm consumption	ς	2	2.271183
depreciation rate of housing	δ_h	0.015	Fixed
depreciation rate of capital in goods sector	$\delta_{k,c}$	0.03	Fixed
depreciation rate of capital in housing sector	$\delta_{k,h}$	0.04	Fixed
Capital share (normal goods production)	α	0.34	0.694728
Capital share (house production)	ω	0.2	0.212652
Calvo contract non-resetting	φ	0.67	0.751866

probability			
monetary policy inertia	ρ_R	0.75	0.84493
interest-rate response to inflation	φ_π	1.5	1.363183
interest-rate response to output growth	φ_x	0.125	0.161848
Capital demand coefficient	k_{c1}	0.51	0.703043
Capital demand coefficient	k_{c2}	0.47	0.276586
Capital demand coefficient	k_{c3}	0.02	0.010011
Capital demand coefficient	k_{c4}	0.25	0.269579
Capital demand coefficient	k_{h1}	0.51	0.764432
Capital demand coefficient	k_{h2}	0.47	0.223012
Capital demand coefficient	k_{h3}	0.02	0.012556
Capital demand coefficient	k_{h4}	0.25	0.257197
Trans-Wald (y, qh, R)		**7.6**	**1.0128**
p-value		**0**	**0.11**

The empirical results indicate that the model with calibrated parameters was initially rejected but passed after estimation. First, we evaluated the DSGE model with the calibrated data using the indirect inference evaluation method. The test statistic value is 7.6, which exceeds the critical value of 1.645, placing it in the rejection region. The P-value was 0, signifying that the model did not pass the test. These results suggest that the benchmark DSGE model with calibrated parameters cannot explain the behavior of the data, implying it is unable to simulate data with real-world data properties. This discrepancy could stem from either model specification issues or parameter inaccuracies.

To further investigate the model equation issues or parameter inaccuracies, we apply the indirect inference estimation method to search for the parameters that minimize the value of the transformed Wald test. We then reevaluated the model with these new parameters to determine if it could pass the test. The table shows that the transformed Wald test value decreased to 1.0128, which is below the critical value of 1.645, indicating that the test statistic does not lie in the rejection region. The P-value increased to 0.11, above the threshold of

0.05, meaning the model passed the test. This suggests that the DSGE model with estimated parameters can explain the performance of real-life data. The reduction of the transformed Wald test value from 7.6 to 1.0128 demonstrates that the model's fit to the data improved significantly after applying the indirect inference estimation method.

For the estimated parameters, the fourth column in Table 3.3 displays the best set of parameters. It is noted in Table 3.3 that certain parameters remain fixed, including the household discount factor β, the depreciation rate of housing δ_h, and the depreciation rates of capital in the goods sector $\delta_{k,c}$ and the housing sector $\delta_{k,h}$. These parameters are held fixed because they are either challenging to estimate accurately or are better identified using additional information.

The change of parameters will be discussed. In the household sector, the table reveals that following estimation, the elasticity of consumption in the general goods sector ι has increased from 2 to 2.24. Similarly, the elasticity of consumption in the housing sector ψ has increased from 1 to 1.11. The estimated ι (2.24) remains higher than the estimated ψ (1.11). A higher ι indicates lower intertemporal substitution in the general goods sector, implying that the responsiveness of consumption in the general good sector to the real interest is relatively insensitive. The increased elasticity of consumption in the housing sector suggests that consumption in housing is relatively less sensitive to changes in real interest rates compared to its calibrated value. The behavior of households in the estimated model regarding sensitivity to changes in the real interest rate in both the general goods and housing sectors aligns with typical household behaviors observed in China. Consumption in the general goods sector demonstrates minimal responsiveness, while consumption in the housing sector shows greater sensitivity to fluctuations in the real interest rate in China. For inverse elasticity of labor supply $\aleph$, it increases from 0.5 to 0.595277, which implies the falling of elasticity of labor supply from 2 to around

1.68. It indicates that the labor supply becomes less sensitive to the change in real wage compared to its calibrated value. The elasticity of labor substitution across sectors of general goods and houses declines from 0.5 to 0.437682. This positive value suggests varying degrees of sector specificity in labor allocation.

Regarding the firms' parameters, the elasticity of firm consumption ς increases from 2 to 2.27, stating that firm consumption is less sensitive to changes in the real interest rate compared to its calibrated value. The capital share in normal goods production α increases from 0.34 to 0.694, which is similar to the empirical results of Gai, Minford, and Zhirong (2020), who found an increase from 0.34 to 0.79. They analyzed the DSGE model of China and used the indirect inference method to estimate parameters. The capital share in housing production ω slightly decreases from 0.2 to 0.21, showing minimal change.

The Calvo contract non-resetting probability φ increases from 0.67 to 0.75, indicating a 'sticker' economy. For Taylor's rule, inflation has more impact on real interest rates than the other two elements. The value of monetary policy inertia ρ_R rises from 0.75 to 0.84493. The value of interest-rate response to inflation φ_π decreases from 1.5 to 1.363183. Interest-rate response to output growth φ_x increases from 0.125 to 0.1618. Despite the decrease in the estimated value of the interest-rate response to inflation, it remains higher than the other two parameters. Regarding the capital demand parameters, the values for k_{c1}, k_{c2}, k_{c3}, and k_{c4} in the general firm sector shift from 0.51, 0.47, 0.02, and 0.25 to 0.70, 0.27, 0.01, and 0.27, respectively. In contrast, in the housing sector, k_{h1} increases from 0.51 to 0.76, k_{h2} changes from 0.47 to 0.22, k_{h3} adjusts from 0.02 to 0.012, and k_{h4} remains stable around at 0.25.

3.43 Residuals and shocks property

This section analyses residuals and shocks' properties to determine each residual's autoregressive process. We collect the residuals based on the estimated model and unfiltered data. Stationarity tests, including the Augmented Dickey-Fuller (ADF) test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test, are all utilised to investigate the residuals' properties. The results of the ADF and KPSS tests may be different because they have different null hypotheses. The null hypothesis of the ADF test is a series has a unit root, while that of the KPSS is that the series is stationary. The results table of the stationarity test provides the potential residual process. Eventually, the Wald test determines the residual process characteristics. After knowing the properties of each residual, we model each residual using its AR process. Table 3.4 displays the stationarity test results and estimated AR coefficients.

From the stationarity tests, it is concluded that two productivity shocks should be regarded as non-stationary series. The remaining six are either stationary or trend stationary. For both technology shock shocks, the ADF test shows P-values greater than 0.05, indicating the null of having a unit root cannot be rejected. Meanwhile, the KPSS test rejects the null hypothesis of stationary with LM-statistic greater than critical. Two tests suggest that two productivity shocks are non-stationary. Therefore, these two follow the ARIMA (1,1,0) process. Monetary policy shock, Labor supply shock and inflation shock are assumed to follow AR (1) processes, as the ADF and KPSS tests indicate that these three are stationary.

The tests display conflicting conclusions regarding government spending shock, preference shock, and housing demand shock. At least one test provides evidence of stationarity. Besides, with the AR (1) assumption for these three residuals, the model passes the Wald test. In conclusion, two productivity shocks are assumed to be non-stationary processes, and others are assumed to be stationary processes in the model. Figures 3.2 and 3.3 illustrate the residual and innovation for each shock.

Table 3.4 Stationarity test of residuals

Residual	Stationary Test ADF p-value H0: non-stationary	 KPSS LM-Stat. H0: stationary	Conclusion	Estimated coefficient
Government spending	0.0166	1.056184***	Stationary	0.977068
Preference	0.1212	0.168209	Trend Stationary	0.957671
Labor supply	0.0287	0.200898	Stationary	0.947597
Housing demand	0.3323	0.274935	Trend Stationary[b]	0.96016
Inflation	0.0000	0.049301	Stationary	0.503197
Monetary policy	0.0000	0.190392	Stationary	0.441665
Productivity (general goods)	0.0902	1.074359***	Non-stationary	0.664525
Productivity (houses)	0.9676	0.990815***	Non-stationary	0.555459

1. ADF test: A p-value of less than 0.05 and 0.1 indicates the rejection of the null hypothesis of unit root at 5% and 10%.
2. KPSS test: The LM-statistic value with ** and *** denotes rejection of the null hypothesis of stationarity at the 5% and 1% levels, respectively. The critical values are 0.739 at 1%, 0.463 at 5%, and 0.347 at 10%.
3. [b] denotes that the series is trend stationary with AR (1) less than 1.

Figure 3.2 Model Structure Residual

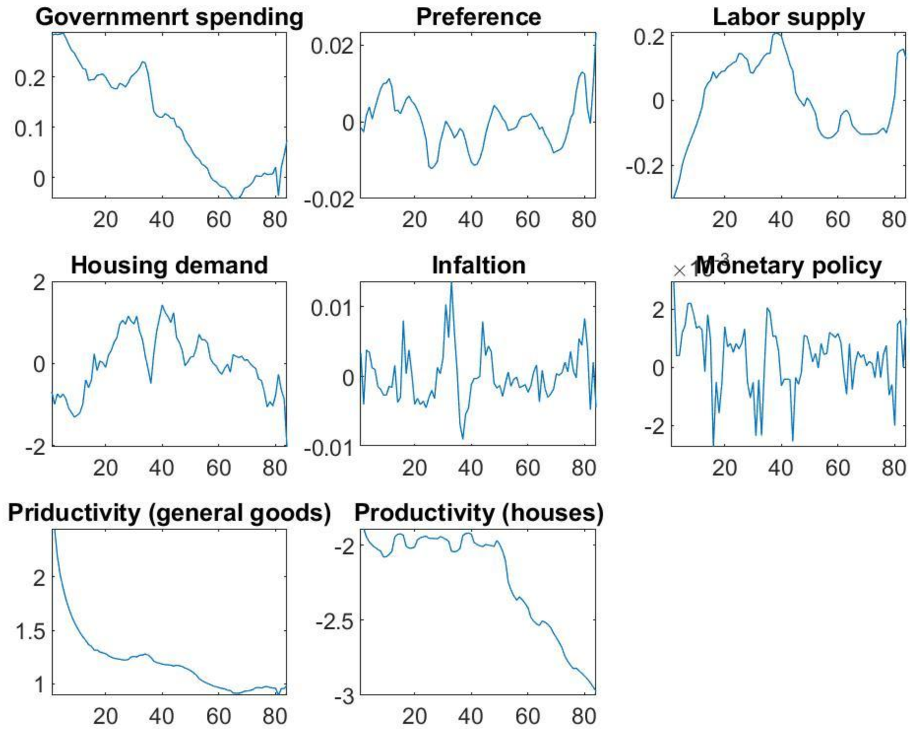
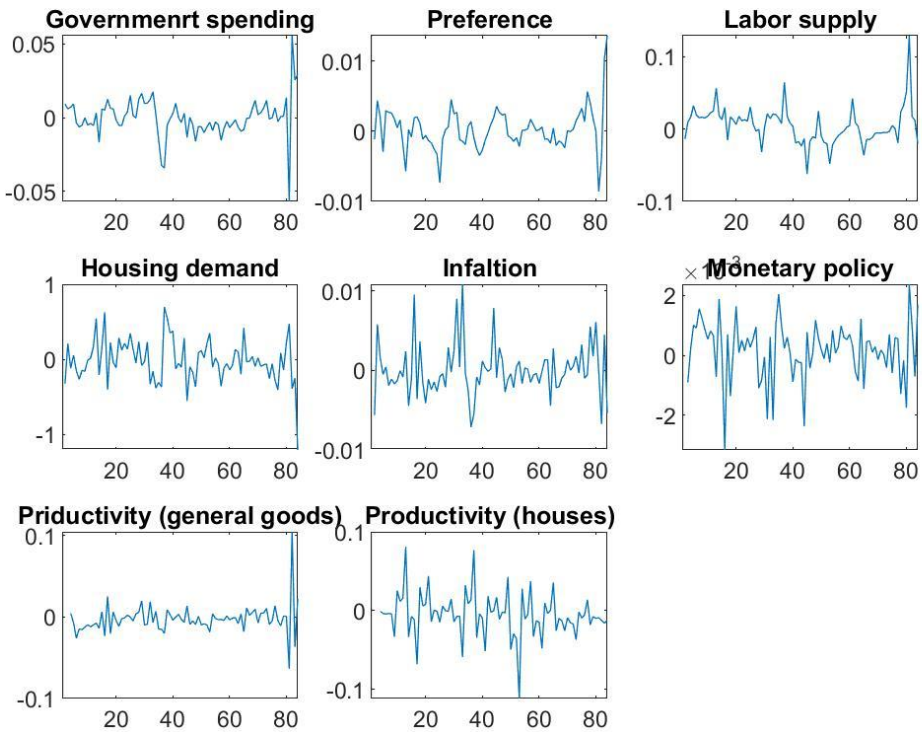


Figure 3.3 Model Innovation



3.44 Properties of the Model

In the previous section, we get the estimated DSGE model with the indirect inference estimation, which passed the test. In this section, we employ this estimated DSGE model to address the following research questions: How are housing prices affected under the DSGE model with the Taylor rule? What are the main drivers of housing price dynamics?

To analyze the factors influencing housing prices, we investigate the variance decomposition, impulse response function of key variables, and the historical decomposition of housing prices. In the variance decomposition, we consider variables such as housing prices, the new output of houses, interest rates, inflation, and GDP. For the impulse response function, our focus is on variables like consumption, output in the general sector, which reflect household behavior in the general sector, housing demand, housing prices, and output, representing the behavior of firms.

Variance decomposition

Variance decomposition analysis identifies how each structural shock contributes to the forecast error variance of endogenous variables over different time horizons. In this section, the variance decomposition will be used to investigate what drives fluctuations in the Chinese economy. The following tables present the variance decomposition of forecast errors for housing prices, housing output, interest rates, inflation, and GDP across various time horizons: short-term (quarterly and one year), medium-term (2.5 years and ten years), and long-term (25 years).

Housing prices are a key element in this thesis, and the determinants of housing prices will be discussed first (Table 3.5). In the short run, housing demand shocks and technology shocks in the general sector play significant roles in the variance of housing prices, with the former accounting for 39.85% and the latter for approximately 46.53%. Housing productivity shocks also contribute to the volatility of housing prices, increasing from 11.92% in the first quarter to 33.21% in the long run. In the long run, housing prices are driven primarily by technology shocks in the general sector and housing sector, accounting for about 63.45% and 33.21%, respectively. This is because technology shocks have permanent effects. The contributions of monetary policy shocks, preference shocks, and inflation shocks are negligible.

The next variable related to the housing sector is the new output of houses. Similar to housing prices, housing demand shocks play a significant role in the volatility of new housing output, accounting for about 87% in the short run (one quarter). Additionally, labor supply shocks explain part of the variance in new housing output, accounting for 11.73% in the short run (a quarter). The impact of technology shocks in the housing sector significantly increases in a year to 39.8% and continues to increase to 75% in the long term. In the long run, the impacts of technology shocks in the general goods sector, housing demand shocks, and labor supply shocks are 10.40%, 13.17%, and 1.33%, respectively. The effects of monetary policy, preference, and inflation shocks are approximately zero in all periods.

The results from the variance decomposition show that housing demand shocks cause most of the short-term changes in the housing market, while technology shocks increasingly prevail in the long run. This is consistent with the non-stationary properties of two productivity shocks, which have permanent effects on the economy. In the model, the productivity shock in the housing sector is interpreted as an exogenous supply shock. The declining contribution of demand shocks and the growing influence of productivity shocks suggest that short-term housing market dynamics are demand-driven, but long-term trends are primarily affected by supply-side improvements. The essential role of housing demand shocks in the Chinese housing market has also been widely mentioned in the literature by Liu and Ou (2021) and Gai, Minford and Ou (2020). However, some literature mentions the importance of monetary policy shocks. In the benchmark model we have, the monetary policy shock has no significant impact on housing prices.

Table 3.5 Variance decomposition

Variable	Forecast horizon	$A_{c,t}$	$A_{h,t}$	g_t	$\varepsilon_{h,t}$	$\varepsilon_{l,t}$	$\varepsilon_{MP,t}$	$\varepsilon_{p,t}$	$\varepsilon_{\pi,t}$
qh	1	46.53	11.92	0.66	39.85	0.08	0.56	0.00	0.40
	4	48.44	14.21	0.80	35.54	0.12	0.41	0.00	0.47
	10	54.57	17.84	0.81	26.09	0.13	0.24	0.00	0.31
	40	64.22	27.64	0.37	7.57	0.05	0.07	0.00	0.09
	100	63.45	33.21	0.15	3.11	0.02	0.03	0.00	0.03
y_h	1	0.00	1.02	0.18	87.00	11.76	0.00	0.04	0.00
	4	0.11	39.80	0.09	53.19	6.79	0.00	0.03	0.00
	10	0.13	60.35	0.04	35.34	4.12	0.00	0.02	0.00
	40	1.30	76.78	0.03	19.83	2.02	0.01	0.01	0.01
	100	10.40	75.03	0.04	13.17	1.33	0.01	0.01	0.01

For the non-housing variables, the variance decomposition of output, inflation and interest rates will be discussed. Table 3.6 indicates the common cause of movement in these three variables. The technology shock in the general sector significantly influences the variance of interest rates, inflation, and GDP. In the short run, technology shock explains 69%, 58.76%, and 39.29% of the fluctuations in interest rates, inflation, and GDP, respectively, and has lasting and undiminished effects. For other points, in terms of interest rates, inflation shock, monetary policy, and government spending shock account for 15.14%, 7.58%, and 6.31% of the variance in one quarter. The impact of inflation and monetary policy shocks decreases to 5.91% and 3.29% in the long run. The labor supply shock initially explains 0.73% of the change in interest rates, increasing to 10% in the long run.

For inflation volatility, the second most important factor is the inflation shock, which decreases from 33.64% to 19.30%. The contributions of government spending, labor supply, and monetary policy shocks are 3.18%, 2.61%, and 1.64% in the very short term. The first two increase to 8.93% and 7.67% in the long run, while the impact of monetary policy shock diminishes over time.

Regarding the volatility of output, government spending shock contributes significantly, explaining 45.4% initially and decreasing to 16.6% in the long run. Housing demand, labor supply, and monetary policy shocks contribute 6.49%, 2.59%, and 3.03% in the short run, decreasing to 2.72%, 1.13%, and 0.19% in the long run. The remaining shocks have minor impacts.

Overall, technology shock in the general sector accounts for a substantial portion of fluctuations in the variables for the non-housing market and the whole economy, with additional contributions from inflation and government spending shocks.

Table 3.6 Variance decomposition

Variable	Forecast horizon	$A_{c,t}$	$A_{h,t}$	g_t	$\varepsilon_{h,t}$	$\varepsilon_{l,t}$	$\varepsilon_{MP,t}$	$\varepsilon_{p,t}$	$\varepsilon_{\pi,t}$
R	1	69.70	0.14	6.31	0.35	0.73	7.58	0.06	15.14
	4	70.56	0.08	6.91	0.22	2.40	6.57	0.11	13.15
	10	71.43	0.10	9.47	0.21	5.00	4.63	0.19	8.98
	40	68.11	0.13	12.37	0.21	9.35	3.39	0.31	6.13
	100	67.46	0.14	12.58	0.21	10.08	3.29	0.33	5.91
π	1	58.76	0.05	3.18	0.03	2.61	1.64	0.08	33.64
	4	63.44	0.08	5.24	0.05	4.19	1.75	0.14	25.11
	10	63.02	0.09	7.06	0.08	5.60	1.60	0.18	22.36
	40	62.26	0.10	8.75	0.11	7.37	1.57	0.24	19.61
	100	62.07	0.10	8.93	0.11	7.67	1.56	0.25	19.30
GDP	1	39.29	1.38	45.43	6.49	2.59	3.03	0.04	1.75
	4	40.35	0.57	44.30	6.59	3.56	2.21	0.02	2.40
	10	45.41	0.27	41.11	6.17	4.07	1.30	0.01	1.65
	40	63.11	0.40	28.91	4.08	2.49	0.44	0.00	0.58
	100	78.04	1.05	16.62	2.72	1.13	0.19	0.00	0.25

Historical decomposition

Historical decomposition is a technique used to analyze the historical movement of a variable by breaking it down into the contributions of different shocks. The figure displays the contribution of various shocks to the volatility of real housing prices from 2000Q1 to 2020Q4. The model includes eight shocks: government spending shock, preference shock, labor supply shock, housing demand shock, inflation shock, monetary policy shock, and productivity shocks for both sectors. In Figure 3.4, in general, the housing demand shock primarily affected housing prices between 2000 and 2020, with the relatively small contribution of technology labor supply and government spending shocks.

In 1998, in response to the Asian financial crisis and to expand domestic demand, China launched a housing market reform. The policy focus shifted from stimulating exports to boosting domestic demand, with the real estate industry identified as a key sector for support. The housing system transitioned from government-run welfare to a market-based system, and the banking system started improving concurrently in 1998. With the completion and improvement of the banking system and the support for the real estate industry by the Chinese government, housing demand increased sharply in 2005. The positive housing demand shock significantly contributed to the substantial rise in housing prices since 2005. Unlike mature housing markets in developed countries, China's market required government intervention to stabilize. To address signs of overheating and upward pressure in real estate, many tightening policies were issued after 2005. Like, in 2007, the central bank raised the benchmark lending rate six times, cancelled the preferential lending rate, and increased the lending rate to 1.1 times the benchmark rate. The down payment requirement for purchasing a second property was raised to no less than 40% in December 2007. These measures have curbed investment fever but did not stop housing prices from rising.

The 2008 financial crisis severely impacted the Chinese housing market, causing a significant fall in housing prices. International economic uncertainty led households to lose confidence in the housing market, preferring to save rather than invest in housing, which decreased housing demand. In response, the government issued many loose policies to support the real estate market in late 2008. As a result, housing prices temporarily dropped in 2008 and rebounded in 2009. Housing prices increased dramatically in 2009 due to the positive housing demand shock and the technology shock in the general sector, reaching their previous peak.

To ensure the stable development of the housing market, stringent policies were introduced, including financial restrictions for homebuyers, tax policies, land supply policies, and housing supply policies. These policies effectively cooled the housing market, and the figure shows that housing prices decreased from 2010 onward, alongside decreasing housing demand shock. Since 2016, the central government has maintained the stance that "houses are for living in, not for speculation." The figure shows that housing prices began to stabilize in 2016 with a balance among the housing demand shock, technology shock in the general sector, labor supply shock, and government spending shock. However, the outbreak of COVID-19 disrupted this equilibrium in 2020, causing a sharp decline in housing prices due to a decrease in the housing demand shock.

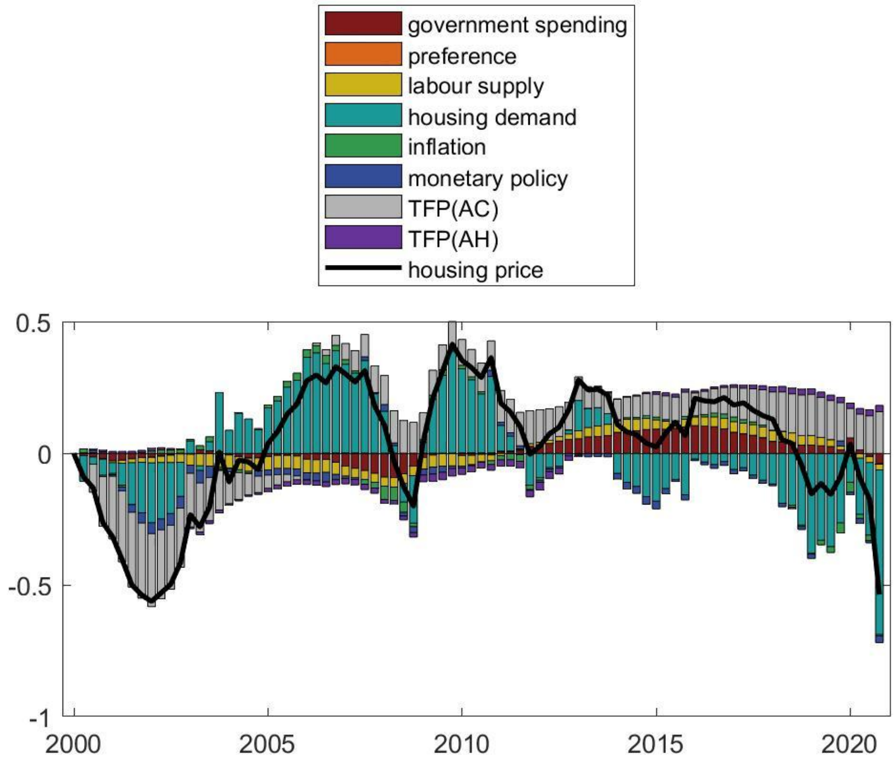


Figure 3.4 Historical decomposition of house prices

Impulse response functions

The impulse response functions generated from the estimated benchmark model are analyzed to investigate the reaction of key variables in the economy. Variance decomposition and historical decomposition in the previous section highlighted that the housing demand shock is a critical factor in the Chinese housing market. In this section, we consider housing demand shocks, technology shocks in both sectors, and monetary policy shocks in the impulse response functions. To clearly view the reactions to these shocks in the general sector and housing sector, the first row of graphs displays the reactions of central variables in the general sector, and the second row shows the reactions in the housing sector. Specifically, the first row presents the reactions of consumption, output in the general sector, and inflation. The second row illustrates the reactions of housing demand, output in the housing sector, and housing prices. The third row depicts the reactions of the real interest rate and GDP. The bottom right corner of the sub-graphs displays the shock. We set the standard deviation of shocks at 0.02. The reactions of the other variables are available in Appendix C.

Housing demand shock

As a crucial element in the economy, housing demand shocks warrant initial discussion. Figure 3.5 illustrates the responses of key variables in the Chinese economy to a positive housing demand shock. In the model, the housing demand shock is assumed to follow the exogenous process. $ln\varepsilon_{h,t} = \rho_h ln\varepsilon_{h,t-1} + u_{h,t}$. The increase in housing demand caused by a positive housing demand shock is straightforward. Increased housing demand leads to higher housing prices. To meet this elevated demand, housing output increases. The housing boom also stimulates production in the general sector, resulting in a modest output increase compared to the housing sector. The positive housing demand shock shifts consumption preferences from normal goods towards housing, causing a decline in consumption. Consequently, the increase in production across both sectors leads to a rise in GDP.

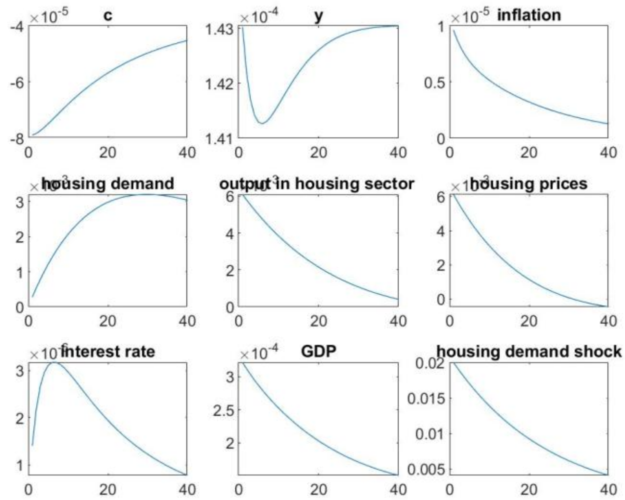


Figure 3.5 IRF (housing demand shock)

Monetary policy shock

The dynamics of the model with a positive monetary shock are displayed in Figure 3.6. The monetary policy shock follows $ln\varepsilon_{MP,t} = \rho_{MP} ln\varepsilon_{MP,t-1} + u_{MP,t}$. A positive $\varepsilon_{MP,t}$ indicates a contractionary monetary policy shock. Figure 3.6 illustrates the impact of this shock on key economic variables. A positive monetary policy shock leads to a decrease in most variables due to an increase in the real interest rate. In the general goods sector, tight monetary policy reduces consumption, easing upward pressure on prices and leading to a decrease in the inflation rate. This decline in consumption is coupled with a decrease in the production of general goods. Similarly, contractionary monetary policy inhibits activity in the housing market, resulting in a decrease in housing demand, housing output, and housing prices. From the perspective of the total economy, a contractionary monetary policy shock leads to a decline in total output in both sectors, causing a decrease in GDP.

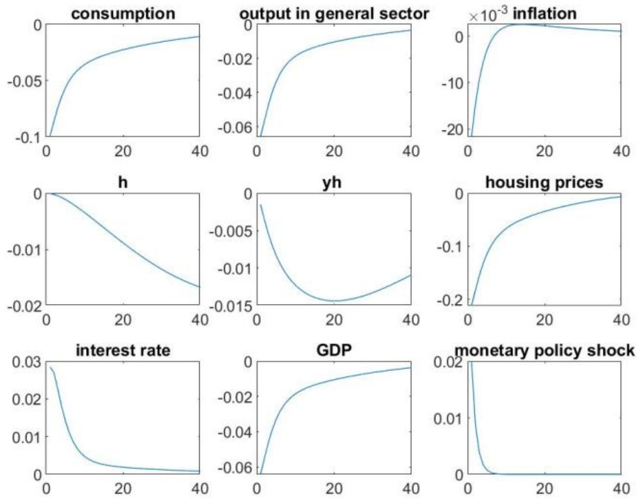


Figure 3.6 IRF (Monetary policy shock)

Technology shock in general sector

Figure 3.7 plots the impulse response function to a permanent positive technology shock in the general sector. The technology shock in the general sector follows the equation $lnA_{c,t} = lnA_{c,t-1} + \rho_{A_c}(lnA_{c,t-1} - lnA_{c,t-2}) + u_{Ac,t}$. Technology shocks in both sectors of the model are nonstationary, having a permanent impact on most variables, including consumption, output in both sectors, GDP, housing demand, and housing prices. In the general sector, a positive technology shock leads to increased output and consumption. This shock enhances production efficiency, thereby boosting output and contributing to higher GDP. As output increases, income rises, thus contributing to increased consumption. Additionally, the labor market may tighten due to the surge in output, resulting in higher wages. This, in turn, may increase costs, leading to upward pressure on prices and potentially causing inflation to rise. However, as consumption and output continue to grow, interest rates also rise, dampening inflation and causing it to decrease relatively. Hence, the response of inflation exhibits an initial increase followed by a subsequent decrease. Furthermore, the positive technology shock influences the housing market. Initially, housing demand and output decline, followed by an increase. Housing prices increase as well.

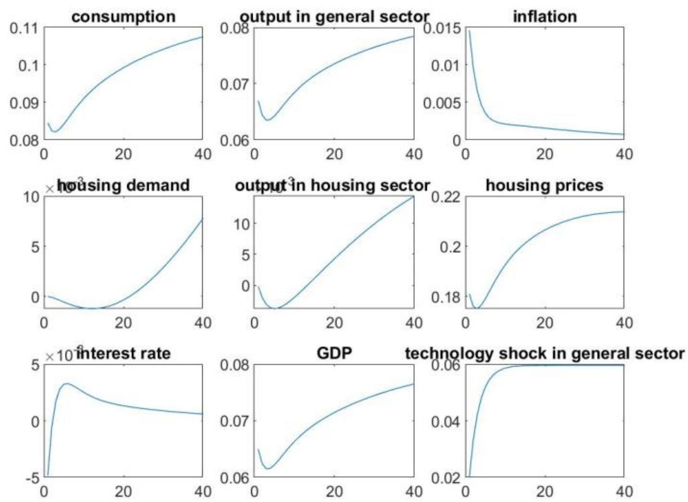


Figure 3.7 IRF (technology shock in general sector)

Technology shock in housing sector

Figure 3.8 shows the behavior of the main macroeconomic variables in response to a positive technology shock in the housing sector. A technology shock in the housing sector is nonstationary, thereby exerting a lasting influence on the economy. The technology shock in the housing sector follows the equation $lnA_{h,t} = lnA_{h,t-1} + \rho_{A_h}(lnA_{h,t-1} - lnA_{h,t-2}) + u_{Ah,t}$.

A positive technology shock reduces the production costs of houses, leading to an increase in housing sector output. The higher supply of houses results in lower housing prices, consequently stimulating housing demand. Additionally, the positive technology shock in the housing sector has a small impact on the general goods sector. There is a slight decrease in general goods output and a slight increase in the consumption of general goods, measured in units of 1×10^{-4}. GDP experiences a decrease due to the reduction in general goods output. Overall, the positive technology shock in the housing sector primarily boosts houses output.

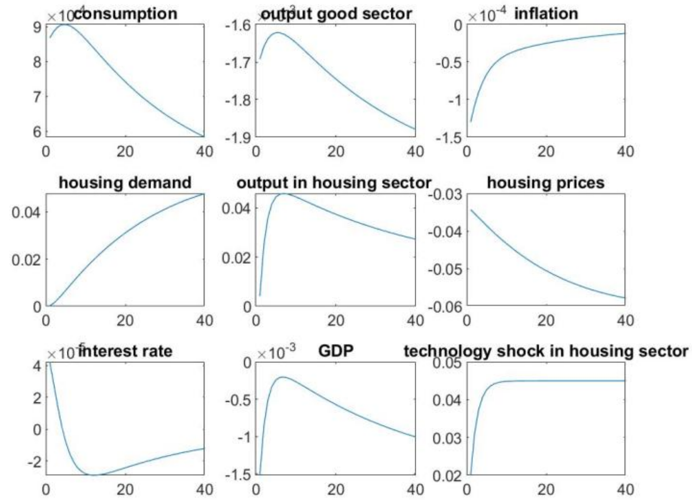


Figure 3.8 IRF (technology shock in housing sector)

3.5 Conclusion

This chapter constructs and estimates a New Keynesian DSGE model with a housing sector to investigate the drivers of housing market dynamics. The model is estimated with Chinese macroeconomic data from 2000 to 2020, using the indirect inference estimation method. The estimated model shows good performance in replicating the behavior of key macroeconomic variables and is subsequently used for analysis.

The main findings indicate that housing demand is the primary driver of housing market dynamics in the short run, while productivity in both the general and housing sectors becomes dominant in the long run, as shown by the variance decomposition. Monetary policy has limited influence on the housing market. The impulse response functions reveal that housing demand directly drives housing prices and the output of new houses. The productivity shock in the general sector raises household income, boosting consumption of both general goods and housing, which in turn raises housing prices. Productivity shocks in the housing sector reduce the cost of house construction, leading to lower housing prices.

These findings are consistent with the evolution of China’s housing market based on historical decomposition. The housing booms of 2003–2007 and 2009–2010 were driven by strong housing demand, caused respectively by the complete cancellation of welfare housing distribution and a series of expansionary policies. Similarly, the sharp declines in housing prices in 2008 and 2020, triggered respectively by the Global Financial Crisis and COVID-19 pandemic, were associated with negative housing demand. The relatively stable housing prices between 2015 and 2019 are mainly driven by housing demand shocks and productivity in the general sector.

4. Chapter 4

Model with Chinese characteristic monetary policy

4.1 Introduction

The primary purposes of monetary policy are to achieve economic growth and maintain stable prices. These goals require balancing the stimulation of economic growth with the control of inflation. Real estate is a crucial component of China's economy; thus, promoting economic stability inherently involves stabilizing the housing market. The central bank utilizes monetary policy as a tool to influence the housing market, primarily through adjustments to benchmark lending rates and the reserve requirement ratio. These two instruments are closely linked to housing prices. From 2000 to 2020, China's economy experienced three distinct phases: 2000 to 2008, characterized by economic overheating and financial risks; 2009 to 2015, marked by loose monetary policy and economic adjustment post-financial crisis; and 2016 to 2020, featuring a stable economy impacted by the shock of Covid-19.

From 2000 to 2003, the benchmark interest rate and reserve requirement ratio remained relatively low, following an easing monetary policy initiated after the late 1990s Asian financial crisis, which supported domestic reforms aimed at sustaining export growth and housing development. During this period, housing prices experienced stable growth. During this period, housing prices experienced stable growth. Between 2004 and 2008, as rapid economic growth and increasing inflationary pressures emerged, the central bank frequently raised the benchmark interest rates and reserve requirement ratio to curb the overheated economy and rapidly rising property prices. In 2007 alone, the benchmark interest rates were increased five times, while reserve requirement ratios rose ten times, from 9% to 14.5%. As a result, in early 2006, the growth rate of housing prices was negative but subsequently began to rise due to the high demand following the abolition of the welfare-oriented public housing distribution system.

The Global Financial Crisis significantly impacted the economy, particularly the housing market, leading to a substantial drop in housing prices. Consequently, in 2008, the benchmark interest rates and reserve requirement ratio were reduced and remained relatively low until 2010 to support an economic rebound, effectively revitalizing the housing market and pushing the growth rate back to its previous peak. To control high housing prices and inflation, the benchmark interest rates and reserve requirement ratio were increased between 2011 and 2012, leading to a decrease in housing prices.

In the period from 2014 to 2015, the slowdown in economic growth prompted the central bank to lower the benchmark interest rates and reserve requirement ratio, thereby increasing liquidity to support the economy. From 2016 to 2019, the economy experienced stable growth, with benchmark interest rates remaining stable and a gradual decrease in the reserve requirement ratio, accompanied by a steady growth rate in housing prices. In response to the shock of COVID-19, both the Loan Prime Rate and reserve requirement ratio were reduced.

Monetary policy is characterized by the use of multiple tools and incremental adjustments. Small adjustments allow the market to gradually adapt, reducing uncertainty and fluctuations resulting from policy changes. This approach also enables the central bank to make corrections, thereby decreasing the risk of policy errors. Incremental adjustments allow the central bank to observe the impact on the economy and make further adjustments based on feedback. This small adjustment feature can also be seen in the liberalization of lending and deposit interest rates. The bounds on lending and deposit rates were gradually removed from 1978 to August 2019. However, an implicit floor on lending rates and a ceiling on deposit rates still existed, referred to as a "semi-market" interest rate system or half-bounded interest rates in this thesis.

The monetary policy in China features multiple tools, incremental adjustments, and a "semi-market" interest rate system. Some studies, such as those by He and Wang (2012) and Chen et al. (2013), have constructed models of the Chinese banking system. He and Wang (2012) developed a model considering a dual interest-rate system, with bounded lending interest rate floors and deposit interest ceilings, as well as market-determined bound rates. Their model also incorporates the reserve requirement ratio and examines how these tools influence market interest rates. Chen et al. (2013) built a banking system model that considers adjustments to the reserve requirement ratio and a half-bounded interest rate framework to investigate the determination of retail lending rates and interbank rates. Another study by Chen, Funke, and Paetz (2012) focused on the construction of a Chinese characteristic monetary policy model, using a DSGE framework to explore the influence of monetary policy on the economy. However, no model has been developed to explore the behavior of the housing market in relation to China's specific monetary policy. This thesis fills this gap. Additionally, the model will be tested and estimated using the indirect inference method. Two models—the benchmark model created in Chapter 3 and the model developed in this chapter—will be compared in terms of model fitness and empirical analysis of monetary policy.

The structure of Chapter 4 is as follows: Section 4.2 illustrates the model setting, including the commercial banking sector, which incorporates monetary policy tools such as benchmark interest rates and the reserve requirement ratio, enabling the "semi-market" interest rate system to function. Section 4.3 covers data description, model evaluation, and estimation using indirect inference and standard analysis. This section also discusses the comparison between the benchmark model and the model incorporating specific Chinese monetary policy. The final section, 4.4, presents the conclusion.

4.2 Model with specific monetary policy

To explore the impact of monetary policy on housing prices in China, this study utilizes models built by Iacoviello and Neri (2010) and Chen, Funke, and Paetz (2012). These models help construct a Chinese economy, incorporating a banking sector and specific monetary policies. The benchmark model includes households, firms, retailers, and monetary policy. In this chapter, the model is extended to include the banking sector, featuring benchmark interest rates, semi-market interest rates, and the reserve requirement ratio. The overall model structure is based on Iacoviello and Neri (2010), while the behavior of the private banking sector follows the model of Chen, Funke, and Paetz (2012). Unlike the benchmark model, the extended model incorporates 11 shocks, including two non-stationary technology shocks in different sectors. Additionally, it includes two benchmark interest rate rule shocks and reserve requirement ratio rule shocks. The central bank determines the rules for benchmark interest rates and reserve requirement ratios in each period, which has an exogenous impact on the economy due to the floor on lending rates and the ceiling on deposit rates based on these rules. Commercial banks need to adjust the lending and deposit rates in response to these rules, affecting the behavior of economic agents. Households make savings decisions based on deposit rates, while firms make lending decisions based on lending interest rates.

The household, firm, and retail sectors in this model are similar to those in the benchmark model but with some differences. In this model, interest rates are differentiated into loan interest rates and deposit interest rates. A commercial bank sector is introduced to represent the ‘semi-market’ system with the regulation rule issued by the central bank. Households save in commercial banks with deposit rates, and firms lend from commercial banks with lending rates. The discount factors for households and firms differ, with firms having a relatively lower discount factor. The different equations between this model and the benchmark model will be presented in this chapter. The description of the banking sector will be the primary focus of this chapter.

4.21 Households

The households and firms are largely the same as those in the benchmark model, except for the deposit interest rate in the households and loan interest rates in the firm sector. Therefore, the different equations in the extended model in both households and firm sectors are just displayed here.

Households

The households have a budget constraint, which is given by:

$$c_t + s_t + q_{h,t}[h_t - (1-\delta_h)h_{t-1}] = w_{c,t}n_{c,t} + w_{h,t}n_{h,t} + s_{t-1}(1 + r_{t-1}^d) + F_t^B + F_t^F - t_t \tag{4.1}$$

r_t^d denotes the deposit interest rate. Households hold savings s_t in commercial banks and earn a net return of r_t^d. The deposit gain from the last period is $s_{t-1}(1 + r_{t-1}^d)$.

Households choose c_t, s_t, h_t, $n_{c,t}$ $n_{h,t}$ to maximize the utility function subject to budget constraints. The followings display Lagrange and first order conditions.

$$L = \sum_{t=0}^{\infty} \beta^t \varepsilon_{p,t} \left[\frac{c_t^{1-\iota}}{1-\iota} - \varepsilon_{l,t} \left[\frac{\left({n_{c,t}}^{1+\vartheta} + {n_{h,t}}^{1+\vartheta}\right)^{\frac{1+\aleph}{1+\vartheta}}}{1+\aleph} \right] + \varepsilon_{h,t} \frac{(h_t)^{1-\psi}}{1-\psi} \right] + \lambda_t \Big[w_{c,t}n_{c,t} + w_{h,t}n_{h,t} + s_{t-1}\left(1 + r_{t-1}^d\right) + F_t^F + F_t^B - t_t - c_t - s_t - q_{h,t}[h_t - (1-\delta_h)h_{t-1}] \Big] \tag{4.2}$$

First order conditions:

$$\frac{\partial L}{\partial c_t}: \frac{\varepsilon_{p,t}}{c_t^l} = \lambda_t \tag{4.3}$$

$$\frac{\partial L}{\partial s_t}: \beta E_t \lambda_{t+1}\left(1 + r_t^d\right) = \lambda_t \tag{4.4}$$

Combining equations (4.3) and (4.4), we get the Euler equation, which shows a dynamic optimal decision for consumption today and tomorrow.

$$\frac{\varepsilon_{p,t}}{c_t^l} = \beta E_t \frac{\varepsilon_{p,t+1}}{c_{t+1}^l}\left(1 + r_t^d\right) \tag{4.5}$$

4.22 Firms

These equations are the same as those in the benchmark model, except the lending rate is r_{t-1}^l.

Budget constraint:

$$c_t^e + w_{c,t}n_{c,t} + w_{h,t}n_{h,t} + \frac{k}{2}(\Delta k_{c,t})^2 + \frac{k}{2}(\Delta k_{h,t})^2 + (1 + r_{t-1}^l)b_{t-1} + i_{c,t} + i_{h,t} = \frac{Y_t}{X_t} + q_{h,t}Y_{h,t} + b_t \tag{4.6}$$

To solve entrepreneurs' problems, we have Lagrange and first order conditions.

$$L = E_0 \sum_{t=0}^{\infty} \beta_e^t \varepsilon_{p,t}\left[\frac{{c_t^e}^{1-\varsigma}}{1-\varsigma}\right] + \lambda_{e,t}\left[\frac{A_{c,t}{n_{c,t}}^{1-\alpha}{k_{c,t-1}}^{\alpha}}{X_t} + q_{h,t}A_{h,t}{n_{h,t}}^{1-\omega}{k_{h,t-1}}^{\omega} + b_t - c_t^e - w_{c,t}n_{c,t} - w_{h,t}n_{h,t} - k_{c,t} + \left(1 - \delta_{k,c}\right)k_{c,t-1} + (1 + r_{t-1}^l)b_{t-1} - k_{h,t} + \left(1 - \delta_{k,h}\right)k_{h,t-1} - \frac{k}{2}(k_{c,t} - k_{c,t-1})^2 - \frac{k}{2}(k_{h,t} - k_{h,t-1})^2\right] \tag{4.7}$$

First order conditions:

$$\frac{\partial L}{\partial c_t^e}: \frac{\varepsilon_{p,t}}{c_t^{e\varsigma}} = \lambda_{e,t} \tag{4.8}$$

$$\frac{\partial L}{\partial b_t}: \lambda_{e,t} = \lambda_{e,t+1}\beta_e(1 + r_t^l) \tag{4.9}$$

$$\frac{\partial L}{\partial k_{c,t}}: \beta_e\lambda_{e,t+1}\left[\alpha * \frac{Y_{t+1}}{X_{t+1}k_{c,t}} + \left(1 - \delta_{k,c}\right) + k\left(k_{c,t+1} - k_{c,t}\right)\right] = \lambda_{e,t}\left[1 + k\left(k_{c,t} - k_{c,t-1}\right)\right] \tag{4.10}$$

$$\frac{\partial L}{\partial k_{h,t}}: \beta_e\lambda_{e,t+1}\left[\omega\frac{q_{h,t+1}Y_{h,t+1}}{k_{h,t}} + \left(1 - \delta_{k,h}\right) + k(k_{h,t+1} - k_{h,t})\right] = \lambda_{e,t}\left[1 + k(k_{h,t} - k_{h,t-1})\right] \tag{4.11}$$

Combining (4.8) and (4.9), we get the Euler equation (4.12), which is similar to the household section.

$$\frac{\varepsilon_{p,t}}{c_t^{e\varsigma}} = \beta_e\frac{\varepsilon_{p,t+1}}{c_{t+1}^{e\ \varsigma}}(1 + r_t^l) \tag{4.12}$$

Combining (4.8) and (4.10), we have capital demand for general goods, equation (4.13). Equation (4.13) can be rearranged to the other form, equation (4.14).

$$\beta_e\frac{\varepsilon_{p,t+1}}{c_{t+1}^{e\ \varsigma}}\left[\alpha * \frac{Y_{t+1}}{X_{t+1}k_{c,t}} + \left(1 - \delta_{k,c}\right) + k\left(k_{c,t+1} - k_{c,t}\right)\right] = \frac{\varepsilon_{p,t}}{c_t^{e\varsigma}}\left[1 + k\left(k_{c,t} - k_{c,t-1}\right)\right] \tag{4.13}$$

$$\alpha * \frac{Y_{t+1}}{X_{t+1}k_{c,t}} + \left(1 - \delta_{k,c}\right) + k\left(k_{c,t+1} - k_{c,t}\right) = \left(1 + r_{t-1}^l\right)\left[1 + k\left(k_{c,t} - k_{c,t-1}\right)\right] \tag{4.14}$$

Combining (4.8) and (4.11), we have capital demand for houses, equation (4.15). Equation (4.15) also can be rearranged into (4.16).

$$\beta_e\frac{\varepsilon_{p,t+1}}{c_{t+1}^{e\ \varsigma}}\left[\omega\frac{q_{h,t+1}Y_{h,t+1}}{k_{h,t}} + \left(1 - \delta_{k,h}\right) + k(k_{h,t+1} - k_{h,t})\right] = \frac{\varepsilon_{p,t}}{c_t^{e\varsigma}}\left[1 + k(k_{h,t} -\right.$$

$$k_{h,t-1})] \tag{4.15}$$

$$\omega \frac{q_{h,t+1}Y_{h,t+1}}{k_{h,t}} + \left(1-\delta_{k,h}\right) + k(k_{h,t+1} - k_{h,t}) = \left(1 + r_{t-1}^{l}\right)[1 + k(k_{h,t} - k_{h,t-1})] \tag{4.16}$$

4.23 Banking system

Commercial banks in China operate under strict supervision and regulation by the People's Bank of China (PBoC). The majority of these banks are state-owned. The PBoC plays a crucial role in formulating and executing monetary policy, which dictates the rules and regulations that commercial banks must follow.

Commercial bank

We adopt the methodology of Chen, Funke, and Paetz (2012) to integrate the commercial banking sector into a DSGE model. Specifically, Chen, Funke, and Paetz (2012) incorporate the characteristics of Chinese monetary policy as outlined in He and Wang (2012) and Chen et al. (2013), integrating these aspects into the wholesale banking framework presented in Gerali et al. (2010). This model simplifies by excluding retail branches and banking capital, focusing instead on the transmission of Chinese monetary policy. Within this framework, commercial banks gather deposits from households, extend loans to firms, and make optimal decisions regarding deposit demand and loan supply. In an unregulated environment, the deposit and lending rates are determined by the market.

The intertemporal optimization problem

A representative commercial bank determines the quantities of loans $\mathrm{b_t}$, deposits $\mathrm{s_t}$, and borrow from interbank market IB_t. Interbank borrowing is included to capture the role of liquidity adjustment in the banking sector under reserve requirements. It helps banks manage short-term funding and satisfy reserve constraints. By introducing interbank borrowing, the bank is able to independently choose both loan and deposit quantities, which permits the separate determination of loan and deposit rates. However, without the inclusion of interbank borrowing, the bank's optimization problem is subject to a strict constraint $(1-\mathrm{\eta_t})\mathrm{s_t} = \mathrm{b_t}$, in which loans are fully determined by deposits, removing one degree of freedom from the bank's decision-making process. The function $\mathrm{C}(b_t, s_t)$ in equation (4.18) represents quadratic management costs associated with loans and deposits. Maximizing the discounted sum of cash flows is the main objective of the representative bank. β_b^t represents the discount factor, and η_t denotes the required reserve ratio. r_t^l, r_t^d, r_t^r are interest rates on loans, deposits and minimum reserves.

$$\sum_{t=0}^{\infty} \beta_b^t \big\{ \big(1 + r_t^l\big) b_t - b_{t+1} + (1 - \eta_{t+1}) s_{t+1} - (1 + r_t^d) s_t + \eta_t (1 + r_t^r) s_t - (1 + r_t^{ib}) \mathrm{IB}_t + \mathrm{IB}_{t+1} - \mathrm{C}(b_t, s_t) \big\} \qquad (4.17)$$

$$\mathrm{C}(b_t, s_t) = \frac{1}{2}(\delta_b b_t^2 + \delta_s (1 - \eta_t) s_t^2) \qquad (4.18)$$

Subject to a flow budget constraint:

$$(1 - \mathrm{\eta_t})\mathrm{s_t} + \mathrm{IB}_t = \mathrm{b_t} \qquad (4.19)$$

By combining equations (4.17), (4.18), and (4.19), the bank's problem can be formulated as equation (4.20), representing a period-by-period profit maximization objective. The Lum-sum profit belongs to households.

$$F_t^B = \big(1 + r_t^l\big) b_t - (1 + r_t^d) s_t + \eta_t (1 + r_t^r) s_t - (1 + r_t^{ib})(\mathrm{b_t} - (1 - \mathrm{\eta_t})\mathrm{s_t}) - \frac{1}{2}(\delta_b b_t^2 + \delta_s (1 - \eta_t)^2 s_t^2)$$

(4.20)

First order conditions:

$$\frac{\partial F_t^B}{\partial b_t} = \left(1 + r_t^l\right) - \left(1 + r_t^{ib}\right) - \delta_b \mathrm{b_t} = 0$$

$$r_t^{l\_md} = r_t^l = r_t^{ib} + \delta_b \mathrm{b_t} \tag{4.21}$$

$$\frac{\partial F_t^B}{\partial s_t} = -(1 + r_t^d) + \eta_t(1 + r_t) + \left(1 + r_t^{ib}\right)(1 - \eta_t) - \delta_s(1 - \eta_t)^2 \mathrm{s_t} = 0$$

$$r_t^{d\_md} = r_t^d = \eta_t r_t^r + r_t^{ib}(1 - \eta_t) - \delta_s(1 - \eta_t)^2 \mathrm{s_t} \tag{4.22}$$

In an optimum, the banking sector determines the quantities of deposits, loans, and interbank market borrowing. Equations (4.21) and (4.22) illustrate the optimal decisions for making deposits and loans by equating marginal costs with marginal benefits. Equation (4.21) defines the opportunity cost for loans, which equals the sum of the interbank interest rate and management costs. Equation (4.22) specifies the opportunity cost for deposits, accounting for management costs, the interbank interest rate, and the yield on reserves. Following the assumption of Gerali et al. (2010), banks have unrestricted access to lending facilities. Therefore, in this model, the interbank interest rate aligns with the Taylor-type policy rate r_t .

Central bank

The central bank determines the value of restrictions and the reserve requirement ratio each period. Regarding lending and deposit rate regulations, the central bank imposes a floor on the lending rate and a ceiling on the deposit rate based on the benchmark interest rate. Specifically, commercial banks are prohibited from offering deposit rates higher than the benchmark deposit rate and from issuing loans at rates lower than 90% of the benchmark lending rate.

However, the model simplifies this by using the benchmark lending rate as the minimum rate threshold. Additionally, the central bank sets the reserve requirement ratio.

Policy rate (Taylor rule)

To implement a semi-bounded interest rate system, the Taylor-type monetary policy rule remains in effect in the second model, as depicted in equation (4.23). It denotes the policy rate in this model. The benchmark interest rates are determined based on the policy rate. Equations (4.25) and (4.26) specify these benchmark interest rates.

Standard monetary policy (Taylor rule):

$$1 + R_t = (1 + R_{t-1})^{\rho_R}(1 + \pi_t)^{(1-\rho_R)\varphi_\pi}\left({GDP_t}/{GDP_{t-1}}\right)^{(1-\rho_R)\varphi_x}[1 + r^{ss}]^{1-\rho_R}\varepsilon_t^{MP} \tag{4.23}$$

Fisher equation:

$$R_t = r_t + E_t\pi_{t+1} \tag{4.24}$$

Here r_t is the policy rate in real term.

The benchmark interest rates

We use the method of Chen, Funke, and Paetz (2012), where the benchmark lending rate $r_t^{l,cb}$ and deposit rate $r_t^{d,cb}$ move around the r_t, with both rates moving in tandem. The central bank sets benchmark interest rates according to equations (4.25) and (4.26). Additionally, two exogenous shocks are introduced here, which affect the decision-making of the central bank and influence the behavior of economic agents. The preference parameters ϕ_r^d and ϕ_r^l ensure the smoother adjustment of these two rates.

$$r_t^{d,cb} = (1 - \phi_r^d) r_t + \phi_r^d r_{t-1}^{d,cb} + \varepsilon_t^{cb\_d} \quad (4.25)$$

$$r_t^{l,cb} = (1 - \phi_r^l) r_t + \phi_r^l r_{t-1}^{l,cb} + \varepsilon_t^{cb\_d} \quad (4.26)$$

The reserve requirement ratio

We still follow the method of Chen, Funke, and Paetz (2012) and Ahmadian and Shahchera (2014). The reserve requirement ratio depends on inflation (equation 4.27). The shock $\varepsilon_t^{cb\_\eta}$ is exogenous to the economy and affects every decision regarding changes in the reserve ratio.

ϕ_η^π and ϕ_η^η represent weights assigned to the inflation rate and reserve requirement at previous periods. ϕ_η^η indicates the influence of the previous reserve ratio on the current one, ensuring smooth adjustments. $(1 - \phi_\eta^\eta)\phi_\eta^\pi$ represents the impact of the current inflation rate on the reserve requirement, determining how inflation changes affect reserve ratios. ϕ_η^π affects the degree of the inflation change on the proportion of reserve requirements. To close the model, we follow Chen, Funke, and Paetz (2012) and assume the interest rate on required reserves follows the Taylor rule equation (4.23) and the Fisher equation (4.24), where $r_t^r = r_t$.

$$\eta_t = (1 - \phi_\eta^\eta)\phi_\eta^\pi \pi_t + \phi_\eta^\eta \eta_{t-1} + \varepsilon_t^{cb\_\eta} \quad (4.27)$$

The semi-market interest rates system

Benchmark interest rates and market-determined interest rates are applied to present the characteristics of monetary policy in China. The PBoC controls the lowest lending rate and the highest deposit rate. The actual lending rate r_t^l and deposit rate r_t^d are regulated according to central bank guidelines: $r_t^l \geq r_t^{l,cb}, r_t^d \leq r_t^{d,cb}$, where $r_t^{l,cb}, r_t^{d,cb}$ are the lowest lending rate and highest deposit rate, determined by equations (4.26) and (4.25).

Due to the limitations set by the monetary authority, the actual lending and deposit rates are expressed by equations (4.28) and (4.29).

$$r_t^l = max\left(r_t^{l,cb}, r_t^{l\_md}\right) \tag{4.28}$$

$$r_t^d = min\left(r_t^{d,cb}, r_t^{d\_md}\right) \tag{4.29}$$

$r_t^{l,md}, r_t^{d,md}$ represent the market rates. These loan and deposit rates are determined by interactions between commercial banks, households, and firms, as specified in equations (4.21) and (4.22), which are derived from the commercial banking sector.

$$r_t^{l,md} = r_t^{ib} + \delta_b \mathrm{b_t} \tag{4.21}$$

$$r_t^{d,md} = \eta_t r_t^r + r_t^{ib}(1 - \mathrm{\eta_t}) - \delta_s(1 - \eta_t)^2 \mathrm{s_t} \tag{4.22}$$

4.24 Shocks

There are 11 shocks in the model in total. The following three display the additional shocks in the second model. The remaining eight shocks are identical to those in the benchmark model.

Benchmark deposit rates rule shock

$$ln\varepsilon_t^{cb\_d} = \rho_{cb\_d} ln\varepsilon_{t-1}^{cb\_d} + u_{cb\_d,t} \tag{4.30}$$

Benchmark lending rates rule shock

$$ln\varepsilon_t^{cb\_l} = \rho_{cb\_l} ln\varepsilon_{t-1}^{cb\_l} + u_{cb\_l,t} \tag{4.31}$$

Reserve requirement ratio rule shock

$$ln\varepsilon_t^{cb\_\eta} = \rho_{cb\_\eta} ln\varepsilon_{t-1}^{cb\_\eta} + u_{cb\_\eta,t} \tag{4.32}$$

Where $u_{cb\_d,t}, u_{cb\_l,t}, u_{cb\_\eta,t}$ are all i. i. d.

4.3 Empirical results

4.31 Data and calibration

Description of Data

The banking system is incorporated into the second model, introducing three additional variables: reserve requirement ratio η_t, benchmark lending rate $r_t^{d,cb}$ and deposit rates $r_t^{l,cb}$. Figures 4.1 and 4.2 display the 1-year benchmark interest rates and reserve requirement ratio. The quarterly benchmark interest rates, reserve ratios, and the data introduced in Chapter 3 will be used to evaluate and estimate the model. The sources of data can be found in Appendix B.

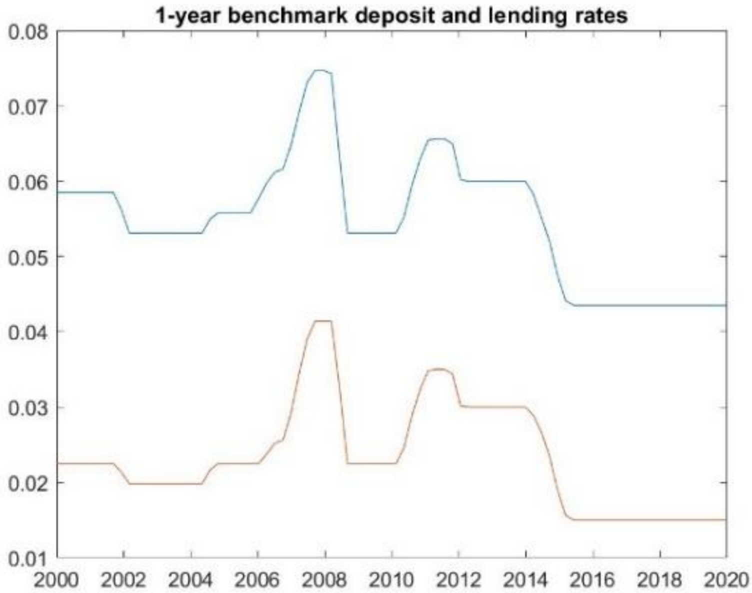


Figure 4.1 1-year benchmark interest rate

Blue line: One-year PBC benchmark lending rate.

Orange line: One-year PBC benchmark deposit rate.

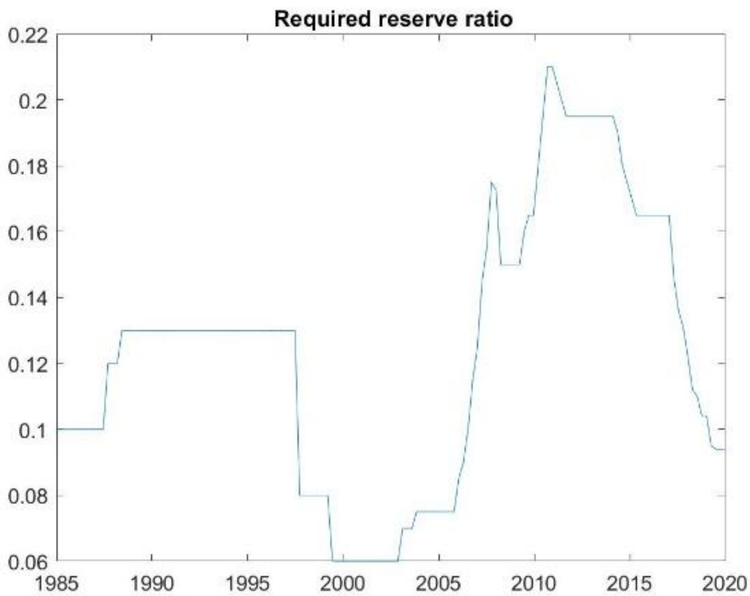


Figure 4.2 Required reserve ratio

Calibration

The calibration of households, firms, retail, and Taylor-type monetary policy matches exactly with the benchmark model, detailed in Table 4.1. The discount factor for firms is calibrated to 0.97, according to Liu and Ou (2019). This section outlines the calibration of the banking system, as presented in Table 4.1, based on Chen, Funke, and Paetz (2012). Commercial banks' management cost parameters δ_b and s_t are set to 2 and 1. The benchmark lending rate parameter ϕ_r^l and deposit rate parameter ϕ_r^d are set at 0.7, allowing interest rate restrictions to follow the Taylor rule slowly. The steady-state value of the reserve ratio is established at 10%, consistent with current levels. Regarding the reserve requirement ratio, ϕ_η^π is set to 10 and ϕ_η^η to 0.6. Under these two values, the inflation changes have a significant impact on the reserve ratio, being four times the rate of inflation. These ensure a smooth transition of reserve ratio from 10% to 20%, responding to an annual inflation growth of about 10%. The steady-state ratios are the same as those in the benchmark model, displayed in Table 4.2.

Table 4.1 Calibrated Parameters – Extended model

Definition	Parameter	Calibration
Household		
discount factor of household	β	0.985
elasticity of consumption	ι	2
elasticity of consumption in houses	ψ	1
inverse elasticity of labor supply	$\aleph$	0.5
Elasticity of labor substitution	ϑ	0.5
Firm		
discount factor of firm	β_e	0.97
elasticity of firm consumption	ς	2
depreciation rate of housing	δ_h	0.015
depreciation rate of capital in goods sector	$\delta_{k,c}$	0.03

depreciation rate of capital in housing sector	$\delta_{k,h}$	0.04
Capital share (normal goods production)	α	0.34
Capital share (house production)	ω	0.2
Calvo contract non-resetting probability	φ	0.67
monetary policy inertia	ρ_R	0.75
interest-rate response to inflation	φ_π	1.5
interest-rate response to output growth	φ_x	0.125
Capital demand coefficient	k_{c1}	0.51
Capital demand coefficient	k_{c2}	0.47
Capital demand coefficient	k_{c3}	0.02
Capital demand coefficient	k_{c4}	0.25
Capital demand coefficient	k_{h1}	0.51
Capital demand coefficient	k_{h2}	0.47
Capital demand coefficient	k_{h3}	0.02
Capital demand coefficient	k_{h4}	0.25
Banking system		
smoothing parameters of the benchmark deposit rate	ϕ_r^d	0.7
smoothing parameters of the benchmark lending rate	ϕ_r^l	0.7
management cost parameter for deposit	δ_s	2
management cost parameter for lending	δ_b	1
Parameter for RRR rule	ϕ_η^π	10
Parameter for RRR rule	ϕ_η^η	0.6

Table 4.2 Steady state ratio – Extended model

Definition	Parameter	Data
Non-residential output ratio	Y/GDP	0.925
Residential output ratio	Y_h/GDP	0.075
Consumption ratio	C/Y	0.5891
Investment ratio	I/Y	0.4108
Household consumption ratio	c/C	0.70
Firm consumption ratio	c_e/C	0.30

Investment ratio for non-housing sector	i_c/I	0.83
Investment ratio for housing sector	i_h/I	0.17

4.32 Indirect inference evaluation and estimation results

After getting the estimated parameters, the indirect inference method is used to evaluate the performance of the macroeconomic model. The objective is to evaluate the performance of the auxiliary model using real-world data and compare its performance with that of simulations generated from the macroeconomic model based on predetermined parameters. A VARX model is selected as the auxiliary model, and the test is based on a function of the VARX coefficients.

The results of model evaluation and estimation are discussed in this section. The auxiliary model is the same as the one in the benchmark model, which is good for comparison. The endogenous variables are still output, interest rate and housing prices. In the case of the calibrated model failing the test, it will move to the estimation process. The value of discount factors of the household sector and firm, as well as the depreciation rate of capital in both the general sector and housing sector and houses, are fixed. The remaining parameters will float at a pre-set range until the optimal one is identified. Table 4.3 displays the calibrated and estimated parameters along with their evaluated test results. The calibrated model fails the indirect inference test, with the Trans-Wald value of 11.5. After the indirect inference estimation, the model passes the test with the Trans-Wald value of 0.9310, which is lower than the critical value of 1.645.

The third column of Table 4.3 displays the calibrated and estimated parameters. For the household sector, the inverses of the intertemporal elasticity of substitution for consumption in general goods ι and houses ψ increase from 2 and 1 to 2.9 and 1.99, respectively. These two estimated values still indicate that households are more willing to adjust their consumption of houses to the interest rate change than to adjust their consumption of general goods. The value of inverse elasticity of labor supply $\aleph$ decreases from 0.5 to 0.434. Lower $\aleph$ (high labor elasticity) means households are more responsive to wage changes. The substitutability of labor for two productions ϑ increases from 0.5 to 0.73, which is still positive. A positive ϑ indicates that there is some degree of specificity in how labor is supplied to different sectors. This means that labor is not perfectly substitutable between sectors.

In the firm sector, the inverse of the intertemporal elasticity of substitution for firm consumption rises from 2 to 2.4, indicating less response to the change of interest rate compared to the calibrated value. The capital share α in general goods production decreases from 0.34 to 0.28, and the capital share ω in house production increases from 0.2 to 0.25. Calvo contract non-resetting probability φ is estimated to be 0.9, higher than the calibrated value, suggesting a "stickier" economy in China. The parameters of Taylor rule φ_{π}, φ_{x}, φ_{R} are estimated to be 1.11, 0.14, and 1.89, respectively. The response of interest rate to inflation is still the highest one, compared to GDP growth and last period's interest rate.

The parameters related to the banking system have been estimated and adjusted as follows. The smoothing parameters of the benchmark deposit rate ϕ_r^d and the benchmark lending rate ϕ_r^l are estimated at 0.51 and 0.47, respectively. The management cost parameters for deposit δ_s and lending δ_b are adjusted to 1.77 and 0.9 with the starting values of 2 and 1, respectively. The parameters of the reserve requirement rule are slightly adjusted. The estimated ϕ_η^π and ϕ_η^η are 9.9 and 0.61 with the start point of 10 and 0.6. For the parameters of the capital demand coefficient, k_{c1} and k_{h1} increase to around 0.86. The others have relatively small changes.

The performance of the models' fitness is compared. Table 4.4 displays the indirect inference test results of two estimated models. Both models use the same auxiliary model, and the variables are all output, nominal interest rate and housing prices. The Trans-Wald test values for the benchmark and extended models are 1.0128 and 0.9310, respectively, below 1.645. This means that the two models explain the data well. However, the lower test value of the extended model suggests that it provides a better fit, which means that the model with a specific monetary policy fits the data better. The analysis results obtained from different model structures and parameters' values can be various. These two models can all be used to do analysis. The benchmark model is proper for standard analysis. The extended one can further explore the effects of specific monetary tools on the economy.

Table 4.3 Estimates of model parameters

Definition	Parameter	Calibration	Estimation
Household			
discount factor of household	β	0.985	Fixed
elasticity of consumption	ι	2	2.900586
elasticity of consumption in houses	ψ	1	1.992282
inverse elasticity of labor supply	$\aleph$	0.5	0.434023
Elasticity of labor substitution	ϑ	0.5	0.739046
Firm			
discount factor of firm	β_e	0.97	Fixed
elasticity of firm consumption	ς	2	2.410135
depreciation rate of housing	δ_h	0.015	Fixed
depreciation rate of capital in goods sector	$\delta_{k,c}$	0.03	Fixed
depreciation rate of capital in housing sector	$\delta_{k,h}$	0.04	Fixed
Capital share (normal goods production)	α	0.34	0.285822
Capital share (house production)	ω	0.2	0.250128
Calvo contract non-resetting probability	φ	0.67	0.906577
monetary policy inertia	ρ_R	0.75	0.896271
interest-rate response to inflation	φ_π	1.5	1.117222

interest-rate response to output growth	φ_x	0.125	0.142158
Capital demand coefficient	k_{c1}	0.51	0.857813
Capital demand coefficient	k_{c2}	0.47	0.397827
Capital demand coefficient	k_{c3}	0.02	0.014388
Capital demand coefficient	k_{c4}	0.25	0.287265
Capital demand coefficient	k_{h1}	0.51	0.877597
Capital demand coefficient	k_{h2}	0.47	0.339462
Capital demand coefficient	k_{h3}	0.02	0.027625
Capital demand coefficient	k_{h4}	0.25	0.192397
Baking system			
smoothing parameters of the benchmark deposit rate	ϕ_r^d	0.7	0.512047
smoothing parameters of the benchmark lending rate	ϕ_r^l	0.7	0.474353
management cost parameter for deposit	δ_s	2	1.774816
management cost parameter for lending	δ_b	1	0.930234
Parameter for RRR rule	ϕ_η^π	10	9.909534
Parameter for RRR rule	ϕ_η^η	0.6	0.6138
Capital demand coefficient	k_{c1}	0.51	0.857813
Trans-Wald (y, qh, R)		**11.5**	**0.9310**
P value		**0**	**0.1570**

Table 4.4 Comparison of the test results

Auxiliary Model-VARX(1)		Benchmark Model	Model with Chinese specific monetary policies
Y,R,qh	**Trans-Wald**	**1.0128**	**0.9310**
	P value	**(0.11)**	**(0.1570)**

4.33 Residuals and shocks property

Analyzing properties for residuals helps identify the integration order of the errors. The residuals are extracted from the estimated model using unfiltered data. Table 4.5 presents the results of the ADF and KPSS tests and the estimated AR coefficients. Both the ADF and KPSS tests indicate that the two productivity shocks are nonstationary. Therefore, for these two shocks, we assume the first differences. The tests confirm that labor supply shock, inflation shock, monetary policy and benchmark deposit rule shock are stationary. Specifically, the ADF test suggests these four variables are stationary at a 1 % level, and KPSS supports this, for all LM-statistic values are less than the critical value. For reserve requirement ratio rule shock, the ADF test indicates the null hypothesis of non-stationarity is rejected at a 10% level. Besides, under the KPSS test, the null hypothesis of stationarity is not rejected at 5%. Based on both tests, we have evidence proving the reserve requirement rate rule shock is stationary. So, they follow the AR (1) process.

There is a case in which the results of these two stationarity tests are inconsistent. For example, reference shock, housing demand shock and benchmark lending rate rule shock are nonstationary, based on the result of the ADF test, not rejecting the null hypothesis of nonstationary with a p-value higher than 0.05. However, the LM statistic values of these three are all less than the critical value, indicating a stationary time series. The ADF tests for government spending state that it’s stationary, but the KPSS test disagrees. In case of conflicting results, The Wald test holds the ultimate decision for the residual process. The model passes the Wald test with these residuals having an AR (1) process. Additionally, these residuals have evidence of stationarity with the approval of at least one test.

In summary, the two productivity shocks are integrated of order one I (1), and the others are integrated of order zero I (0). The innovations are obtained by estimating each residual on its AR process. Figures 4.3 and 4.4 plot the residuals. Figures 4.5 and 4.6 plot the model innovations.

Table 4.5 Stationarity test of residuals

Residual	ADF p-value H0: non-stationary	KPSS LM-Stat. H0: stationary	Conclusion	Estimated coefficient
Government spending	0.0166	1.056184***	Stationary	0.977068
Preference	0.1160	0.172267	Stationary	0.956985
Labor supply	0.0092	0.181486	Stationary	0.951112
Housing demand	0.2627	0.292281	Trend Stationaryb	0.968657
Inflation	0.0000	0.049269	Stationary	0.503316
Monetary policy	0.0000	0.312805	Stationary	0.488255
Productivity (general goods)	0.9947	0.966911***	Non-stationary	0.441965
Productivity (houses)	0.9676	0.990815***	Non-stationary	0.567296
Loan rate limit rule	0.1376	0.203823	Stationary	0.738673
Deposit rate limit rule	0.0000	0.030565	Stationary	-0.15921
Reserve requirement rule	0.0792	0.405885*	Stationary	0.805075

1. ADF test: A p-value of less than 0.05 and 0.1 indicates the rejection of the null hypothesis of unit root at 5% and 10%.
2. KPSS test: The LM-statistic value with ** and *** denotes rejection of the null hypothesis of stationarity at the 5% and 1% levels, respectively. The critical values are 0.739 at 1%, 0.463 at 5%, and 0.347 at 10%.
3. [b] denotes that the series is trend stationary with AR (1) less than 1

Figure 4.3 Model Structure Residual

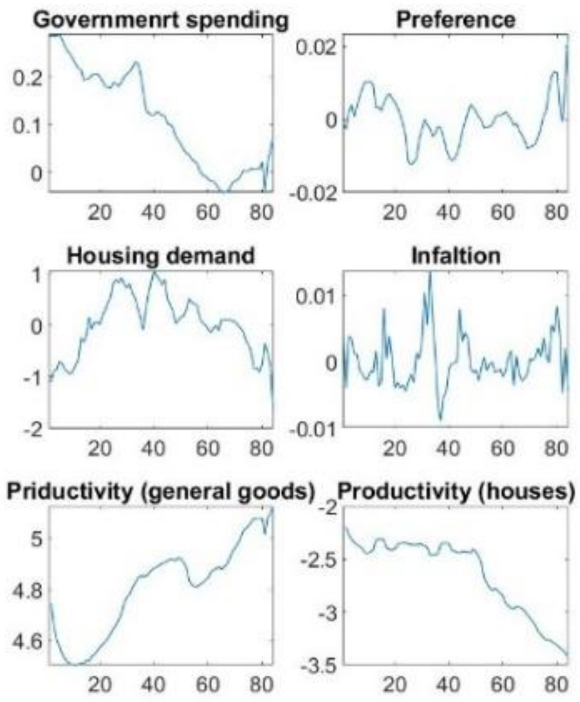


Figure 4.4 Model Structure Residual

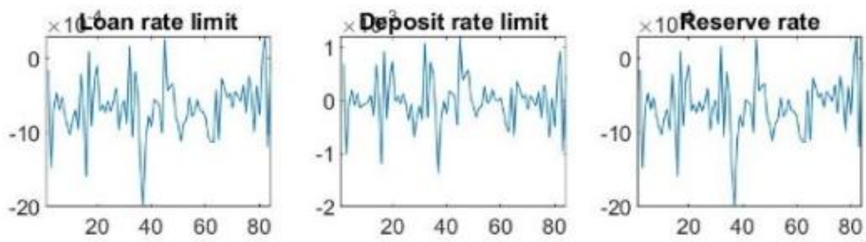


Figure 4.5 Model Innovation

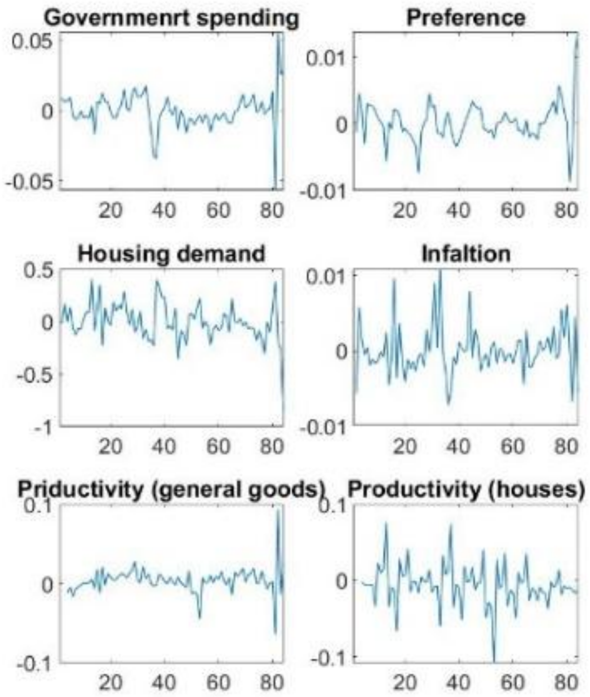
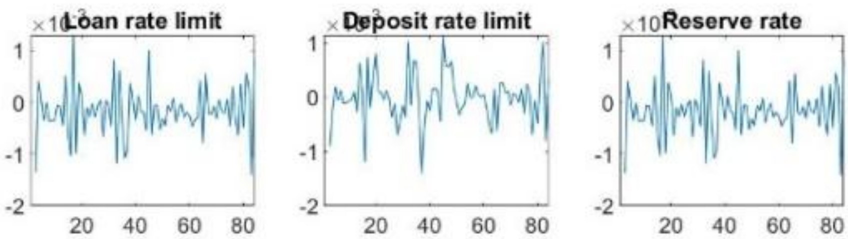


Figure 4.6 Model Innovation



4.34 Standard analysis

Variance decomposition

Forecast error variance decomposition explores how much of the forecast error variance of variables can be attributed to each exogenous shock. The following table displays the forecast error variance decomposition of GDP, housing output, inflation, housing prices, and interest rates at various horizons. We choose horizons of 1, 4, 10, and 100 quarters to investigate how the decomposition changes from the short horizon (one quarter and one year) to the medium horizon (10 quarters) and the long horizon (10 years and 25 years ahead).

Table 4.6 displays the variance decomposition for housing prices and housing output. For housing prices, it shows that housing demand shocks and technology shocks in both sectors are the main causes of variance in the short run, accounting for about 47.1% in housing demand, 12.8% in technology shock in the general sector, and 36% in technology shock in the housing sector in the first quarter. Inflation accounts for 3.2%. Other shocks, such as preference shock, government spending shock, monetary policy shock, and shocks in the banking system, contribute less to the volatility of housing prices, accounting for less than 1% in the short term. The effect of technology shock in the general sector does not change much across various horizons. The portion of technology shock in the housing sector increases from 36% to 83.7%. The portion of housing demand shock decreases, contributing to 2.8% in the long term (25 years). In the long horizon, the dominant causes of housing prices are technology shocks in both sectors, primarily because technology shock is nonstationary, meaning it has a permanent impact on housing prices. Other shocks diminish from a short period to a long period. Some existing literature using the DSGE model indicates that monetary policy shock plays a role in the variance of housing prices, but our model (which fits the data) shows that monetary policy shock has little effect. The variance decomposition under the DSGE-VAR model created by Liu and Ou (2021) also indicates that the monetary policy shock contributes little to the variance of housing prices.

Regarding the volatility of new housing output, the main forces are housing demand shock and labor supply shock, accounting for 81.4% and 7.2% in the short run (1 quarter). Other causes are government spending shock and inflation shock, accounting for 3.6% and 6.8%, respectively. The proportion of these two main drivers decreases from the short period to the long period. The remaining shocks contribute less to the variance of new housing output, each accounting for less than 1%. The contribution of the technology shock in the housing sector increases from the short horizon to the long horizon, rising from 0.3% in one quarter to 86.2% in 25 years. In the long run, the effect of the housing demand shock decreases, accounting for 8.6%. The housing demand dominates in the short run, while the technology shock in the housing sector dominates in the long run.

Table 4.6 Variance decomposition

Variable	horizon	$A_{c,t}$	$A_{h,t}$	g_t	$\varepsilon_{h,t}$	$\varepsilon_{l,t}$	$\varepsilon_{MP,t}$	$\varepsilon_{p,t}$	$\varepsilon_{\pi,t}$	$\varepsilon_t^{cb_l}$	$\varepsilon_t^{cb_d}$	$\varepsilon_t^{cb\_\eta}$
qh	1	12.8	36.0	0.4	47.1	0.1	0.3	0.0	3.2	0.1	0.0	0.0
	4	14.3	43.8	0.5	39.0	0.1	0.4	0.0	1.9	0.1	0.0	0.0
	10	15.4	54.6	0.6	25.0	0.1	0.4	0.0	3.9	0.0	0.0	0.0
	40	14.2	76.7	0.4	6.8	0.1	0.1	0.0	1.7	0.0	0.0	0.0
	100	12.5	83.7	0.2	2.8	0.0	0.0	0.0	0.7	0.0	0.0	0.0
y_h	1	0.0	0.3	3.6	81.4	7.2	0.5	0.0	6.8	0.1	0.0	0.0
	4	0.2	53.5	1.5	37.2	3.7	0.4	0.0	3.4	0.1	0.0	0.0
	10	0.1	72.1	0.7	19.6	2.5	0.2	0.0	4.7	0.0	0.0	0.0
	40	0.4	84.6	0.3	10.2	1.5	0.1	0.0	2.8	0.0	0.0	0.0
	100	1.2	86.2	0.3	8.6	1.3	0.1	0.0	2.3	0.0	0.0	0.0

The variance decomposition for the interest rate, inflation, and GDP is displayed in Table 4.7. For the interest rate, the government spending shock, inflation shock, and housing demand shock are the dominant driving forces, explaining 21.7%, 39.1%, and 15% of the variance in the short run (one quarter), respectively. The main components leading to the volatility of the interest rate remain consistent between the short run and the long run. The effects of these three shocks persist into the long term. The technology shock in the general sector, labor supply shock, and monetary policy shock also play roles, accounting for 9.2%, 7.7%, and 6%, respectively. In the long run, the technology shock in the general goods sector becomes significant, increasing to 12.3%.

In terms of the volatility of inflation, inflation shock plays a dominant role, explaining over 63% in the short term (one quarter) and decreases to 26.8 in the long term (25 years). The labor supply shock and housing demand shock contribute 12% and 17% in the very short term, increasing to 16% and 25.7% over 25 years. The government spending shock increases from 5.8% to 17.2%. Other shocks account for a minor portion of the variance in inflation, all contributing less than 13% across various horizons.

For GDP, the technology shocks in the general sector and housing demand shock play significant roles in explaining the variance in the short run, accounting for 22% and 55.7% in one quarter, respectively. Minor contributors include the inflation shock, labor supply shock, and monetary policy shock, explaining 8.1%, 5.9%, and 6.0%, respectively. The contribution of the technology shock in the general sector increases from the short run to the long run, explaining 60% over 25 years. In contrast, the influences of the housing demand shock and labor supply shock on GDP decrease. The influence of the inflation shock increases to 28% in the long term.

Table 4.7 Variance decomposition

Variable	horizon	$A_{c,t}$	$A_{h,t}$	g_t	$\varepsilon_{h,t}$	$\varepsilon_{l,t}$	$\varepsilon_{MP,t}$	$\varepsilon_{p,t}$	$\varepsilon_{\pi,t}$	$\varepsilon_t^{cb_l}$	$\varepsilon_t^{cb_d}$	$\varepsilon_t^{cb\_\eta}$
R	1	9.2	0.5	21.7	15.0	7.7	6.0	0.5	39.1	0.3	0.0	0.0
	4	4.6	1.0	19.9	13.8	9.3	10.7	0.5	40.1	0.2	0.0	0.0
	10	3.4	1.3	24.4	16.9	12.3	9.8	0.7	31.1	0.1	0.0	0.0
	40	2.5	1.0	33.1	23.0	13.5	6.5	0.8	19.6	0.1	0.0	0.0
	100	12.3	2.1	30.6	21.3	11.4	5.4	0.7	16.2	0.0	0.0	0.0
π	1	0.1	0.9	5.8	16.9	12.0	0.6	0.4	63.4	0.0	0.0	0.0
	4	0.1	1.4	9.7	26.4	17.3	1.0	0.7	43.3	0.0	0.0	0.0
	10	0.1	1.6	13.1	30.4	18.6	1.3	0.8	34.2	0.0	0.0	0.0
	40	0.2	1.6	18.2	29.1	18.2	1.4	0.8	30.6	0.0	0.0	0.0
	100	9.9	2.3	17.2	25.7	16.0	1.2	0.7	26.8	0.0	0.0	0.0
GDP	1	22.5	0.3	0.3	55.7	5.9	6.0	0.5	8.1	0.8	0.0	0.0
	4	16.5	0.4	0.4	35.4	2.8	2.7	0.4	40.8	0.5	0.0	0.0
	10	15.0	0.2	0.2	17.0	1.0	1.0	0.1	65.4	0.2	0.0	0.0
	40	38.2	0.9	0.9	8.5	0.7	0.6	0.2	49.9	0.1	0.0	0.0
	100	60.0	3.2	3.2	4.8	0.4	0.4	0.0	28	0.1	0.0	0.0

Historical decomposition

The variance decomposition has been discussed in the last section. This section will focus on the historical decomposition of housing prices from 2000 to 2020, illustrating the contribution of each shock to the volatility of housing prices. The historical decomposition of housing prices shares some features with the forecast error variance decomposition. Figure 4.7 displays the historical decomposition of housing prices.

From Figure 4.7, we find that housing demand shocks, technology shocks in the goods sector, government spending shocks, and inflation shocks play an important role in the volatility of real housing prices. The figure shows an increase in housing prices from 2005 to 2007, driven by positive housing demand shocks. This increase is primarily due to the reform of the housing system, transitioning from a welfare housing system to a market-based housing system. Since 1998, China has ceased distributing welfare housing and has encouraged the development of the real estate market. Additionally, rapid progress in banking reforms, improvements in housing credit, provident fund management, and other systems have increased housing demand, pushing up housing prices.

Compared to mature real estate markets in most developed countries, China's real estate market was still in its initial stages. Government intervention was necessary to control and stabilize the housing market. To ensure the healthy development of the housing market, the Chinese government issued tightening policies to curb the rapid growth of housing prices. As a result, housing prices did not increase significantly nor suffer a sharp decrease from 2005 to 2007. The financial crisis of 2008 seriously affected China's housing market, leading to a sharp decrease in housing prices from 2008 to 2009. Figure 4.7 shows that negative housing demand shocks and negative inflation shocks contributed to this sharp decline. A sudden decline in housing demand is a typical market reaction to a financial crisis. The RMB 4 trillion stimulus package in 2008 indirectly contributed to the housing price surge through massive credit expansion and infrastructure-driven urbanization. Simultaneously, the mortgage down payment was reduced from 30% to 20%, and taxes on the stamp duty and land value increase were abolished. Furthermore, the eligibility criteria for obtaining a mortgage on a second property were relaxed for potential buyers. With loose monetary policy, housing demand experienced a dramatic increase. Positive housing demand shocks and government spending shocks led to a dramatic rise in housing prices from 2009 to 2010, which was also aided by inflation shocks. After that, many measures were implemented, such as increasing the down payment requirement and raising the deposit reserve rate to restrict speculative housing demand. Additionally, in 2016, Xi Jinping stated that "houses are for living in, not for speculation", which is a political directive aimed at curbing speculative housing demand. Housing demand fell after 2011, and continued negative housing demand and inflation shocks led to a major slowdown in housing prices. The outbreak of COVID-19 disrupted this equilibrium in 2019, resulting in a sharp decline in housing prices.

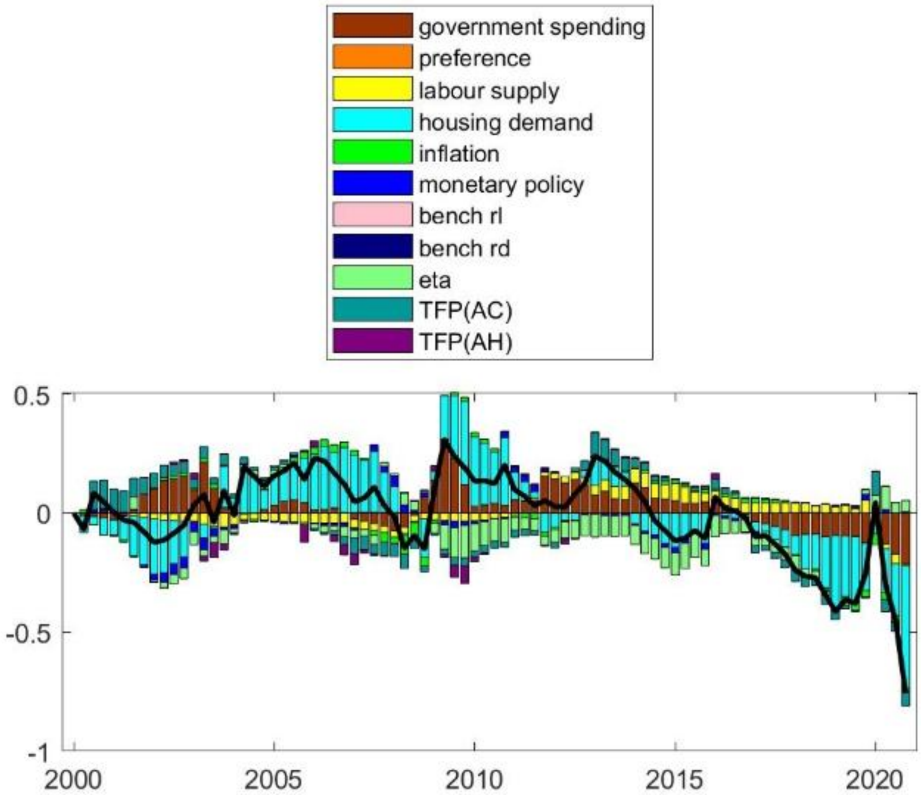


Figure 4.7 Historical decomposition

Impulse response function

In this section, we compare the impulse response functions derived from the estimated benchmark model and the extended model. To focus on the different responses between the two models, both models use shocks with identical scales (0.02 standard error of innovation). For the general sector, variables such as general consumption, output, and inflation have been chosen. For the housing sector, we analyze housing demand (consumption of houses), output in housing production, and housing prices. GDP represents the overall economy. The real interest rate and the behavior of the shock are included. All these variables are displayed in a single graph. The blue lines display the impulse response function for the benchmark model. The yellow lines represent the impulse response function for the extended model. The interest rate in the yellow line in this graph is the real monetary policy rate derived from the Taylor rule. Specific lending and deposit rates of the extended model and the interest rate of the benchmark model are displayed in a separate graph.

The third graph is used to identify whether the economy chooses the market lending rate as the lending rate (when $r_t^{l\_md} > r_t^{l,cb}$) or sticks to the benchmark lending rate (when $r_t^{l\_md} < r_t^{l,cb}$), showing the floor restriction. It also shows whether the market deposit rate is chosen as the deposit rate (when $r_t^{l\_md} < r_t^{l,cb}$) or the benchmark deposit rate is chosen (when $r_t^{l\_md} > r_t^{l,cb}$), displaying the ceiling restriction. The benchmark interest rates are shown in red. Lending and deposit rates, which are the interest rates applied in the economy, are displayed in green. Therefore, each impulse response function analysis includes three graphs. The first and second graphs are for comparison, and the third explores the response in the 'semi-market' interest system. The comparison primarily focuses on the housing market.

Tight monetary policy shock

Under the unique characteristics of Chinese monetary policy, a tight monetary policy shock is caused by an increased reserve requirement ratio and an increase in the two benchmark interest rates. However, from the variance decomposition analysis, the contribution of the reserve requirement ratio and two boundary shocks on the economy is close to zero. Figure 4.1 shows that the benchmark lending and deposit rates follow the same trend, either increasing or decreasing simultaneously. These two benchmark interest rates move in line with the Taylor-type monetary policy, and this shock affects both rates in the same direction. Therefore, a positive Taylor-type monetary policy shock is considered for comparison. Without considering the benchmark interest shocks and reserve requirement ratio shock, the difference in the extended model is the effect of the Taylor rule on the limits and the inclusion of a banking sector.

In Figure 4.10, the red line represents the benchmark interest rates (restrictions), and the green line represents the interest rates applied in the economy. In the top half of Figure 4.10, the green line is higher than the red line, indicating that the lending rate is above the benchmark lending rate (floor). In the bottom half, the green line is below the red line, indicating that the deposit rate is below the benchmark deposit rate (ceiling). The first row of Figure 4.8 displays responses in the general sector, while the second row shows responses in the housing sector. The bottom right corner subset graph in Figure 4.8 displays the Taylor-type monetary policy shock. Since the shock is the same in both models, the two colors overlap, showing only yellow. Figure 4.9 illustrates the applied lending and deposit rates of the extended model and the interest rate of the benchmark model. In brief, the first and second figures (4.8 and 4.9) are for comparison, and the third Figure (4.10) helps to determine whether the applied interest rates differ from the restrictions.

A tight monetary policy negatively affects most variables across all sectors and two models. The real interest rate increases under tight monetary policy, leading to decreases in other economic variables. In Figure 4.8, the different responses in these two models show that in the general sector, consumption, output, and inflation all decrease. In the housing sector, housing demand and output are lower than in the benchmark model, but housing prices in the extended model are slightly higher. The higher lending rate in the extended model increases the cost of building houses, thereby raising housing prices. Meanwhile, the relatively lower deposit rate results in higher consumption. Households relatively prefer to consume general goods. As a result, housing demand and output in the housing sector decrease more in the extended model compared to the benchmark model. For the overall economy, GDP decreases due to the decline in output in both sectors.

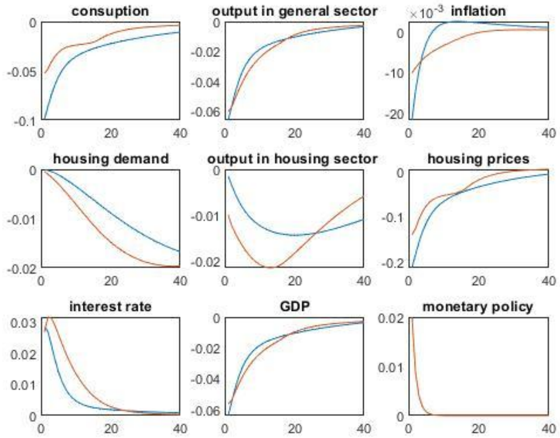


Figure 4.8 IRF comparison (main variables)

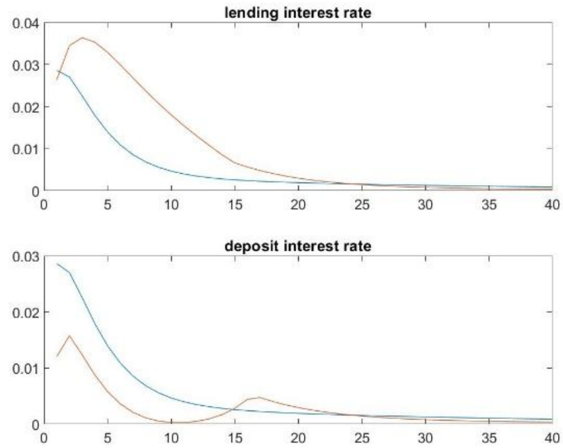


Figure 4.9 IRF comparison (interest rates)

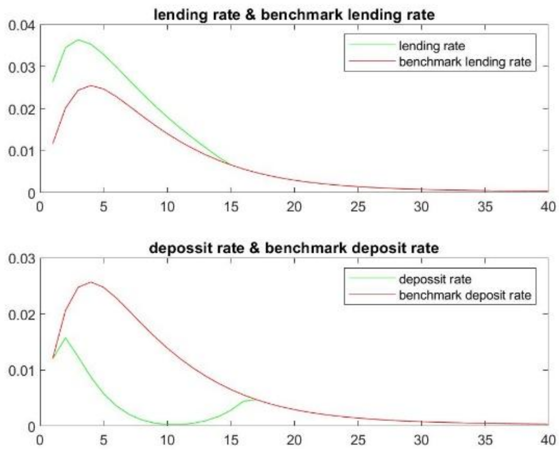


Figure 4.10 IRF for benchmark & model applied rates

Positive house demand shock

In both models, a positive house demand shock leads to higher housing demand, resulting in a lower market share for the general goods sector. The increased housing demand necessitates higher output in the housing sector to meet this demand, and housing prices also increase. This positive housing demand shock also impacts the general goods sector, where output and inflation both increase. For the overall economy, GDP rises as outputs in both production sectors grow. The difference between the two models lies primarily in the 'semi-market' system of the extended model, which leads to a higher lending rate and a lower deposit rate (Figure 4.13). As shown in Figure 4.12, the lending rate in the extended model is higher than in the benchmark model, and the deposit rate is lower. As a result, on the one hand, the higher lending rate in the extended model increases the financial cost of building, which raises housing prices. On the other hand, the relatively lower deposit rate in the extended model boosts normal consumption, which reduces housing demand, leading to lower house production and, consequently, lower housing prices. These two effects balance out, making the housing prices in the extended model comparable to those in the benchmark model. Under a positive housing demand shock, housing demand and house output are lower in the model with a 'semi-market' interest rate system.

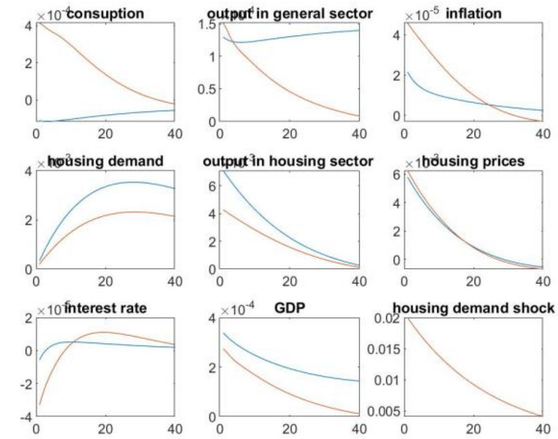


Figure 4.11 IRF comparison (main variables)

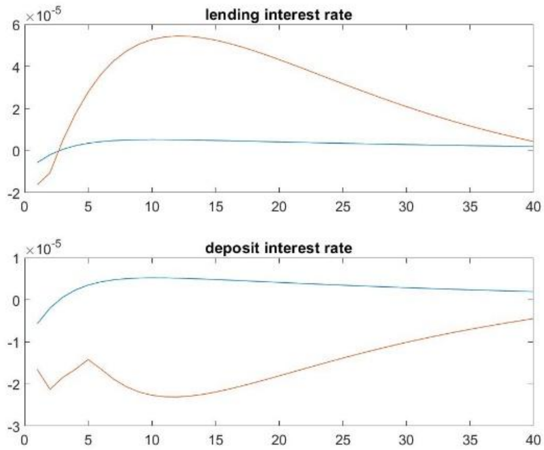


Figure 4.12 IRF comparison (interest rates)

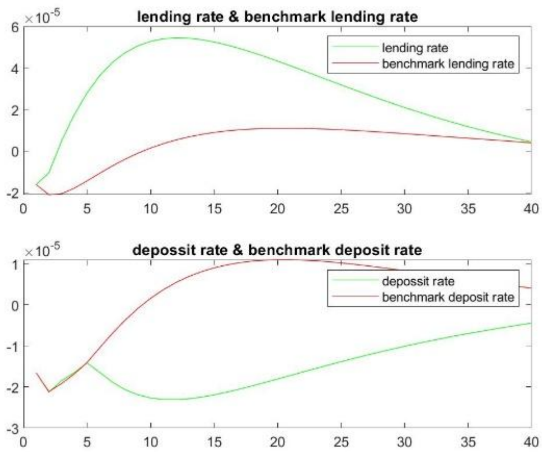


Figure 4.13 IRF for benchmark & model applied rates

Technology shock in housing sector.

A positive technology shock in the housing sector decreases the cost of producing houses, leading to higher housing output, increased housing consumption, and lower housing prices. The shock has a minimal impact on the general sector, with the scale of responses in consumption, output, and inflation in the general sector being quite small, at most 1×10^{-4} unit.

Under a positive technology shock in the housing sector, both lending rates and deposit rates in the 'semi-market' system remain aligned with the floor and ceiling, showing no divergence. Figure 4.16 only shows a line in each sub-figure, which means that the benchmark interest rates and lending rate or deposit rate stick together. Figure 4.15 illustrates that both lending and deposit rates in the extended model are slightly higher than in the benchmark model, not due to the 'semi-market' system but because of the inclusion of the banking sector and differences in model parameters. The housing demand, output in the housing sector, and housing prices are all lower in the second model.

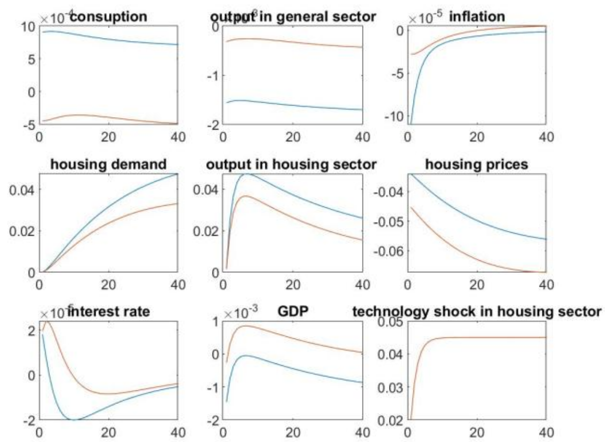


Figure 4.14 IRF comparison (main variables)

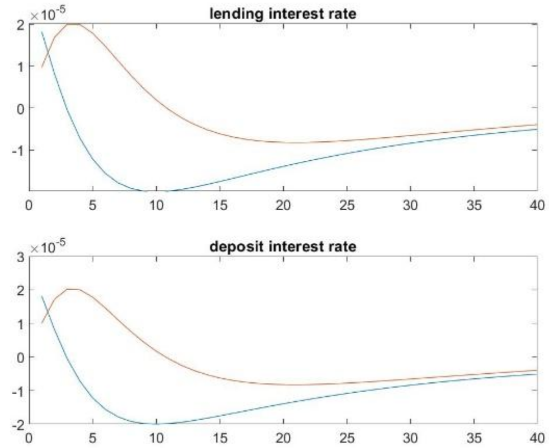


Figure 4.15 IRF comparison (interest rates)

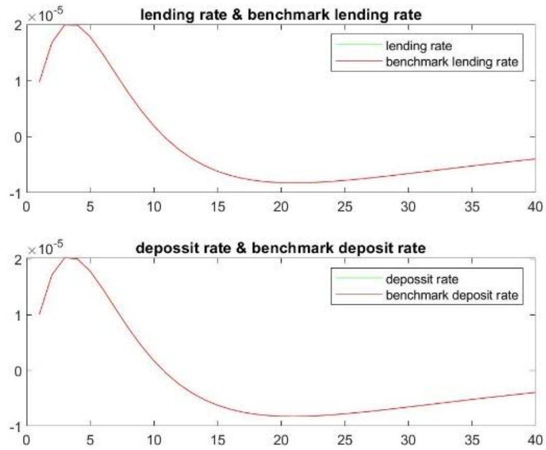


Figure 4.16 IRF for benchmark & model applied rates

Technology shock in general sector.

Positive technology shocks in the general sector lead to lower production costs for general goods, boosting their output. Increased output and high production efficiency raise household income, which in turn leads to higher consumption. This increased consumption further encourages firms to expand production, requiring more labor and thus driving up wages. Initially, the high demand for consumption and rising wages caused inflation. As inflation rises, the central bank is likely to gradually raise interest rates to curb excessive demand, thereby depressing inflation at a later stage. Figure 4.17 shows an initial increase in inflation, followed by a decrease as interest rates gradually rise. Positive technology shocks also impact the housing market; they gradually increase house purchases and production, leading to higher housing prices.

Regarding the differences between the two models, similar to the positive technology shocks in the general sector, the extended model adheres to the benchmark interest rates. Both lending and deposit rates in the extended model are higher than those in the benchmark model (Figures 4.18 and 4.19). Housing demand, output in the housing sector, and housing prices are more stable in the extended model. Housing demand, housing prices, and output are relatively lower in the second model.

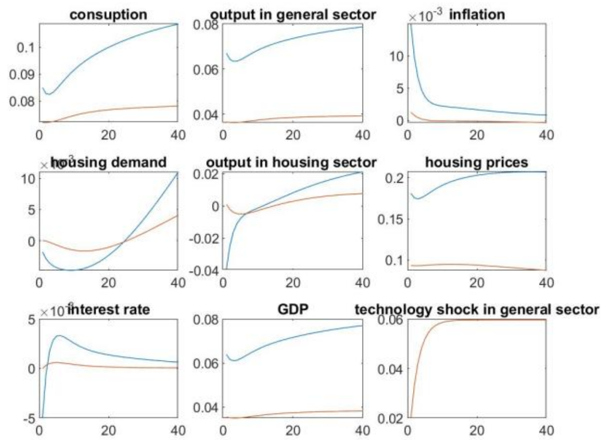


Figure 4.17 IRF comparison (main variables)

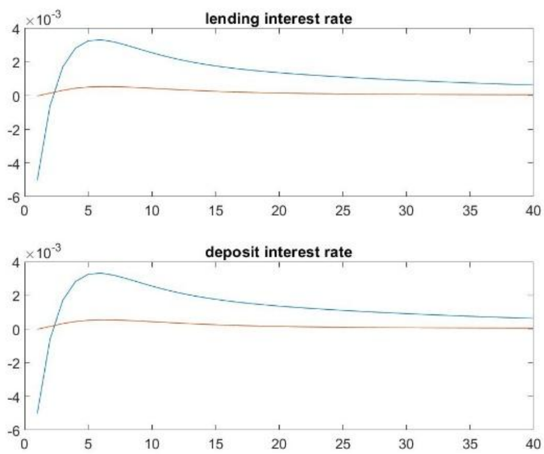


Figure 4.18 IRF comparison (interest rates)

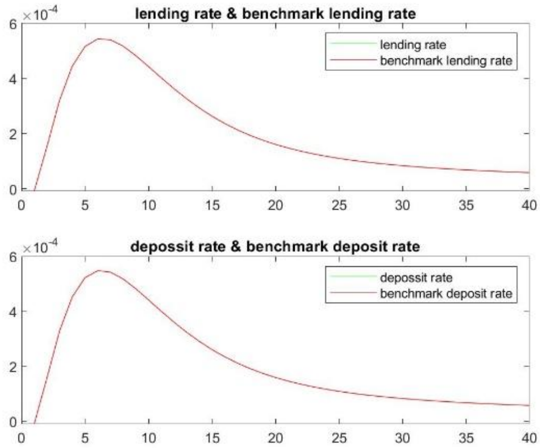


Figure 4.19 IRF for benchmark & model applied rates

4.4 Conclusion

In terms of the model's fitness, the results of the indirect inference test show that both the benchmark model, a New Keynesian DSGE model, and the extended model, which incorporates specific monetary policy tools, can explain the real data well. The extended model demonstrates a better fit, with a lower Wald statistic. The standard analysis in Chinese economic studies can use the benchmark model. The extended model is more suitable for analyzing the impact of specific monetary tools.

The results indicate that the response of housing demand and output in the extended model is relatively lower than in the benchmark model. The 'semi-market' interest rate system allows the extended model to adopt a market-determined lending rate when it exceeds the benchmark lending rate. Therefore, under a high housing demand scenario, firms are likely to borrow more from the commercial bank to increase production, which raises the market-determined lending rate. This leads to higher lending rates offered by commercial banks. In turn, these high lending rates affect the behavior of both firms and customers. This is a process of market regulation. High lending interest rates effectively dampen activity in the real estate market, affecting both demand and supply. The high lending rate increases the financial cost of producing houses, which directly raises house prices. At the same time, firms choose to produce fewer houses. Furthermore, the higher cost of purchasing a home can deter buyers from entering the market. Therefore, the ‘semi-market’ interest rate system is a combination of market self-regulation and government regulation, effectively controlling the housing market. For the volatility of housing prices, both variance decomposition and historical decomposition show that housing demand is the primary influence. As shown in the variance decomposition in Table 4.6, technology shocks in the housing sector contribute significantly to long-term price movements. Monetary policy tools affect customers’ decisions when buying houses.

5. Chapter 5

Welfare analysis

5.1 Introduction

The indirect inference test for the two models shows that these two models explain the data well. The best-fitting model is the fully complex one that incorporates extra money policy elements plus a banking model. The comparison of the welfare loss analysis for the two models will be discussed in this chapter to identify which model gets better welfare. A welfare analysis is conducted for the complex model, replacing the monetary policy with its additional components by a simple Taylor Rule. We follow Rotemberg and Woodford (1999) to evaluate different monetary performances by considering output and inflation variability.

The following is the structure of Chapter 5: section 5.2 displays the welfare analysis for the benchmark and extended models. Concludes in section 5.3.

5.2 Welfare analysis for benchmark and extended model

The monetary policy in the benchmark model is the Taylor-type monetary policy rule. The extended model combines the Taylor-type monetary policy rule and the commercial banking sector to create a 'semi-market' interest rate system, which aligns better with China's circumstances. The central bank imposes restrictions on interest rates, setting a floor on lending rates and a ceiling on deposit rates. The performance of these two different monetary policies will be compared.

Average Welfare Loss Function

$$L = \lambda_\pi * Var(\pi_t) + \lambda_y Var(y_t) \tag{5.1}$$

Where λ_π and λ_y are weight parameter.

We simulated these two models 1000 times for each of the 1000 periods and calculated the variances of output and inflation for each simulated data set. We then obtained the average variance of both inflation and output. The simulated output was detrended before the variance calculation.

$VAR(\pi_t)$ and $Var(y_t)$ denote the variance of inflation and variance of output, respectively. The welfare Loss Function is a weighted average of the two variances with the weights determined by their relative size. λ_π and λ_y are the weights of inflation and output, respectively, determined by their relative sizes.

From the last chapter, we find the extended model is the better-fitting model. Therefore, it is the best to use in the analysis of policy choices. In the extended model, commercial banks have been included and have the option to determine interest rates between benchmark interest rates and market-determined interest rates. The extended model has been subdivided into two scenarios to investigate the average welfare loss under different monetary policies.

1. Scenario one is the Talor rule-only economic model. The Chinese characteristic monetary elements (commercial banking sector, restrictions, benchmark interest rates and reserve requirement ratio) are all removed from the extended model. This is effectively the benchmark model.
2. Scenario two is the model with a ‘semi-market’ interest rates system, which is an option system between benchmark and market-determined interest rates. This is the extended model.

Table 5.1 Average Welfare Loss

	Scenario one Benchmark model	Scenario two The extended model
$Var(\pi_t)$	7.2933e-05	3.9056e-04
$Var(y_t)$	0.0630	0.1462
L	0.063	0.14

The average welfare loss function is displayed in Equation 5.1. The variance of output and inflation is based on the simulated data for the two models. The average welfare losses for the two models will be compared. Table 5.1 displays the value of the variance of inflation and output and the average welfare value for each scenario. By including the 'semi-market' interest rate system, the value increases, indicating an unstable economy. The results indicate that the 'Chinese characteristics' monetary policy elements reduce welfare. With the replacement of monetary policy in the extended model to a Taylor rule only without the commercial banking sector, the volatility of output significantly decreases, and the welfare rises.

5.3 Conclusion

The estimation conclusion in Chapter 4 displays that the extended model fits better than the benchmark model, but the policy conclusion shows that replacing the extended model 'Chinese' monetary policy with a standard Taylor Rule (no extra bits) reduces output variability and raises welfare. The system of 'semi-market' interest rates, namely the restriction on interest rates, leads to economic volatility. According to this analysis, the PBOC should drop all its extra interventions.

Models with two types of monetary policy pass the test, which implies that the PBoC follows some form of Taylor rule regardless of the specific tools employed. The welfare comparison suggests that a pure Taylor rule delivers a more stable economy. This can be intuitively explained by the nature of the policies. The Taylor rule allows for smooth and continuous adjustments in policy rates in response to changes in inflation and output. Chinese-specific policy tools, such as reserve requirement ratio adjustments, loan rate floor and deposit rate cap, may distort credit allocation and constrain the commercial banks' responsiveness to economic conditions, amplifying economic volatility. The higher welfare loss for the extended model indicates the cost of using restrictive and less flexible tools, revealing a trade-off between targeted interventions (eg., controlling housing demand) and macroeconomic stability.

Chapter 6

Conclusion

The economy in China is closely linked to the housing market. A late start, rapid development, and volatility in housing prices characterize this market. Many authors have investigated the volatility of housing prices in China through both empirical and theoretical analyses. What particularly interests me is the complex monetary policy tools used in China. Like the housing market, the enhancement of the banking system also experienced a late start. Since 1978, China has transitioned from a single banking system to one with commercial banks. As a new economy, China has developed its own monetary policy system to achieve multiple targets, such as stabilizing prices and promoting economic growth. Various policy tools have been employed to meet these objectives. The benchmark interest rates and reserve requirement ratio have been frequently adjusted to stabilize the economy. Additionally, the central bank sets a floor on the lending rate and a ceiling on deposit rates. Specifically, the central bank uses the benchmark lending rate as the floor for lending rates and the benchmark deposit rate as the ceiling for deposit rates. If the market-determined lending rate is higher than the benchmark lending rate, the market rate is used; otherwise, the benchmark rate is applied. Similarly, if the market-determined deposit rate is lower than the benchmark deposit rate, the market rate is used; otherwise, the benchmark rate is applied. These complex monetary policies motivate me to construct a theoretical model incorporating these specific policies to explore their effects on housing prices.

Two models are constructed in this thesis: one is a New Keynesian DSGE model as a benchmark, and the other combines this benchmark model with specific monetary tools. These models will be used to explore the volatility of housing prices. The indirect inference method will be used to test and estimate both models to identify which one fits the data better. Welfare analysis is also included.

The estimated benchmark model and the extended model both pass the indirect inference test. The model with complex monetary policy fits the data better. Both models indicate that housing demand is the main cause of house price volatility, with technology shocks in the general sector also playing a role. A comparison of housing market control between the two models reveals that the extended model has relatively lower housing demand and output based on the impulse response function.

The 'semi-market' interest rate system in the extended model allows the economy to choose the market-determined lending rate when it is higher than the benchmark rate. We found that positive housing demand shocks result in higher market lending rates in the economy. The higher lending rate leads to lower housing output due to the higher loan costs, which also decreases housing demand. This 'semi-market' interest rate system combines market self-regulation and government intervention, representing a necessary step towards interest rate liberalization. Under supply shocks, the lending rate equals the benchmark lending rate. Additionally, the benchmark interest rate can be adjusted by the central bank, allowing for more flexible economic management. Data on the benchmark interest rate shows it was frequently adjusted; for example, in 2008, in response to the financial crisis, the benchmark interest rates were decreased five times. The central bank can flexibly adjust the benchmark interest rates based on the latest data and economic changes, responding promptly to various issues. Therefore, the semi-market system can better control house prices.

Welfare analysis for the two models indicates that the model with specific monetary policy tools and a full banking sector implies that shocks create much more volatility under this monetary setting; hence, the model is welfare inferior despite its better fit to the data compared to the simple Taylor rule model. If these extra ‘Chinese characteristic’ elements in PBOC policy were dropped in favour of a simple Taylor Rule, welfare would increase substantially as stability in output and inflation both improve. This is the key policy conclusion of this thesis. Therefore, combining the above conclusions, we find that while restrictions on interest rates can control house prices, they come at the cost of economic instability.

The indirect inference method is rigorous and is known for easily rejecting mis-specified models. In this thesis, however, both models pass the test. The main differences between models are monetary policy specifications. The benchmark model uses a single-equation Taylor rule, while the extended model has multiple policy instruments and equations. In this context, the extended model benefits from a broader parameter space in the monetary policy component, which may increase the possibility of identifying a combination of parameters that can replicate the features of the auxiliary model and thus pass the test. Moreover, the fact that both models pass suggests that PBoC’s monetary policy behavior is broadly consistent with a Taylor-type rule at the aggregate level.

In this thesis, we consider the specific monetary policies affecting firm loans and their influence on the housing market. Household borrowing for purchasing houses also impacts the housing market. Besides monetary policy factors, there are other non-monetary policy tools, such as adjustments to the down payment ratio. In addition, this study focuses on housing demand, while housing supply is treated in a simple way. However, housing supply is affected by some factors, like land acquisition costs, expected housing prices, and financing constraints—particularly collateral-based lending mechanisms. This study does not model the construction decisions of developers in response to these factors. This study also abstracts from the openness of the Chinese economy. These elements will be analyzed further in future research as appropriate, depending on the research objectives.

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Appendix A

Log linearization equation

Benchmark Model

households

$$\widehat{w_{c,t}} = \widehat{\varepsilon_t^l} + (\aleph - \vartheta)\frac{{n_c}^{1+\vartheta}\widehat{n_{c,t}} + {n_h}^{1+\vartheta}\widehat{n_h}}{{n_c}^{1+\vartheta} + {n_h}^{1+\vartheta}} + \vartheta\widehat{n_{c,t}} + \widehat{c_t} \tag{A1}$$

$$\widehat{w_{h,t}} = \widehat{\varepsilon_t^l} + (\aleph - \vartheta)\frac{{n_c}^{1+\vartheta}\widehat{n_{c,t}} + {n_h}^{1+\vartheta}\widehat{n_{h,t}}}{{n_c}^{1+\vartheta} + {n_h}^{1+\vartheta}} + \vartheta\widehat{n_{h,t}} + \widehat{c_t} \tag{A2}$$

$$\widehat{h_t} = \frac{(1-G)}{\mathrm{G}h}\widehat{q_{h,t+1}} - \frac{1}{\mathrm{G}h}\widehat{q_{h,t}} + \frac{1}{\mathrm{G}h}\widehat{c_t} - \frac{(1-G)}{\mathrm{G}h}\widehat{c_{t+1}} - \frac{(1-G)}{\mathrm{G}h}\left(\widehat{\varepsilon_t^p} - \widehat{\varepsilon_{t+1}^p}\right) + \frac{1}{h}\widehat{\varepsilon_t^h} \tag{A3}$$

$$\widehat{\varepsilon_t^p} - \widehat{c_t} = \widehat{\varepsilon_{t+1}^p} - \widehat{c_{t+1}} + \widehat{r_t} \tag{A4}$$

Firms

$$c^e\widehat{c_t^e} + w_c n_c\left(\widehat{w_{c,t}} + \widehat{n_{c,t}}\right) + w_h n_h\left(\widehat{w_{h,t}} + \widehat{n_{h,t}}\right) + +i_c\widehat{\iota_{c,t}} + i_h\widehat{\iota_{h,t}} =$$

$$\frac{Y}{X}\left(\widehat{Y_t} - \widehat{X_t}\right) + q_h Y_h\left(\widehat{q_{h,t}} + \widehat{Y_{h,t}}\right) \tag{A5}$$

$$\widehat{Y_t} = \widehat{A_{c,t}} + (1-\alpha)\widehat{n_{c,t}} + \alpha\widehat{k_{c,t-1}} \tag{A6}$$

$$\widehat{Y_{h,t}} = \widehat{A_{h,t}} + (1-\omega)\widehat{n_{h,t}} + \omega\widehat{k_{h,t-1}} \tag{A7}$$

$$\widehat{k_{c,t}} = \left(1-\delta_{k,c}\right)\widehat{k_{c,t-1}} + \delta_{k,c}\widehat{\iota_{c,t}} \tag{A8}$$

$$\widehat{k_{h,t}} = \left(1-\delta_{k,h}\right)\widehat{k_{h,t-1}} + \delta_{k,h}\widehat{\iota_{h,t}} \tag{A9}$$

$$\widehat{n_{c,t}} = \widehat{Y_t} - \widehat{X_t} - \widehat{w_{c,t}} \tag{A10}$$

$$\widehat{n_{h,t}} = \widehat{q_{h,t}} + \widehat{Y_{h,t}} - \widehat{w_{h,t}} \tag{A11}$$

$$\widehat{c_{t+1}^e} = \widehat{c_t^e} - \frac{\varepsilon_{p,t} - \widehat{\varepsilon_{p,t+1}} - \widetilde{r_t}}{\varsigma} \tag{A12}$$

$$\widehat{k_{c,t}} = \frac{\alpha * \frac{\beta_e Y}{X k_c}}{\left(\alpha * \frac{\beta_e Y}{X k_c} + \beta_e k k_c + k k_c\right)} \left(\widehat{Y_{t+1}} - \widehat{X_{t+1}}\right) + \frac{\beta_e k k_c}{\left(\alpha * \frac{\beta_e Y}{X k_c} + \beta_e k k_c + k k_c\right)} \widehat{k_{c,t+1}} + \frac{k k_c}{\left(\alpha * \frac{\beta_e Y}{X k_c} + \beta_e k k_c + k k_c\right)} \widehat{k_{c,t-1}} + \frac{1}{\left(\alpha * \frac{\beta_e Y}{X k_c} + \beta_e k k_c + k k_c\right)} \left\{\widehat{\varepsilon_{p,t+1}} - \varsigma \widehat{c_{t+1}^{e}} - (\widehat{\varepsilon_{p,t}} - \varsigma \widehat{c_t^e})\right\} \quad \text{(A13)}$$

(A13) simplified as (B13)

$$\widehat{k_{c,t}} = k_{c1}\left(\widehat{Y_{t+1}} - \widehat{X_{t+1}}\right) + k_{c2}\widehat{k_{c,t+1}} + k_{c3}\widehat{k_{c,t-1}} + k_{c4}\left\{\widehat{\varepsilon_{p,t+1}} - \varsigma \widehat{c_{t+1}^{e}} - (\widehat{\varepsilon_{p,t}} - \varsigma \widehat{c_t^e})\right\} \quad \text{(B13)}$$

Where $k_{c1} + k_{c2} + k_{c3} = 1$

$$\widehat{k_{h,t}} = \frac{\omega * \frac{\beta_e q_h Y_h}{k_h}}{k_h k + \beta_e k k_h + \omega * \frac{\beta_e q_h Y_h}{k_h}} \left(\widehat{q_{h,t+1}} + \widehat{Y_{h,t+1}}\right) + \frac{k * \beta_e k_h}{k_h k + \beta_e k k_h + \omega * \frac{\beta_e q_h Y_h}{k_h}} \widehat{k_{h,t+1}} + \frac{k_h k}{k_h k + \beta_e k k_h + \omega * \frac{\beta_e q_h Y_h}{k_h}} \widehat{k_{h,t-1}} + \frac{1}{k_h k + \beta_e k k_h + \omega * \frac{\beta_e q_h Y_h}{k_h}} \left\{\widehat{\varepsilon_{p,t+1}} - \varsigma \widehat{c_{t+1}^{e}} - \left(\widehat{\varepsilon_{p,t}} - \varsigma \widehat{c_t^e}\right)\right\} \quad \text{(A14)}$$

(A14) can be simplified as (B14)

$$\widehat{k_{h,t}} = k_{h1}\left(\widehat{q_{h,t+1}} + \widehat{Y_{h,t+1}}\right) + k_{h2}\widehat{k_{h,t+1}} + k_{h3}\widehat{k_{h,t-1}} + k_{h4}\left\{\widehat{\varepsilon_{p,t+1}} - \varsigma \widehat{c_{t+1}^{e}} - \left(\widehat{\varepsilon_{p,t}} - \varsigma \widehat{c_t^e}\right)\right\} \quad \text{(B14)}$$

Where $k_{h1} + k_{h2} + k_{h3} = 1$

Retailer

$$\widehat{\pi_t} = \beta^F E_t \widehat{\pi_{t+1}} - \frac{(1-\varphi)(1-\beta^F \varphi)}{\varphi} \widehat{X_t} + \widehat{\varepsilon_{\pi,t}} \quad \text{(A15)}$$

Monetary policy

$$\widehat{R_t} = \widehat{R_{t-1}} + (1-\rho_R)\varphi_\pi \widehat{\pi_t} + (1-\rho_R)\varphi_x \widehat{GDP}_t - (1-\rho_R)\varphi_x \widehat{GDP_{t-1}} + \widehat{\varepsilon_t^{MP}} \tag{A16}$$

Fisher identity:

$$\widehat{R_t} = \widehat{r_t} + E_t \widehat{\pi_{t+1}} \tag{A17}$$

Market clearing

$$\widehat{Y_t} = \frac{C}{Y}\widehat{C_t} + \frac{I}{Y}\widehat{I_t} + \frac{G}{Y}\widehat{G_t} \tag{A18}$$

$$\widehat{C_t} = \frac{c}{C}\widehat{c_t} + \frac{c^e}{C}\widehat{c_t^e} \tag{A19}$$

$$\widehat{I_t} = \frac{i_c}{I}\widehat{\iota_{c,t}} + \frac{i_h}{I}\widehat{\iota_{h,t}} \tag{A20}$$

$$\widehat{GDP}_t = \frac{Y}{GDP}\widehat{Y_t} + \frac{\overline{q_h} Y_h}{GDP}(\widehat{q_{h,t}} + \widehat{Y_{h,t}}) \tag{A21}$$

$$h\widehat{h_t} - (1-\delta_h)h\widehat{h_{t-1}} = Y_h \widehat{Y_{h,t}} \tag{A22}$$

The Extended model

The log linearization equations added to the benchmark model displays in this section.

Commercial bank

$$\widehat{s_t} = \widehat{b_t} + \frac{\eta}{1-\eta} * \widehat{\eta_t}^{1} \tag{B1}$$

$$\widehat{r_t^{ml}} = \widehat{r_t^{ib}} + \delta_b \mathrm{b}\widehat{\mathrm{b}_t} \tag{B2}$$

$$\widehat{r_t^{md}} = \widehat{r_t} - s\delta_s(1-\eta)^2\widehat{s_t} + \{2(1-\eta)\delta_s s\}\widehat{\eta_t} \tag{B3}$$

Benchmark interest rates

$$r_t^{d,cb} = (1-\phi_r^d)r_t + \phi_r^d r_{t-1}^{d,cb} + \varepsilon_t^{cb\_d} \tag{B4}$$

$$r_t^{l,cb} = (1-\phi_r^l)r_t + \phi_r^l r_{t-1}^{l,cb} + \varepsilon_t^{cb\_d} \tag{B5}$$

Reserve requirements ratio rule

$$\eta_t = \left(1-\phi_\eta^\eta\right)\phi_\eta^\pi \pi_t + \phi_\eta^\eta \eta_{t-1} + \varepsilon_t^{cb\_\eta} \tag{B6}$$

The restriction for interest rates issued by the central bank

$$r_t^l = Max\,(r_t^{ml}, r_t^{l,cb}) \tag{B7}$$

$$r_t^d = Max\,(r_t^{md}, r_t^{d,cb}) \tag{B8}$$

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[1] The aggregate net position of the banking sector in the interbank market must equal zero.

Appendix B

Table B.1 Data Description and Source of two Models

Symbol	Variables	Source	Indicator
Variables for the benchmark model			
c	Household consumption	NBSC	Household Consumption Expenditure (100 million yuan)
qh	Housing prices	NBCS	Average Selling Price of Commercialized Residential Buildings(yuan/sq.m)
h	Housing stock	Model implied	$h_t - (1-\delta_h)h_{t-1} = Y_{h,t}$
w_c	Wage for normal goods	CSYL	weekly wage for all sector
n_c	Employment in good sector	CSYL	weekly working hours in urban area in all sectors * population working for all sector except real estate
w_h	wage for house	CSYL	weekly wage for real estate
n_h	Labor for house	CSYL	weekly working hours in urban area in Real Estate * population working for real estate
r	Real interest rate	Model implied	$R_t - E_t\pi_{t+1} = r_t$
c_e	Consumption for firm	Model implied	$C_t - c_t = c_t^e$
i_c	Investment for normal goods	Model implied	$i_{c,t} = I_t - i_{h,t}$
i_h	Investment for housing	NBCS	Real Estate Development (100 million yuan)
y	Nominal output	Model implied	$GDP_t - \overline{q_{h,t}}Y_{h,t} = Y_t$

x	Mark-up prices	Model implied	$(1-\alpha)\frac{Y_t}{w_{c,t}n_{c,t}} = X_t$
y_h	Output of house	NBCS	Floor Space of Residential Buildings Completed (10000 sq.m)
k_c	Capital for intermediate goods	Model implied	$k_{c,t} = \left(1-\delta_{k,c}\right)k_{c,t-1} + i_{c,t}$
y_h	Capital for house	Model implied	$k_{h,t} = \left(1-\delta_{k,h}\right)k_{h,t-1} + i_{h,t}$
π	Inflation	CQER (Quarter-on-quarter growth)	CPI Quarter-on-quarter growth
R	Nominal interest rate	CQER	LendingRatePBC1year
GDP	Gross Domestic Product	CQER	Nominal GDP
C	Total consumption	NBCS	Final Consumption Expenditure(100 million yuan)
I	Total investment	NBCS	Investment in Fixed Assets (Excluding Rural Households) (100 million yuan)
CPI	CPI	CQER	CPI
Added variables for the extended model			
b	Household saving	PBOC	Household's deposits
$r_t^{d,cb}$	Benchmark deposit rate	CQER	One-year PBC benchmark lending rate divided by four
$r_t^{l,cb}$	Benchmark lending rate	CQER	One-year PBC benchmark lending rate divided by four
η	Required reserve ratio	CQER	Required reserve ratio
pop	Working age population	International Labour Organization	Labor force, total

Note on Table B.1:

CSYL (China Statistical Yearbook of Labour 2000-2022);

CQER (The Center for Quantitative Economic Research (CQER) of the Federal Reserve Bank of Atlanta);

NBSC (National Bureau of Statistics of China);

PBOC (THE PEOPLE'S BANK OF CHINA, monetary Policy Department)

1) w_c, w_h

The yearly average wage for all sector and real estate are collected from China Statistical Yearbook of Labour. And we transfer it in to quarterly data and divided by 13 (assume there are 52 weeks in a year) and weekly working hours to get the hourly wage. Wage is weekly wage and labor supply is weekly working hours multiplying by employment.

2) n_c, n_h

Labor supply for normal goods is obtained by weekly working hours in urban area in all sectors times population working for all sector except real estate. Labor supply for housing is obtained by weekly working hours in urban area in Real Estate times population working for real estate.

we used $R_t - E_t\pi_{t+1} = r_t$ to get real interest rate. R_t is the nominal interest rate directly get from CQER. The expected inflation rate $E_t\pi_{t+1}$ get by constructing a VAR (1) with constant on output, inflation and nominal interest rate. The fitted value of inflation in period t+1 is denoted as $E_t\pi_{t+1}$

Capital for normal goods, capital for housing and housing stock are got by the equations $k_{c,t} = \left(1 - \delta_{k,c}\right)k_{c,t-1} + i_{c,t}$, $k_{h,t} = \left(1 - \delta_{k,h}\right)k_{h,t-1} + i_{h,t}$and $h_t - (1 - \delta_h)h_{t-1} = Y_{h,t}$ respectively. For this case we assumed the original start value of $k_{c,t-1}$, $k_{h,t-1}$ and h_{t-1} equal to zero.

3) b

Household saving is households' deposits in the flows of fund statement in the financial accounts on the people's bank of China.

Table B.2 Adjustments of data

		Divided by CPI?	Divided by working population?	Seasonally adjusted
c	Household consumption	YES	YES	YES
qh	Housing prices	YES	NO	YES
h	Housing stock	NO	YES	YES
w_c	Wage for normal goods	YES	NO	YES
n_c	Labor for normal	NO	YES	YES
w_h	Wage for house	YES	NO	YES
n_h	Labor for house	NO	YES	YES
r	Real interest rate	NO	NO	NO
c_e	Consumption for firm	YES	YES	YES
i_c	Investment for normal goods	YES	YES	YES
i_h	Investment for housing	YES	YES	YES
y	Nominal output	YES	YES	YES
x	Mark-up prices	YES	YES	YES
y_h	Output of house	NO	YES	YES
k_c	Capital for intermediate goods	YES	YES	YES
y_h	Capital for house	YES	YES	YES
π	Inflation	NO	NO	YES
R	nominal interest rate	NO	NO	NO
GDP	Gross Domestic Product	YES	YES	YES
C	total consumption	YES	YES	YES
I	total investment	YES	YES	YES
CPI	CPI	NO	NO	YES
b	Household saving	YES	YES	YES
$r_t^{d,cb}$	Benchmark deposit rate	NO	NO	NO
$r_t^{l,cb}$	Benchmark lending rate	NO	NO	NO
η	Required reserve ratio	NO	NO	NO
pop	Working age population	NO	NO	YES

Table B.3 Statistical summary of data

	Mean	Std.Dev	Min	Max
Real GDP	9.510707	0.585758	8.433019	10.34604
Real consumption	8.558471	0.531144	7.682595	9.353729
Real houses price	8.526891	0.363762	7.915872	9.131466
Housing price inflation	0.014646	0.02292	-0.09589	0.123939
Investment in real estate development	6.874007	0.914802	4.958308	8.031626
Labor hours in general sector	2.119139	0.163109	1.923077	2.368843
Labor hours in housing sector	-1.93262	0.49397	-2.6565	-1.13558
CPI	0.880191	0.136282	0.696397	1.114637
Inflation	0.004882	0.005617	-0.00865	0.020192
Nominal interest rate	0.013695	0.00207	0.010875	0.018675
Real wage in general sector	2.763906	0.586082	1.615218	3.605633
Total investment	8.657905	0.826638	7.093766	9.632898
Household's deposit	6.976555	0.609493	5.517692	8.103634

Appendix C

Impulse reponse functions

Benchmark model

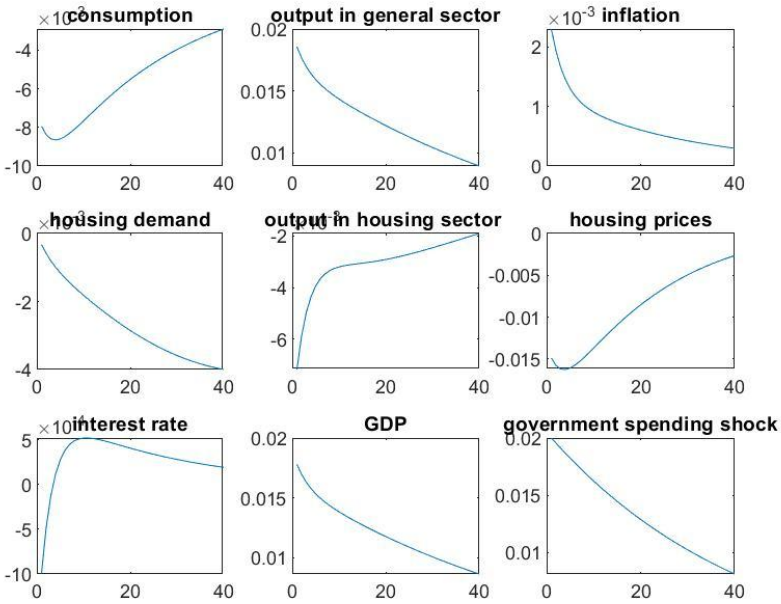

Figure C.1 Government spending shock

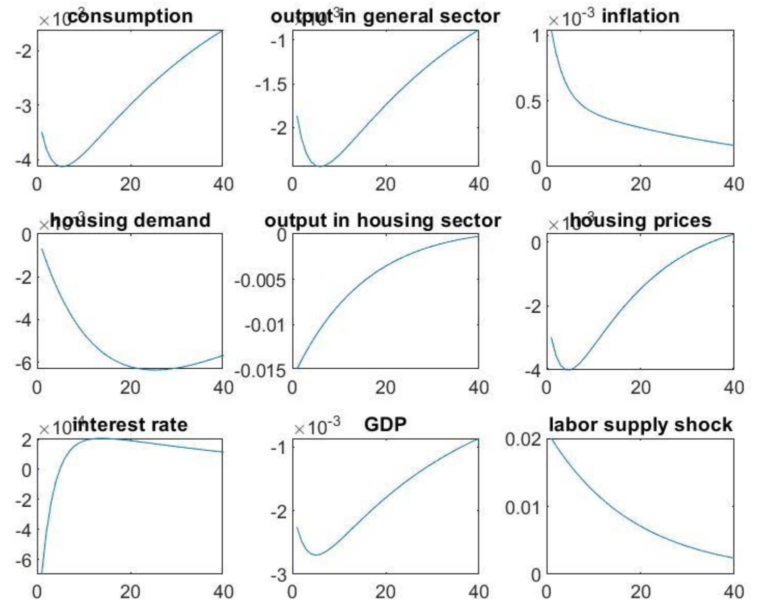

Figure C.2 Labor supply shock

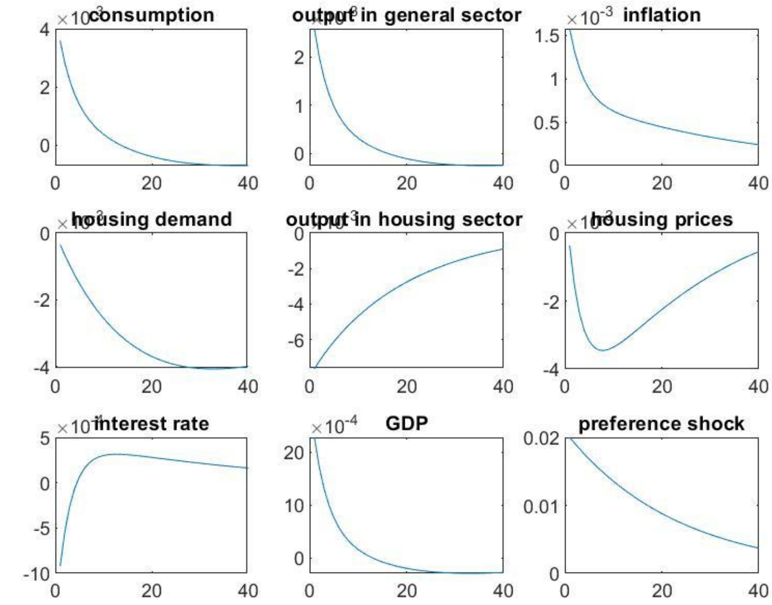

Figure C.3   Preference shock

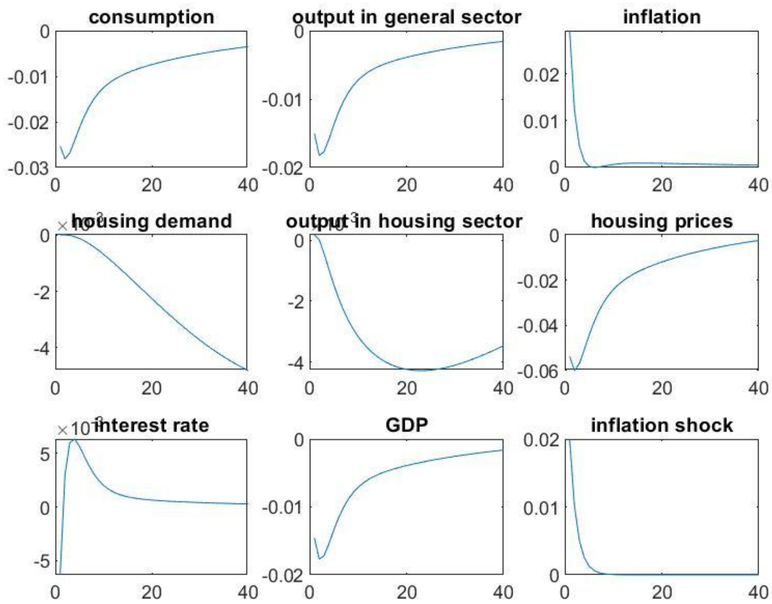

Figure C.4 Inflation shock

The extended model

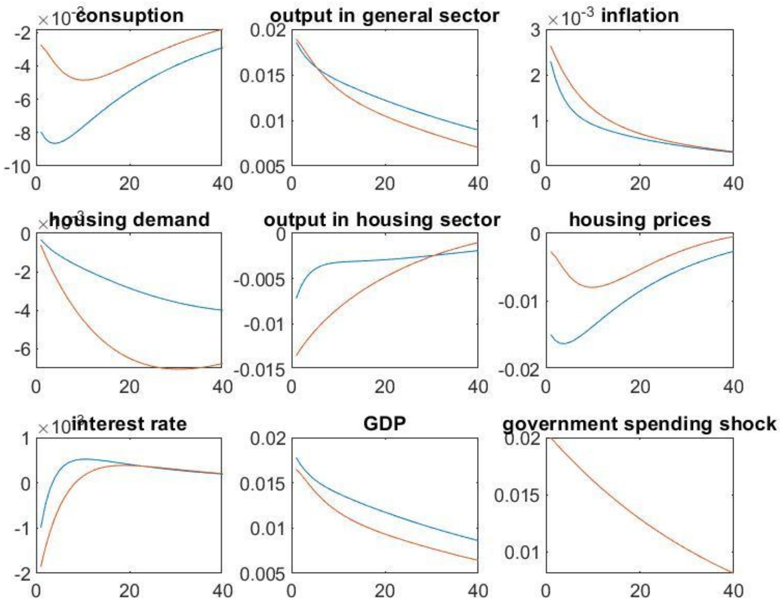

Figure C.5 Government spending shock

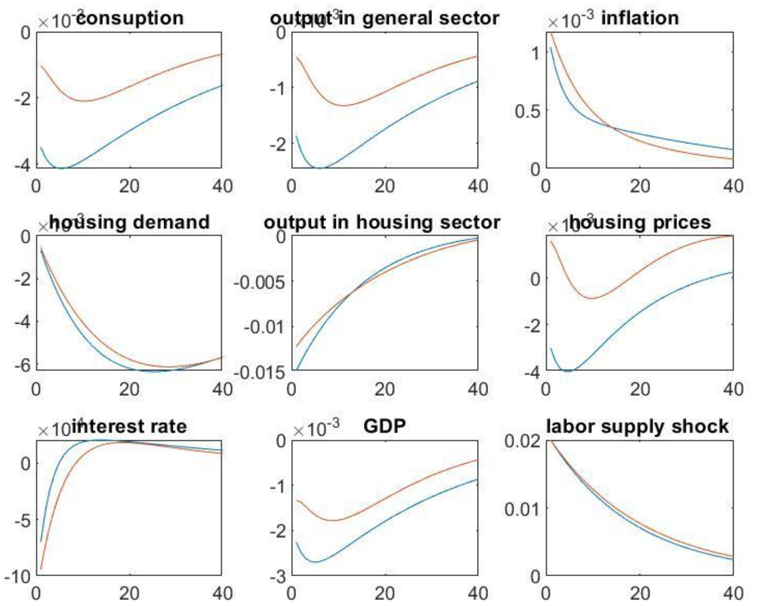

Figure C.6 Labor supply shock

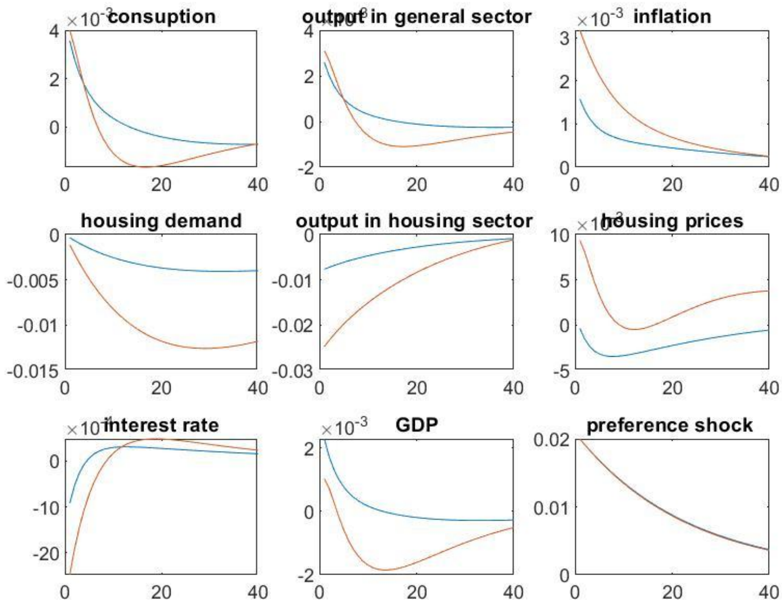

Figure C.7 Preference shock

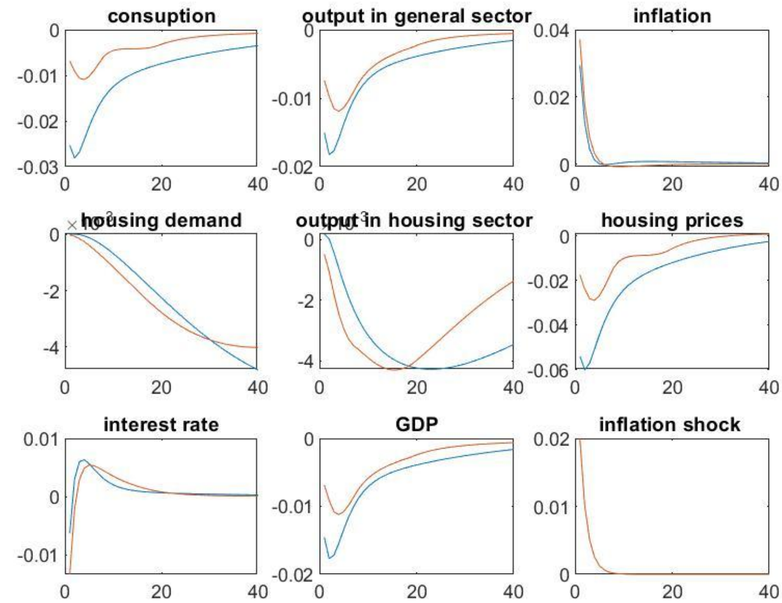

Figure C.8 Inflation shock