Three Essays on the Impacts of China’s Monetary Policy

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THREE ESSAYS ON THE IMPACTS OF CHINA’S MONETARY POLICY

by,

Shen Chen

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Shen Chen
THREE ESSAYS ON THE IMPACTS OF CHINA’S MONETARY POLICY

Shen Chen, Ph.D.
Western Michigan University, 2018

China has experienced high speed of economic growth, trying to catch up with the developed countries. Monetary policy has played a more and more important role in China. This dissertation studies the impacts of China’s monetary policy on China’s housing market, stock market, and China’s economic growth.

The first essay examines macroeconomic determinants of China’s housing price by constructing a VAR model. Granger Causality tests, impulse response functions and variance decompositions are used to analyze the impacts of macroeconomic factors on the housing price. By using the monthly data from 2005 to 2015, the results show that a contractionary monetary policy will cause the growth rate of housing prices to decline in China. However, output growth doesn’t play an important role in housing price in China. Besides, it will take about half a year for a contractionary monetary policy to start to influence the housing prices and the effect will last for approximately two years after the policy is initially implemented.

The second essay conducts empirical analysis of the influence of economy growth and monetary policy on the stock index in China. From 2008 to 2017, China’s GDP growth remained above 6% and China surpassed Japan to become the world's second largest economy in 2011. However, after the financial crisis in 2007 China’s stock market remained weak and stock index fluctuated up and down at the level of 2008. Some scholars believe that the downturn of stock market in China is the result of a slowdown in China's economy. And some argue that it can be caused by the government’s intervention to stock market. This paper examines the determinant
of China’s stock index by constructing a VAR model. The results of the empirical study show that none of the real economic variables is a cause of the stock index. And monetary policy doesn’t have significant effect on the stock market in China.

The third essay employs a Dynamic Stochastic General Equilibrium (DSGE) model with Bayesian approach to model the China economy and to analyze the impacts of monetary policy shocks. The data are on a quarterly basis and from 1992 to 2014. Based on the results of the posterior distributions and impulse response functions, I find that the monetary policy shock does have significant effects on China’s output and inflation. However, based on the results of variance decomposition I find that the monetary policy shocks didn’t play significant role in China’s business cycle. Hence, the monetary policy might not be the major driver for China’s economic growth. The reason of the ineffectiveness of China’s interest rate policy might be the imperfect financial market and interest rate control in China.
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CHAPTER I
AN EMPIRICAL STUDY ON CHINA’S HOUSING PRICE

1.1 Introduction

After the U.S. subprime crisis, the Federal Reserve has been under attack for its loose monetary policies during the years preceding the crisis. Many economists believed that abundant liquidity and low interest rates were probably the most important macroeconomic factors in the formation of the bubble in the U.S. housing market. (Bernanke (2009), Holt (2009)) Since the crisis, there has been increasing recognition among economists and policymakers that central banks should monitor asset prices.

World Bank (1993) reported that housing is the largest component of household net wealth, representing 30% of the world’s wealth. Housing investment accounts for 2-8% of national output and 10-30% of total fixed capital investment in the world. Davis and Heathcote (2001) find that the market value of the US residential property stock is approximately equal to the annual average GDP. By using the US national data, they show that the correlation between the residential property price and the real output is 0.53 and statistically significant. Fluctuations in house prices have a direct impact on the level of macroeconomic activity by influencing private consumption and investment. Simultaneously, housing price is affected by macroeconomic variables such as real income, interest rate, and the supply of credit. Hence, it is important to study the macroeconomic determinants of housing price.

Although the case of China’s housing market is different from the U.S. housing market, China’s experience in the past 10 years still provides a good case study of how macroeconomic variables may affect housing price. Based on Hou (2010), the housing price in China has risen more than two times in major cities such as Beijing and Shanghai since
2000. The total value of China’s housing market reached 91.5 trillion Yuan (13.4 trillion US dollars) at the end of 2009, which was nearly three times the nominal GDP in the same year. Hence, in the recent years economists and policymakers have become increasingly worried about China’s housing bubble. Concerns about the potential risk of housing bubble have caused the policy maker to take a number of actions.

In the last two decades, the People’s Bank of China (PBC) has implemented both expansionary and contractionary monetary policies. For example, in order to combat the economic slowdown during the 2008-2009 global financial crisis, the PBC adopted a highly expansionary monetary, which included a tremendous increase in money supply, bank loans, and a series of cuts in interest rates. The PBC also lowered the minimum down payment for home purchases. The housing market seemed to respond strongly and favorably to this expansionary monetary policy. According to Xu and Chen (2012), the national home price growth index rebounded in a short period of time, from −1.1% in the first quarter of 2009 to 5.8% in the fourth quarter of 2009. Starting from the second half year of 2009, the PBC took a series of actions, which included raising the reserve ratio and interest rates to tighten its monetary policy and increasing the minimum down for home purchases.

Since 2013, China’s housing price growth begun to slow down and even stopped. This phenomenon occurred especially in some big cities such as Shanghai, Beijing and Shenzhen. Since 2014, housing price began to fall in more and more cities in China. In June 2014, the Wall Street Journal reported that “China Housing Prices Fall for Second-Straight Month in June”(Fung 2014). China Real Estate Index System announced that China’s housing price declined 0.3% in May 2014 from April 2014 and 0.5% in June 2014 from May 2014. 71 cities out of 100 cities surveyed showed a decline in home prices. Fung (2014) believe that many home buyers have stayed on the sidelines in anticipation of further price cuts, which has cased home sales fell and driven prices down.
China's economic growth slowdown occurred in five recent years. The quarterly GDP growth of China has dropped from higher than 10% to only 7%. Some economists have predicted that China's economic growth will fall to 5% in 2020. The slowdown of China’s economy was most likely due to the disappearance of the demographic dividend and globalization dividend, and the worldwide depression. In the mean time, the slowdown in economic growth is likely to affect China's house prices.

In this paper, we use a vector autoregression model (VAR) to investigate the macroeconomic determinants of China’s housing price, with a special focus on real economic fluctuation and monetary variables. This paper examines the impact of macroeconomic variables on the China’s housing price, by using Granger causality test, impulse response functions and variance decompositions.

Our results show a contractionary monetary policy does exert a downward pressure on housing prices in China. In particular, a positive interest rate shock, that is an increase in short-term interest rates, has a significant and negative impact on housing prices. However, a shock to money supply does not have an influence on the housing prices. Besides, output growth doesn’t play an important role in housing price in China. We also find that it will take about half a year for a contractionary monetary policy to start to influence the housing prices and the effect will last for approximate two years after the policy is initially implemented.

1.2 Literature Review

Previous relevant literature can be discussed in three aspects. First, studies show that macro economic variables may affect the housing market. Second, monetary policy plays an important role in the housing market. Third, there are studies that focus on China’s housing market.
The first group of studies investigates the relationship between macro-economic variables and housing market. Englund and Ioannides (1997) study the dynamics of housing prices in 15 OECD countries. By using the yearly data and OLS, they show that one percentage faster GDP growth this year gives 0.77 percentage faster house price growth next year. The coefficient for the real interest rate has the expected negative sign, and is very significant. Hence, they conclude that lagged GDP growth and the real interest rate exhibit significant predictive power.

Adams and Fuss (2010) also examines the dynamics of macroeconomic variables on international housing prices, using a panel cointegration analysis. They argued that an increase in employment or real industrial production increases the housing price. A higher long-term interest rate increases the return of other fixed-income assets such as bonds relative to the return of real estate, thus shifting the demand from real estate into other assets. By estimating an error correction model, they find that macroeconomic variables significantly impact house prices. In particular, a 1% increase in economic activity raises the demand for houses and house prices over the long run by 0.6%. A 1% increase in the long-term interest rate which reduces the demand for housing lowers house prices by 0.3% in the long run.

Tsatsaronis and Zhu (2004) employ a vector autoregression (VAR) mode, which included the growth rate of GDP, CPI, real short-term interest rate, the term spread and the growth rate of bank credit to private sector. Their main findings show the strong and long-lasting link between inflation and nominal interest rate with housing price. They make this argument based on the results of variance decomposition. The surprising result they find is that household income has a very small explanatory power over housing price movements. They also find that in response to a 1% cut in interest rate, house price growth would increase by 2.6% over five years in the floating mortgage rate countries, compared with 1.8% in the fixed mortgage rate countries.
There is also literature that studies the individual countries. Holly and Jones (1997) study the behavior of house prices in the UK, using a data set from 1939 to 1994. They examine the effects of some macroeconomics variables such as real income, interest rate on housing prices. They find that the single most important determinant of real house prices is real income. They also find that the adjustment of house prices to innovations in income is asymmetrical, and the effect depends on whether real house prices are above or below the trend implied by the long run determinants of house prices.

Gerlach and Peng (2005) study the relationship between residential property prices and bank lending in Hong Kong. Using the quarterly data from 1982 to 1998, they estimate a VAR model, which included GDP, interest rate, property price, bank lending. Based on the empirical results, they conclude that property prices determine bank lending, but that bank lending does not appear to influence property prices in Hong Kong.

The second group of literature discusses the linkage between monetary policy and housing market. Based on Bernanke and Gertler (1995), there are two channels for monetary policy to affect the housing market. The first is the household income channel. For example, the increase of interest rate which is a contractionary monetary policy shock can cause household income to decrease, which reduces the household investment in the housing market. The second is the bank lending channel. When the interest rate increases, the cost of buying a house will increase because of the mortgage rate.

Iacoviello and Minetti (2003) examine the credit channel of monetary policy, especially the bank-lending channel, in four housing markets, including Finland, Germany, Norway and the UK. They find that the response of housing price to interest rate shocks offers tentative evidence of the credit channel. Iacoviello (2005) estimates a VAR using U.S. quarterly data from 1974 to 2003 and finds that monetary policy shocks have significant negative effects on housing price.
Some literature evaluates conditions in Chinese housing market. Xu and Chen (2012) examine the impact of monetary policy variables on the real estate price growth in China, using quarterly data from 1998:Q1 to 2009:Q4 and monthly data from July 2005 to February 2010. They find expansionary monetary policy tends to accelerate the housing price growth. They argue that Chinese monetary policy actions are the key driving forces behind the change of real estate price growth in China. James and Hui (2010) and Koivu (2010) both employ the structural vector autoregression approach and use the Chinese data to study the impact of monetary policy on asset prices. Their results both indicate that the monetary policy variables have a significant impact on asset prices.

Yao and Luo (2012) investigate the dynamic and long-run relationships between monetary policy and asset prices in China. They find monetary policies have little immediate effect on asset prices in China. They argue the simultaneous increase in interbank rate and housing price suggests that a contracting monetary policy is ineffective in curbing housing price and Chinese investors may be ‘irrational’ and ‘speculative’.

Zhang and Zhao (2010) apply a non-linear model-ling approach to investigate determinants of housing price in China. They find that monetary variables are the most important explanatory factors for Chinese housing price, including mortgage rate, producer price, and real effective exchange rate. Meanwhile, they results indicate that some real economy variables such as personal disposable income and GDP are not independently significant with housing price. Li and Chen (2015) investigate the dynamic interaction between the housing market and the macroeconomic variables based on Evolutionary Co-spectral Method. Their empirical results show that China’s housing market has relatively high correlation between the change of long-term interest rate, employment rate and monetary supply, while there is a moderate coherence between housing market and the inflation rate
and economic growth rate, and the correlation between the short-term rate of interest and housing market is the lowest.

In sum, there is evidence suggesting that the housing price response significantly to the real economy variables and monetary policy shocks. In this paper, we analyze the influence of macroeconomic variables and monetary policy on the housing policy in China using monthly data from 2005 to 2014. This paper contributes to this field by providing a case study of the relationship of monetary policy and housing price using China, an emerging market, as an example.

1.3 Empirical Study

1.3.1 Empirical Model

To study the impacts of monetary policy on housing price, I employ a structural VAR model with six variables: the housing price index (House), the industrial added value growth rate(Y), the consumer price index (CPI), the money supply (M2), the interest rate (R), and the real exchange rate (EX). I choose a VAR model to allow all six system variables to influence each other endogenously. The basic reduce form VAR process is given as:

\[ y_t = A(L)y_t + u_t, \]

where \( y_t = (y_1t, y_2t, \ldots, y_nt) \) contains N endogenous variables and L is the lag term, \( A(L) = A_1L + A_2L^2 + \ldots + A_iL^i \), \( u_t \) is an N-dimensional process and assumed to be serially uncorrelated.

In this paper, we want to model the contemporaneous relations between the system variables. Hence, we need the structural form of the VAR model:

\[ Ay_t = A^*(L)y_t + B\varepsilon_t = A^*_1y_{t-1} + A^*_2y_{t-2} + \ldots + A^*_iy_{t-i} + B\varepsilon_t, \]

where the structural errors \( \varepsilon_t \) are assumed to be serially and cross-sectional uncorrelated. We can obtain the relationship between error terms of system variables in the
reduced and structural forms: \( u_t = A^{-1}B\varepsilon_t \). Then, we can have \( Au_t = B\varepsilon_t \) and decompose the structural errors. In my case, the contemporary relations are as following:

\[
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 \\
* & 1 & 0 & 0 & 0 \\
* & * & 1 & 0 & 0 \\
* & * & * & 1 & 0 \\
* & * & * & * & 1 \\
\end{bmatrix}
\begin{bmatrix}
u_t^Y \\
u_t^{CPI} \\
u_t^{M2} \\
u_t^{EX} \\
u_t^{HP} \\
\end{bmatrix} =
\begin{bmatrix}
b_{11} & 0 & 0 & 0 & 0 \\
0 & b_{22} & 0 & 0 & 0 \\
0 & 0 & b_{33} & 0 & 0 \\
0 & 0 & 0 & b_{44} & 0 \\
0 & 0 & 0 & 0 & b_{55} \\
0 & 0 & 0 & 0 & b_{66} \\
\end{bmatrix}
\begin{bmatrix}
\varepsilon_t^Y \\
\varepsilon_t^{CPI} \\
\varepsilon_t^{M2} \\
\varepsilon_t^{EX} \\
\varepsilon_t^{RP} \\
\varepsilon_t^{HP} \\
\end{bmatrix}
\]

where * indicates the parameter that is estimated in the system. Following the literature Vargas-Silva (2008), the industrial added value growth rate (Y) is presumed to be slow to adjust and only allowed to react to shocks of other system variables with a lag. And the inflation is allowed to react immediately to shocks to output. Besides, the output, inflation and M2 can affect the interest rate contemporarily. The monetary policy can affect the exchange rate and housing price only after a lag of one period. The housing price is allowed to respond immediately to shocks to all other system variables.

1.3.2 Data

Six variables are included in my analyses, which are the housing price index (House), the industrial added value growth rate (Y), the consumer price index (CPI), the money supply (M2), the interest rate (R), and the real exchange rate (EX). All the data in my study are monthly from 2005 to 2014 and Chinese. The data of the real exchange rate come from the World Bank database. The data of the housing price index, the industrial added value growth rate, the consumer price index is from Statistical Yearbook of China. The interest rate and the money supply are released by the Central Bank of China.

The housing price growth rate index is measured by the monthly growth rate of China’s 70 major cities’ housing index. This index is released by China's National Bureau of Statistics from 2005. It’s a commonly used housing price index in China. These data have
also been used by Ahuja (2010). The industrial added value growth rate is measured by the growth rate of gross industrial output value in China. The interest rate is measured by 7-day interbank offering rate in China. This interbank offering rate is the benchmark interest rate offered by the central bank of China, People’s Bank of China. There are two reasons to use this interest rate as a measure of the monetary policy in China. First, People’s bank of China claims that the interest rate policy is an important part of monetary policy and one of the principal instruments of implementing monetary policy. Second, both housing demand is affected by both mortgage and loan interest rates, which are determined by the interbank offering rate. The real exchange rate is measured by real effective exchange rates of Chinese Yuan. It is measured by the Bank for International Settlements (BIS) effective exchange rates with 2010 as the indices' base year. Table 1.1 shows the statistical description of all system variables.

1.4 Results

1.4.1 Unit Root Test

I use the Augmented Dickey-Fuller test to examine whether the variables in my study have unit roots or not. If more than one variable in the model has unit roots, they might be cointegrated. That means these variables are non-stationary, but their linear combination is stationary. In my study, the level of M2, CPI and exchange rate are I(1), which means they have a unit root. Hence, the Johansen cointegration test is necessary for this paper.

1.4.2 Johansen Cointegration Test

Cointegration exists when two or more series are non-stationary, but their linear combination is stationary, which can indicate a long run equilibrium relationship among the variables. In this paper, the level of M2, CPI and exchange rate are I(1), cointegration test is conducted on these three variables. The P-value is 0.1086, so none of them has cointegration.
Hence, no cointegration is found between these three variables. And the structural VAR model is applicable to use to examine the empirical model.

1.4.3 Granger Causality Test

Granger Causality Test is employed to test the relationship between the housing price and real economy, and specifically whether macroeconomic variables have a significant impact on the housing price. Hence, I focus on the causal relationships between housing price and other system variables. The lag length I selected is 2 based on the Akaike Information Criterion (AIC). Besides, I conduct the residual tests by running a VAR residual serial correlation LM test. The results indicate that there is no autocorrelation up to lag 11. Table 1.2 reports the Granger causality test results.

According to the results of Granger causality tests, the interest rate does Granger-cause housing price, indicating that the change in monetary policy will result in a change in housing price in China. The P-value of the interest rate is 0.0138, which indicates statistically significant at the 5% level. With the exception of the interest rate, the P-values of all the other variables are greater than 10%. This means the industrial added value growth rate, inflation rate, money supply, and exchange rate do not Granger-cause the housing prices.

1.4.4 Impulse Response Function

In this paper, I construct the VAR model using the Choleski decomposition. Following the literature Vargas-Silva (2008), the ordering I employed is Y, CPI, R, M2, EX, House. To analyze the impacts of the monetary policy shocks on the housing price index, I conduct impulse response functions (IRFs). IRFs describe the response of housing price index to a one standard deviation innovation of another variable for 48 months. Based on the AIC and SIC Criterion, the lag length of the VAR model is 2. The IRFs which show the impact of a shock to R on House are shown in Figure 1.2. The IRFs which show the impact of a shock to Y on House are shown in Figure 1.3.
Figure 1.2 illustrates that the impacts on housing price of a shock to R are significant. First, we can find that a positive shock to interest rate doesn’t have a significantly impact on housing price in the first six months. However, the impact becomes significant after six months. The results also show that a 1% increase in the interest rate lowers housing prices by 0.1%. The impact is negative as theory predicts, which means a contractionary monetary policy will decrease the growth rate of housing price. Based on the bank lending channel, the increase of interest rate should have negative impacts on the housing price.

Figure 1.3 shows that the shock to output does have an impact on housing price. Consistent with the theory, the positive shock to output growth have positive impacts on the housing price. However, these impacts are not significant in first ten months and die out after ten months. This implies that the output growth is not a major determinant of housing price in China.

1.4.5 Variance Decomposition

This paper focuses on the influence of real economy variables on the housing price. I study the Variance Decompositions (VDCs) for the proportion of the forecast error variance in House which can be explained by the shocks to all other variables. I focus on the first 24 months which is reported in Table 1.3.

The results of the VDCs show that the shock of interest rate can explain less than 1% of the forecast error variance of the housing price in the first three months. However, the contribution of interest rate shock to explain the forecast error variance of the housing price keeps increasing. Starting from the ninth month, the interest rate accounts for the largest portion of the variance of the housing price among all the five system variables. After 12 months, more than 16% of the forecast error variance of the housing price can be explained by the interest rate shock. Moreover, from 12 months to 18 months, the portions of the
forecast error variance of the housing price than can be explained by the interest rate are statistically significant at the 10% level.

For the shock of output growth, it can explain only 1.17% of the forecast error variance of the housing price in the first three months. Besides, its contribution doesn’t change much in next twenty months. After 12 months, still only 4.41% of the forecast error variance of the housing price can be explained by the output growth shock. And all that impacts are insignificant in all 24 months. That means the results of VDC also shows that output growth doesn’t play an important role of the housing price in China.

1.5 Conclusion

This study examines the relationship between the Chinese housing price index and Chinese macro-economic variables over the period 2005 to 2014. The study focuses on the macroeconomic determinant of China’s housing price. The Granger causality test, impulse response functions, and variance decomposition are used to analyze the impact based on a VAR model. The findings and contributions of this study have both academic and policy implications, which are summarized as follows.

First, our results show that the short-term interest rate proxied by the 7-day interbank offered rate is a key monetary policy variable that consistently exerts a significant impact on the housing prices in China. A 1% increase in the 7-day interbank offered rate reduces the housing prices by 0.1%. After 18 months, more than 18% of the forecast error variance of the housing price can be explained by the 7-day interbank offered rate shock. This implies that the 7-day interbank offered rate is an effective and reliable monetary policy instrument used by the PBC to deal with housing prices. Therefore, the PBC should rely more heavily on market-based instruments such as the 7-day interbank offered rate to conduct its monetary
policy. Besides, interest rate liberalization in China will help to enhance the effectiveness of the use of market-based monetary policy instruments by the PBC.

Second, our results exhibit the timing of the impact of interest rate on the housing market in China. The impulse response functions illustrate that a positive shock to the 7-day interbank offered rate significantly reduces the housing prices during a period from five months to nine months after the initial shock occurs. The variance decomposition function shows that the 7-day interbank offered rate is able to explain a statistically significant portion of the variance of the housing price over a window from one year to one and a half years. Both of the results imply that a contractionary monetary policy implemented by the PBC has no immediate impact on the housing prices in China. It will take about half a year for a contractionary monetary policy to start to influence the housing prices and the effect will last for approximate two years after the policy is initially implemented.

Third, based on the results of Granger causality and impulse response functions, we find that output growth doesn’t have significant impacts on the housing price. The Variance Decompositions shows its contribution over the long horizon is less than 5% of total housing price variability. That means output growth doesn’t play an important role of housing price in China. Hence, the recent decrease in housing price in China might cause by central bank’s housing price regulation, instead of economic slowdown.

1.6 References


Ahuja, Ashvin; Cheung, Lillian; Han, Gaofeng; Porter, Nathan ; Zhang, Wenlang. “Are House Prices Rising Too Fast in China?” IMF Working Paper, No. 10/274, 2010


Feng, Qu; Wu, Guiying Laura. “Bubble or riddle? An asset-pricing approach valuation on China's housing market,” Economic Modelling, Vol.46, 2015, pp.376–383


Table 1.1 Statistical Descriptions of Data

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Note: The housing price growth rate index (House) is measured by the growth rate of monthly housing price of China’s 70 major cities in percentage. The industrial added value growth rate (Y) is measured by the growth rate of gross industrial output value in percentage in China. The money supply (M2) is measured by the growth rate of M2 in percentage. The interest rate (R) is measured by 7-day interbank offering rate in China. The real exchange rate is measured by the Bank for International Settlements (BIS) effective exchange rates with 2010 as the indices’ base year. The data are Chinese data and are on a monthly basis.
<table>
<thead>
<tr>
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Note: This table reports the Granger causality test results. The numbers are the P-value. *Statistically significant at the 5% level; **Statistically significant at the 10% level
Table 1.3 VDCs with Ordering Y, CPI, R, M2, EX, House

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Note: This table reports the forecast error variance decomposition of housing price on the first 24 months. Numbers in brackets are standard errors. **Statistically significant at the 10% level
Figure 1.1 Plots of system variables in the sample period

Note: The data are Chinese data and are on a monthly basis. The data sources are the Statistical Yearbook of China, the Central Bank of China and the Bank for International Settlements.
Figure 1.2 Impulse Responses of Housing Price to Interest Rate Shocks

Figure 1.3 Impulse Responses of Housing Price to Output Growth Shocks
CHAPTER 2
WHAT CAUSED THE DOWNTURN OF CHINA’S STOCK MARKET AFTER 2008?
ECONOMIC SLOWDOWN OR MONETARY POLICY

2.1 Introduction

The correlation between development level of macro-economy and fluctuations in stock price has always been an important topic in finance economy research. According to the research of Fama (1990), Tobin (1969), and Rozff (1974), fluctuations in stock market price are mainly determined by economic variables such as economic cycle, money supply, and interest rate. In a country with mature market economy, take US for example, the macro-economy is substantially consistent with securities market in the long run. Hence central bank is able to stabilize stock market using monetary instruments.

As a country with immature market economy, Chinese stock index fluctuated wildly since the beginning of the generation of Chinese stock market. China still needs to make improvements in law, regulation and market guidance, etc., although its securities market has formed the initial shape after more than 10 years of development. As shown by development in recent years, the economy of China has demonstrated a great upward tendency. China’s macro-economy has developed fast since June 2001.

The growth rate of GDP from the first quarter to the second quarter in 2004 was as high as 9.7%. However, the stock market as barometer of national economy showed a reverse tendency. Ever since 2001, the stock market has been in prolonged depression with Shanghai Composite Index declining from more than 2,000 points to more than 1,500 points. In 2004, it rose from 1,509 points in January to 1,783 points in early April, hitting a new high in the three years. When investors unanimously predicted that it would rise to 2,000 points, it plunged to 1,258 points, which was the lowest in the five years. In 2007, the Shanghai
Composite Index rose from 2,786 points in January to 5,954 points in October, hitting a new unimagined high. When investors unanimously predicted that it would surge because of the Beijing Olympic Games, it declined to 2,500 points in 2008, leaving many investors suffering heavy losses.

From 2008 to 2017, China’s GDP growth remained above 6% and China surpassed Japan to become the world's second largest economy in 2011. However, after the financial crisis China’s stock market remained weak and stock index fluctuated up and down at the level of 2008. For this phenomenon, both Chinese investors and government believed that the Chinese stock market should not deviate from the macroeconomic fundamentals which have always been good.

However, also some scholars believe that the downturn of stock market in China is the result of a slowdown in China's economy. China's economic growth slowdown has also appeared from 2010. China's economic growth slowed to 7.8% in 2012, from 10.4% in 2010. After 2012, China’s economic growth has continued to decline. GDP growth has fallen below 7% since 2015. Hence, as an indicator of future economic performance the stock market faced the downward pressure in recent years and hot money is pulling out of China at the fast rate.

At the same time, some scholars believe that the most important factor that affects the stock price or stock market index in China is not the fundamentals of the company or the macroeconomic fundamentals, but the policy factors such as the monetary policy. The policy factors have such significant impact on China’s stock market that it is called “policy stock market”. Hence, the lowness of China’s stock index in recently years can be caused by the government’s intervention to stock market.

Besides, the excessive volatility in the stock market affects the confidence of domestic and foreign investors and is harmful to the financial market and even the whole country's
macro-economic healthy development. Hence the emerging securities market in China is necessarily controlled by the central bank through monetary policy. The central bank needs to know how to use the monetary policy to avoid excessive volatility of stock index. The monetary policy tool which the Chinese central bank employs is the money supply and interest rate.

This paper conducts empirical analysis of the influence of economy growth and monetary policy on the stock index in China by using the economics method, such as ADF unit root test, Granger causality test, impulse response function, and variance decomposition. My paper examines whether economy growth and monetary policy has significant effect on the stock market in China based on the monthly data from 2000 to 2017. This paper provides Chinese central bank with knowledge whether their policy works on the stock market.

2.2. Literature Review

Fama (1990) analyzes the relationship between the stock market and the real macro-economy by using the U.S. data for 1953-1987. The result shows that there is a significant and positive relationship between the stock market return and the output growth. He believes the stock index is a barometer of the macro-economy. Kunt and Levine (1996) expand this study to 44 countries which included developed and developing countries. They estimate the relationship between stock market development and long-run economic growth using the data from 1976 to 1993. Their results also supported that the positive relationship between the stock index and the output growth. Yang and Kuang (2005) analyze the influence of stock market on economic growth using Chinese quarterly data from 1994 to 2003. They believed the stock market activity level has impact on the economic growth. Liu (2008) indicated that the economic growth also has a significantly and positive impact on stock market return in
China. Hence all these studies show that there is a significant relationship between stock index and real economic growth.

The portfolio selection theory by Tobin (1969) explains the influence mechanism of interest rate on the stock market: asset substitution effect and capital accumulation effect. When the interest rate decreases, investors tend to hold stocks which have higher return rate. Hence the stock price will increase. The capital accumulation effect means if the interest rate declines, investor will hold more risky assets in order to achieve the goal of wealth accumulation. Rozeff (1974) also provide evidence to proof that the increase of money supply had positive impact on the stock return using the U.S. monthly data from 1947 to 1970. Bernanke and Kuttner (2005) analyze the relationship between the Federal funds rate and equity prices. They show that an unanticipated 25-bais-point decrease in the Federal funds rate target will cause about a 1% increase in the stock index.

Yang and Long (2006) analyzed the impact of monetary policy on the Chinese stock market. They indicated that both money supply and interest rate have significant impact on the Chinese stock index. The central bank can use M1, M2 and nominal interest rate to affect the stock market. Wu and Xu (2006) find that the influence of the interest rate shock on the stock index is weaker than the money supply shock, and the time of duration was also shorter.

In this paper, I construct a Vector autoregression (VAR) model to analyze the influence of monetary policy and macro-economic variables on the stock index in China using the monthly data from 2000 to 2017.

2.3 Empirical Model

To study the impacts of monetary policy on stock index in China, I employ a structural VAR model with five variables: the electricity generation (EG), the consumer price index (CPI), the money supply (M2), the interest rate (R), and Shanghai Stock Exchange Composite
Index (SSE). All the data are monthly and Chinese. The sample period is from January 2000 to March 2017.

The electricity generation (EG) is the electricity generated by all sources included coal, water, nuclear and wind, and is measured in billion kilowatt-hours. According to the Wikileaks cable, China’s Vice Premier Li Keqiang believes that Chinese GDP data are “man-made” and unreliable. Hence, the Economist has created a “Keqiang index” for China’s economy, combining three indicators: electricity generation, volume of railway freight and lending. They find this index is more volatile than the official GDP but has the same trend. The electricity generation is the most important one in these three indicators. 40% of the “Keqiang index” is determined by the electricity generation. Hence, in this study I use the electricity generation as the indicator of output. The data are from “Statistical Yearbook of China”.

Consumer price index (CPI) is an important index of the level of inflation. The high level of inflation represents the market is overheating which means the central bank needs to implement contractionary monetary policies. For my data the year of 2005 is the base year. The data are from the Federal Reserve Bank of St. Louis (FRED).

Money supply (M2) is a measurement of money supply, which is employed by the Chinese central bank as monetary policy instrument. Hence, in this study M2 is the policy variable. The increase of M2 should have positive impact on stock index. M2 is measured in hundred million yuan. The data are from People’s Bank of China which is the central bank of China.

Interest rate (R) is measured by the 1-day interbank offering rate in my study. Since, in China the interbank offering rate is the benchmark interest rate offered by People’s Bank of China. The loan interest rate and deposit interest rate are determined by the interbank offering
rate. The increase of the interest rate should have negative impact on stock index. The data are from People’s Bank of China.

Shanghai Stock Exchange Composite Index (SSE) is an index of all stocks that are traded at the Shanghai Stock Exchange which represents the Chinese stock index. The data are the closing index for the last day of every month and from “Statistical Yearbook of China”.

With the exception of CPI, all the variables are converted into real term. All variables are in log form and seasonally adjusted by adding 11 dummy variables except the interest rate. I choose VAR model to allow all six system variables to influence each other endogenously.

The basic reduce form VAR process is given as:

\[ y_t = A(L)y_t + u_t \]  

where \( y_t = (y_{1t}, y_{2t}, \ldots, y_{nt}) \) contains \( N \) endogenous variables, \( u_t \) is a \( N \)-dimensional process and assumed to be serially uncorrelated, and

\[ A(L) = A_1L + A_2L^2 + \ldots + A_iL^i \]  

where \( A_i \) are \( N \times N \) coefficients matrices.

In this paper, we want to model the contemporaneous relations between the system variables. Hence, we need the structural form of the VAR model:

\[ Ay_t = A^*(L)y_t + B\varepsilon_t = A_1y_{t-1} + A_2y_{t-2} + \ldots + A_iy_{t-i} + B\varepsilon_t \]  

where the structural errors \( \varepsilon_t \) are assumed to be serially and cross-sectional uncorrelated and \( A, A^*(L), B \) are coefficients matrices. And we can obtain the relationship between error terms in the reduced and structural forms:

\[ u_t = A^{-1}B\varepsilon_t \]  

Then we can have

\[ Au_t = B\varepsilon_t \]
and decompose the structural errors. In my case, the contemporary relations are as following:

\[
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 \\
* & 1 & 0 & 0 & 0 \\
* & * & 1 & 0 & 0 \\
* & * & * & 1 & 0 \\
* & * & * & * & 1 \\
\end{bmatrix}
\begin{bmatrix}
u_t^{SSE} \\
u_t^{M2} \\
u_t^R \\
u_t^{EG} \\
u_t^{CPI} \\
\end{bmatrix}
= 
\begin{bmatrix}
b_{11} & 0 & 0 & 0 & 0 \\
0 & b_{22} & 0 & 0 & 0 \\
0 & 0 & b_{33} & 0 & 0 \\
0 & 0 & 0 & b_{44} & 0 \\
0 & 0 & 0 & 0 & b_{55} \\
\end{bmatrix}
\begin{bmatrix}
\varepsilon_t^{SSE} \\
\varepsilon_t^{M2} \\
\varepsilon_t^R \\
\varepsilon_t^{EG} \\
\varepsilon_t^{CPI} \\
\end{bmatrix}
\]

(2.3.6)

where * indicates the parameter that is estimated in the system. The Shanghai Stock Exchange Composite Index (SSE) is only allowed to react to shocks of other system variables with a lag. And the money supply (M2) and interest rate (R) as the measurement of monetary policy is allowed to react immediately to shocks to stock index. Besides, the stock index, money supply and interest rate can affect the output (EG) contemporarily. The output growth can affect the stock index and monetary policy only after a lag of one period. The inflation is allowed to respond immediately to shocks to all other system variables.

### 2.4 Results

#### 2.4.1 Unit Root Test

I use the Augmented Dickey-Fuller test to examine whether the variables in my study are stationary or they have unit roots. If more than one variable in the model have unit roots, they might be cointegrated. That means these variables are non-stationary, but their linear combination is stationary.

In my study, the electricity generation, CPI, M2, and the interest rate are I(0), which means stationary. The Shanghai Stock Exchange Composite Index has unit root, but its first difference are stationary. Hence, only one variable in my model is I(1). The cointegration test is not necessary for this paper. Since SSE is I(0), the difference of log SSE is used in the following empirical analysis.
2.4.2 Granger Causality Test

The Granger causality test is used to determine the existence and direction of causal relationship between variables. In this paper, I want to test the causal relationship between the stock index and real economy, and specifically whether the monetary policy has significant impact on the stock index. Hence, for Granger Causality Test I will focus on the causal relationships between SSE and other variables. Based on VAR model and AIC Criterion, the lag length I selected is 3. Table 2.2 reports the Granger causality test results.

According to the results of Granger causality tests, M2 does not Granger cause SSE. Hence, in the short run the money supply as a policy variable is not a cause of the stock index fluctuation. Moreover, R, EG and CPI do not Granger cause SSE. This finding indicates that none of the real economic variables is a cause of the stock index.

2.4.3 Impulse Response Function

In this paper, I built the VAR model using the Choleski decomposition. The ordering I employed is SSE, M2, R, EG, CPI. The key point of this ordering is that the stock index is placed first in the ordering and the money supply is the second. That means the stock index has the contemporaneous impact on the monetary policy variable, and the monetary policy variable has the contemporaneous impacts on other variables. This allows monetary policy to respond contemporaneously to the stock index fluctuation.

To analyze the impacts of the real economic variables on the stock index, I apply the Impulse Response Functions (IRF). Based on the AIC and SIC Criterion, the lag length of the VAR model is 3. The IRFs which show the impact of a shock to EG, CPI, M2, and R on SSE are shown in Figure 2.2.

Figure 2.2 indicates that the impacts on SSE of a shock to M2, EG, CPI and R are insignificant for all periods. This result is consistent with the result of Granger causality test. That shows none of the real economic variables have significant influence on the stock index.
We can find that a shock to interest rate produces an insignificantly negative impact on SSE from the third period. The impact is negative as theory predicts, which means contractionary monetary policy will make the stock index decrease.

2.4.4 Variance Decomposition

Variance decomposition can show us how many percentage of the forecast error variance of one variable can be explained by an exogenous shock to the other variable. Since, this paper focuses on the influence of real economies variables on the stock index. Table 2.3 reports only the VDCs for the proportion of the forecast error variance in SSE which can be explained by the shocks to SSE, EG, CPI, M2, and R.

The results of the VDCs show that the forecast error variance of the stock index can be explained dominantly by the shock to itself. This result is consistent with the result of Granger causality test. The shock of money supply does not explain the forecast error variance of the stock index in the beginning. However, the contribution of money supply shock and interest rate shock explain the forecast error variance of the stock index keeps increasing. After 12 months, 1.38% of the forecast error variance of the stock index can be explained by the money supply shock, and 1.41% can be explained by the interest rate shock.

2.4.5 Policy Implications

First, based on the results of Granger causality test and variance decomposition there is no significant relationship between the stock index and the real economic variables in China. One explanation is that the Chinese stock market is not mature enough. Stock price manipulation exists in the Chinese stock market commonly. (Zhang and Yao 2016) Hence, Chinese government should enhance regulations of the stock market. The Chinese investors should be more rational and use the information about the real economy. In the long-run, the investors should still consider the macro-economic variables. Besides, if more and more
investors become rational value or growth investors instead of speculators in China, the real economy information will be important for stock market.

Second, the result of Impulse Response Functions shows that the interest rate shock does have negative impact on the stock market after 3 month lags. That means if the central bank applies a contractionary monetary policy, the stock index might respond and decrease in 3 month.

2.5. Conclusion

This study examines the relationship between the Chinese stock index and Chinese real economic variables over the period January 2000 to March 2017. The study focuses on whether the monetary policy has significant impact on the stock index. The analysis methods conducted includes Granger causality test, impulse response functions and variance decomposition based on monthly data.

The Granger causality test and variance decomposition indicate that the real economic variables have no significant impact on the stock index in China. This result does not support the classical theory. The reasons could be the Chinese stock market is not mature enough and stock price manipulation commonly exists in the Chinese stock market. The impulse response functions indicate that shocks to interest rate have negative impact on the stock index after 3 months. This result is consistent with the classical theory. However, the impact is insignificant. That means the monetary policy is not major determinant of stock index in China.

2.6 References


Yang, Zaibing; Kuang, Xia. “Cointegration relationship test of capital market development and economic growth,” *Journal of Tongji University*, 2005(06), pp 848-852

### Table 2.1 Statistical Description of Data

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Note: The Chinese stock index is measured by Shanghai Stock Exchange Composite Index (SSE). The output is measured by the electricity generation (EG) in China. The money supply (M2) is measured by the growth rate of M2. The interest rate (R) is measured by 1-day interbank offering rate in China. The data are Chinese data and are on a monthly basis.
Table 2.2 P-value of Granger Causality Test

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<td>0.59</td>
<td>0.61</td>
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Note: This table reports the Granger causality test results. The numbers are the P-value.

*Statistically significant at the $P \leq 0.1$ level; **Statistically significant at the $P \leq 0.05$ level.

SSE is Shanghai Stock Exchange Composite Index. EG is the electricity generation in China, which measures the output. CPI is the consumer price index in China. M2 is the money supply. R is the interest rate in China.
Table 2.3 VDCs with Ordering SSE, M2, R, EG, CPI

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<thead>
<tr>
<th>Period</th>
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Note: This table reports the forecast error variance decomposition of SSE on the first 24 months. Numbers in brackets are standard errors. SSE is Shanghai Stock Exchange Composite Index. EG is the electricity generation in China, which measures the output. CPI is the consumer price index in China. M2 is the money supply. R is the interest rate in China.
Note: The data are Chinese data and are on a monthly basis. The data sources are the Statistical Yearbook of China, the central bank of China and the Federal Reserve Bank of St. Louis (FRED).

Figure 2.1 Plots of system variables in the sample period
Note: The estimated impulse responses of Shanghai Stock Exchange Composite Index (SSE) to system variables’ shocks. EG is the electricity generation in China, which measures the output. CPI is the consumer price index in China. M2 is the money supply. R is the interest rate in China.

Figure 2.2 Impulse Responses of Shanghai Stock Exchange Composite Index
CHAPTER 3

MONETARY POLICY SHOCK ON CHINA’S ECONOMIC FLUCTUATIONS USING DSGE MODEL WITH BAYESIAN APPROACHES

3.1 Introduction

China has experienced a high speed of economic growth in the past several decades, trying to catch up with the developed countries such as the United States, and Japan. One of the reasons of the sustainable development is the transition from central planned-economy to market economy in 1978. Therefore, monetary policy has played a more and more important role to stabilize the economy in China. While China achieved its long run growth, there also exist short term fluctuations. This paper uses a Dynamic Stochastic General Equilibrium (DSGE) model with Bayesian approach to model the China economy and to analyze the impacts of monetary policy shocks.

The DSGE models attempts to explain aggregate economic pattern, such as economic growth, business cycles, and the impacts of monetary and fiscal policy and so on, using macroeconomic models incorporating many microeconomics principles. There are different methods to estimate the DSGE model, which includes VAR, GMM, Maximum Likelihood, and Bayesian estimation. This paper uses the Bayesian method, because estimation in the Bayesian method is based on the likelihood generated by the DSGE system and Bayesian techniques allow the consideration of priors, which work as weights in the estimation process.

It is a controversial topic that the monetary policy is effective in China. Xie (2003) argued that China’s central bank consider the interest rate as the main monetary tool. From 1989 to 2002, the one-year interest rate has been adjusted 14 times. Especially from
1996 to 1999, the central bank continually cut loan and deposit rates seven times. In 2007, the central bank raised loan and deposit rates six times to cool the over-stimulated economy. In 2008, the central bank lowered its benchmark interest rate to fight against the global financial crisis. However, the GDP growth was 14% in 2007 and 11.3% in 2008. Hence, Li (2013) argued that the relationship between the GDP growth and interest rate is insignificant. He argued there are four reasons of the ineffectiveness of China’s interest rate policy. First, China’s interest rate is not determined by the market. In addition to the strictly controlled capital account, it is difficult for the intervention to play its role. Second, due to the condition of the imperfect financial market, the effects of interest rates cannot be transmitted in the market smoothly. Third, Chinese household precautionary savings are much higher than the households in developed countries because of the imperfect perfect social security system. Precautionary savings is rigid demand which doesn’t respond to the interest rate policy. Fourth, when the large and middle scale state-owned enterprises make an investment decision, they tend to underreact to interest rate policy. It is relatively easier for them to get loans from the state-owned bank, compared to private enterprise. Hence, the investment doesn’t respond to the interest rate policy significantly.

3.2 Literature Review

Smets and Wouters (2003 and 2007) have developed DSGE models for the Euro area and the US economy. They show that modern micro-founded DSGE models are sufficiently rich to capture most of the statistical features of the main macro-economic time series. Moreover, by using Bayesian estimation techniques, they show that even relatively large models can be estimated as a system. The system-wide estimation
procedure can deliver a more efficient estimate of the structural model parameters. Further, it can also provide a consistent estimate of the effects of the structural shock processes on economic developments. Smets and Wouters (2007) also show that the estimated DSGE models perform quite well in forecasting compared to standard and Bayesian vector autoregressions (VARs and BVARs). Although China has not become a developed nation, it has achieved remarkably economic growth since 1978. Besides, the Chinese economy is similar to the Euro area and U.S. economies since it is also a large continental economy. Hence, I can use the DSGE models for the Chinese economy to examine and explain the characteristics of China’s economy.

Fan, Yu and Zhang (2011) investigate the effectiveness of Chinese government’s monetary policies in terms of the money supply and interest rates. They use VAR to analyze the relationships among the official interest rate, the growth rate of the real money supply, the inflation rate, and the output gap. Their impulse response of the inflation rate to the official interest rate is near zero for all the horizons. And the impulse response of the output gap to the official interest rate is also flat around zero for all the horizons. Hence, they conclude that the official interest rate has no effect on the future economic activities.

Liu and Zhang (2010) adopt a New Keynesian model to evaluate the appropriateness of China’s monetary policy. They argued that the underdeveloped banking system and market segmentations have made the interest rate rule alone inadequate in China. They believed that the credit channel of monetary policy transmission in China’s banking system does not appear to be effective and market segmentations have also led to inefficient transmissions of monetary policy via interest rates.
Qin (2005) uses an empirical study to investigate how monetary policy has been transmitted into the macro economy of China. He considered three types of monetary policy instruments: interest rates, the required reserve ratio, and the money supply. His empirical result showed that these instruments are most effective in affecting monetary aggregates and prices but are least effective in affecting the real economy in the long run. All of this literature argued that the impact of interest rate as China’s monetary policy instrument on the real sector of the macro economy is small and insubstantial.

In this paper, I use a Bayesian technique to estimate the DSGE model and examine the influence of monetary policy shock on real economic fluctuations in China. Seven key macro-economic variables are used in the estimation, which are real GDP, consumption, investment, inflation, real wage, employment and the nominal short-term interest rate.

3.3 Empirical Model

The dynamic stochastic general equilibrium models are micro-founded optimization based models, which have been widely used in macroeconomics in recent decades. The DSGE model in this paper is a benchmark stochastic dynamic general equilibrium model developed by Smets and Wouters (2003). This DSGE model is made up of a firm producing final goods, a firm producing intermediate goods, households, and the central bank. Households supply labor to firms and consume the final goods. The intermediate goods firms produce a homogenous intermediate good by combining labor and capital. Final goods firms purchase intermediate goods from intermediate producers in a competitive market, and transform them into composite final goods. There are also bonds which can be traded between households and firms. The government conducts monetary
and credit policies, collects taxes and makes government purchases.

In this model, three sectors are considered, which are the household sector, the firm sector, and the central bank sector. The utility functions of these sectors are described next.

### 3.3.1 Household Sector

Each household chooses consumption and leisure to maximize their utility function. The intertemporal utility function used in this paper follows Smets and Wouters (2003). Household agents determine the supply of labor. The utility function of the households is as below,

\[
E \sum_{s=0}^{\infty} \beta^s \left[ \frac{(C_i^{s+1} - h C_i^{s+2})^{1-\sigma}}{1-\sigma_c} - \frac{L_i^{s+1+\sigma_c}}{1+\sigma_c} \right]
\]

where \( \beta \) is the discount factor, \( C_i \) is consumption, \( L_i \) is work hours provided by household agent, \( h \) represents the consumption habit stock, \( \sigma_c \) is the inverse elasticity of consumption, \( \sigma_l \) is the inverse elasticity of labor supply. Household’s utility depends positively on the consumptions of goods and negatively on labor supply. Households maximize their objective function subject to a budget constraint which is given by:

\[
C_i^j + I_i^j + \frac{B_i^j}{e_i^b R_i P_i} + T_i = \frac{B_{i+1}^j}{P_{i+1}} + y_i^j
\]

where \( T_i \) indicates taxes and \( Div_i \) represents the dividends. \( I_i \) represents the investment of household. \( B_i \) represents the bonds purchased by the household. \( y_i^j \) is the household’s total current income. \( e_i^b \) is an exogenous premium in the return on bonds.

The right hand side of this constraint is the funds inflow of the household, which includes wage, return from lending, and return from bonds.
The left hand side of this budget constraint is the funds outflow of the household, which includes consumption, investment, lending, and tax payments. Household’s total income is given by,

\[
y_t^j = \frac{W_t^j L_t^j}{P_t} + \frac{R_t^j Z_t^j K_{t-1}^j}{P_{t-1}} - a(Z_t^j) K_{t-1}^j + \frac{\text{Div}_t^j}{P_t} \quad (3.3.3)
\]

where \( W_t^j \) is nominal wage rate, \( L_t^j \) is the work hours provided by household agent, \( P_t \) is the price index, \( R_t^j \) is the rental rate on capital, and \( a(\cdot) \) is the cost function of the capital utilization(\( Z_t^j \)).

Total income consists of three components: the labor income for the household \( \frac{W_t^j L_t^j}{P_t} \), the return on the capital stock minus the cost on associated with variations of capital utilization \( \frac{R_t^j Z_t^j K_{t-1}^j}{P_{t-1}} - a(Z_t^j) K_{t-1}^j \), and the dividends received from the intermediated firms \( \frac{\text{Div}_t^j}{P_t} \).

The capital stock is owned by the households and rented out to the intermediate firms at rental rate of \( R_t^k \). Households can also increase the supply of the capital stock, by investing \( I_t^j \) or by changing the utilization rate of installed capital \( Z_t^j \).

Following Smets and Wouters (2003), the capital accumulation equation which is given by:

\[
K_t^j = (1 - \delta) K_{t-1}^j + e_t^j \left[ 1 - S \left( \frac{I_t^j}{I_{t-1}^j} \right) \right] I_t^j \quad (3.3.4)
\]
where $\delta$ is the depreciation rate, $K_j^t$ is the capital services used in production, $S(\cdot)$ is the adjustment cost function, and $\epsilon^i_t$ is a stochastic shock to the price of investment relative to consumption goods. Households own the capital stock and rent out to the intermediate goods firms at a given rental rate.

3.3.2 Firms

The final goods producers buy the intermediate goods $Y^i_t$ as the inputs and package them for resale to consumers, investors and the government as the final goods $Y_t$. The income for the final goods producers is $P_t Y_t$ and the cost is $\int_0^1 P^i_t Y^i_t \text{d}i$. Both final goods producers and the intermediate goods producers are maximizing their profits in this model. The optimization problem for final goods producers is:

$$\max P_t Y_t - \int_0^1 P^i_t Y^i_t \text{d}i$$

(3.3.5)

where $P_t$ and $P^i_t$ are the prices of the final goods and intermediate goods.

The intermediate goods producers use a Cobb-Douglas production function:

$$Y^i_t = \epsilon^i_t [K^i_t]^\alpha \left[ \gamma^i L^i_t \right]^{1-\alpha} - \gamma^i F$$

(3.3.6)

where $K^i_t$ is capital used in production, $L^i_t$ is aggregate labor input, $F$ is a fixed cost and $\gamma^i$ is the labor-augmenting deterministic growth rate of the economy. $\epsilon^i_t$ is the total factor productivity. The profit for the intermediate producers is given by:

$$P^i_t Y^i_t - W_t L^i_t - R^k_t K^i_t$$

(3.3.7)

where $W_t$ is the aggregate nominal wage rate and $R^k_t$ is the rental rate on capital.

3.3.3 Central Bank Sector
The central bank follows a nominal interest rate rule by adjusting its instrument in response to deviations of inflation and output from their respective target levels:

\[
\frac{R_t}{R^*} = \left( \frac{R_{t-1}}{R^*} \right)^{\rho_R} \left[ \left( \frac{\pi_t}{\pi^*} \right)^{\gamma^*} \left( \frac{Y_t}{Y^*} \right)^{\gamma^*} \right]^{1-\rho_R} \left( \frac{Y_t / Y_{t-1}}{Y_t^*/Y_{t-1}^*} \right)^{\epsilon_t^r} \tag{3.3.8}
\]

where \( R^* \) is the gross nominal rate in the steady state, \( \pi^* \) is the inflation rate in the steady state and \( Y_t^* \) is the natural output. \( \rho_R \) determines the degree of interest rate smoothing. \( \epsilon_t^r \) is the monetary policy shock. The central bank responds to deviations of lagged inflation from the inflation objective. There are also the feedback effects from the current growth rate of output and the current change in inflation.

The steady state equations for these three sectors of this model can be found in the Appendix. They determine 9 endogenous variables \( Y_t, C_t, I_t, W_t, L_t, K_t, R_t, \pi_t, Z_t \). Then the Dynare 4.4 and Matlab R2007a are used to solve this model by finding the steady state of the model.

Dynare is the software, which is running under Matlab to solve, simulate and estimate DSGE models. The following steps are used to estimate the DSGE models. Using Dynare, we first define system variables, and parameters. Then, we input the model’s steady state equations to find the steady state of this model. We also need to define the exogenous shocks to the system. After that, we can estimate the impulse response functions and variance decomposition.

This paper estimates the parameters in the model based on Bayesian approach using China’s quarterly data from 1992 to 2014. Bayesian techniques allow the consideration of priors in the estimation process. Further, the likelihood functions which we use to estimate the influence are generated by the system.
### 3.4 Results

In this paper, the DSGE model is estimated with Bayesian methods using seven variables: GDP, consumption, investment, wages, employment, CPI and short-term interest rate. This method is based on Bayes’ rule which is as follows,

\[
P(\theta | y) = \frac{p(y | \theta) p(\theta)}{\int_{\Theta} p(y | \theta) p(\theta) d\theta}
\]  

(3.4.1)

\(P(\theta)\) is prior distribution of the parameter, which is our prior belief for \(\theta\). \(P(y | \theta)\) is the likelihood function, which represents the outcome of \(y\) if we knew \(\theta\) to be true. \(P(\theta | y)\) is posterior distribution of \(\theta\), which is our belief for \(\theta\) having observed dataset \(y\). Hence, by using the Bayesian approach, this paper combines the likelihood function with prior distributions of the parameters to solve the posterior density function. However, for many multiparameter models, the joint posterior distribution is non-standard and difficult to sample from directly. Hence, this paper uses Markov Chain Monte Carlo (MCMC) approach, which means the joint posterior distribution, will be derived from the full-conditional distribution of each parameter. Given a current state \(t\) of the parameter values, I sample \(\sigma^{2(t+1)} \sim p(\sigma^2 | \theta^{(t+1)}, y_1, ... y_n)\) by using \(\theta^{(t+1)}\). \(\theta^{(0)}\) is the parameter, \(\sigma^2\) is standard error, and \(p(\theta | \sigma^{2(t)}, y_1, ... y_n)\) is the conditional distribution of this parameter. In my final step, I can use the joint posterior distribution to estimate the predictive distribution of \(y\) with Monte Carlo approximation.

The advantages of Bayesian estimation is that the likelihood functions, which we use to estimate the influence, are generated by the DSGE system. Moreover, Bayesian techniques allow the consideration of priors in the estimation process. The prior information comes either from micro-econometric studies or previous macro-econometric
studies. Besides, the parameters are interpreted as random which is different with other estimation methods.

I follow Smets and Wouters (2007) to set the parameters’ prior distributions. The data are Chinese data and are on a quarterly basis. The data sources are the World Bank database, Statistical Yearbook of China and the central bank of China. The sample period is from 1992 to 2014. The Chinese economy has achieved huge growth during the past decades since the economic reforms in 1978. Since June 2001, its macro-economy has developed at a high speed. The growth rate of GDP from the first quarter to the second quarter in 2004 was as high as 9.7%. I use quarterly GDP to measure the economic output. Figure 3.1 shows the plot of output and inflation in the sample period.

The consumer price index (CPI) is an important index of the level of inflation. The high level of inflation represents the market is overheating which means the central bank needs to choose contractionary monetary policies. For my data, the year of 2005 is the base year. The interest rate (R) is the monetary policy instrument for Chinese central bank. It is measured by 6-month short run interest rate offered by People’s Bank of China. The data are from People’s Bank of China. The investment is measured by quarterly fixed-asset investment in China. The data for consumption is measured by quarterly per capita consumption. The wage is measured by per capita disposable income. The employment is measured by the number of employed people. The seasonal adjustment is necessary for most of variables. Table 3.1 shows the statistical description of all system variables.

3.4.1 Prior and Posterior Distributions

The distributions of the parameters of the utility function are shown in Table 3.2. The intertemporal elasticity of substitution is set at 1.5 with a standard error of 0.37; the
habit parameter is set at 0.7 with a standard error of 0.1. The share of fixed costs in the production function is set at 0.25. The Taylor rule is the basis for setting the parameters that describe the monetary policy rule. The long-run reaction to the inflation and output gaps are set to follow a Normal distribution, with means of 1.5 and 0.125 and standard errors of 0.125 and 0.05, respectively. The coefficient on the lagged interest rate is set to follow a Normal distribution with a mean of 0.75 and a standard error of 0.1, and this coefficient also describes the persistence of the policy rule. The coefficient of the response to the change in the output gap is set at 0.125. I follow Smets and Wouters (2007) to set the parameters’ prior distributions.

The priors on the standard errors of the innovations are assumed to follow an inverse-gamma distribution with a mean of 0.10 and two degrees of freedom. The persistence of the AR(1) processes follows the beta distribution with a mean of 0.5 and a standard deviation of 0.2. The quarterly trend growth rate is assumed to follow a normal distribution with a mean of 0.4 and a standard deviation of 0.1.

According to the results, some posterior means are relatively close to the means of the prior assumptions, while most of the estimated posterior means are not close to their priors. For example, I examine the parameters of the monetary policy reaction. The mean of the long-run reaction coefficient to inflation is estimated to be 1.87, which is relatively higher than the assumed prior 1.5. The mean of the coefficient on the lagged interest rate is estimated to be 0.88, indicating a considerable degree of interest rate smoothing. The mean of the parameters of policy reactions to an output gap and changes in the output gap are estimated to be 0.126 and 0.116, which means that policy reaction to an output gap is stronger than to changes in the output gap.
3.4.2 Impulse Response Function

Smets and Wouters (2003) estimated that monetary policy shocks played a dominant role in the recession of the early 1980s in the US economy. In this paper, I use the impulse response function to examine the effect of monetary policy shock on China’s output and inflation. Figure 1 shows the impulse responses to the monetary policy shocks.

The result shows that the contractionary monetary policy shock has negative effects on output, inflation, consumption and investment, which is consistent with the literature. This result also suggests the existence of the interest rate channel of monetary policy in China. However, the effects of the monetary policy shock on the key variables are not highly significant, showing that the monetary policy shock is not the main driving force of the movements of the economy. In Figure 3.2, I find one standard deviation positive shock on \( \eta_t \) will cause about 0.2% decrease in GDP growth and 0.08% increase in inflation rate. Further, the posterior mean for its parameter is equal to 0.24. Hence, 1% increase in interest rate will cause about 0.83% decrease in GDP growth and 0.33% increase in inflation rate.

Compared my results of IRF to US economy, Smets and Wouters (2007) found that monetary policy shocks have significant effects on US output and inflation in the short run. The peak effect of a policy shock on inflation occurs before its peak effect on output. The effects of monetary policy shocks die out after four years for both output and inflation. However, in China the monetary policy shocks are much less effective. Especially for output, the effects of monetary policy shocks die out in one year, which supports between the GDP growth and interest rate is insignificant.

There are three reasons for ineffectiveness of China’s interest rate policy. First,
China’s interest rate is not determined by the market and China’s financial market is still emerging and imperfect. At the present stage, the supporting system and the condition of interest rate liberalization is not mature enough. Second, Chinese household precautionary savings is much higher than the households in developed countries because of the imperfect perfect social security system. Chinese households tend to save more because of the economic hard time before the economic reform of the late 1970s, and there is not a pension plan or a legitimate health care system if they fall ill or lose their jobs. Hence, households don’t respond significantly to the monetary policy shock. Third, when the large and middle scale state-owned enterprises make the investment decision, they tend to underreact to interest rate policy. It is relatively easier for them to get loans from the state-owned bank, compared to private enterprise. Hence, investment doesn’t respond to interest rate policy significantly.

3.4.3 Variance Decomposition

Table 3.3 presents the forecast variance decomposition of output, inflation and the short-run interest rate, consumption and investment in infinite horizons. Based on the results of variance decomposition, we can study the effects of exogenous shocks on the real economic variables in my model.

Focusing on the contribution of monetary shocks to output, we can find that in the long run, the monetary policy can only explain 5.02% of output forecast error. The forecasted GDP variances can be mainly explained by the productivity, risk premium and government spending shock. For inflation, the result shows that the price mark-up shock dominates the forecast errors, which contributes 86.05% of inflation variance. The monetary shocks can only explain 0.34% of inflation forecast error. The results are
basically the same for the monetary shocks to other variables. Hence, the monetary policy doesn’t play a very important role in China’s business cycle. Turning to other variables, the volatility of investment is mainly driven by investment shocks, which is a reasonable result. The forecasted Consumption variance can be mainly explained by risk premium shocks. Price mark-up shocks turn out to be the dominant source of both inflation and interest rate fluctuations.

Compared to US economy, in the long run, US monetary policy shock can explain about 10% of inflation forecast error which is higher than 0.34% in China. This result is consistent with IRF’s results and also support that the interest rate plays less important role in China compared to US.

3.4.4 Conditional Variance Decomposition

The results shown in Table 3.4 presents the conditional forecast variance decomposition of monetary shocks to output, inflation and interest rate, consumption and investment in different horizons. The results of the conditional forecast variance decomposition explain how many percentage forecast errors of the system variables can be explained by monetary policy shocks. This table shows the contribution of monetary policy shock to the real economic variables in China after one quarter, after two quarters, after one year, after ten quarters, and after ten years. According to these results, we can tell whether monetary policy plays an important role in China’s business cycle.

Focusing on the contribution of monetary shocks to the real economic variables, I find that the monetary policy can only explain 3.29% of output forecast error in the next quarter. Further, the results don’t change significantly for long-run. For other system variables such as inflation, consumption, and investment, the monetary shock is also not
the dominant factor. Monetary policy shocks contribute only a small fraction of the forecast variance of them at all horizons. Not surprisingly, the monetary policy shock explains a big part of the short-run variations in interest rate. The monetary policy shocks can explain 61.6% of interest rate forecast error in the next quarter. However, these shocks become less dominant in the long-run developments of interest rate. After 10 years, they can only account for 7.76% of the forecast error variance of interest rate. In sum, the monetary policy didn’t play a dominant role in China’s business cycle no matter for short-run or log-run horizon.

In sum, contractionary monetary policy shock has negative effects on output, inflation, consumption and investment according to the impulse response functions. However, the effects of the monetary policy shock on the real economic variables are not highly significant, indicating that the monetary policy shock is not the main driving force of the movements of the economy. The results are consistent using variance decomposition technique. Moreover, the results of conditional variance decomposition show that monetary policy didn’t play an important role in China’s business cycle in neither short-run nor log-run horizon.

3.5 Conclusion

In this paper, I use a Bayesian approach to estimate the DSGE model and examine the influence of monetary policy shock on real economic fluctuations in China. The parameters of the model and the stochastic processes governing the structural shocks are estimated using seven key macro-economic time series in China, which includes real GDP, consumption, investment, inflation, real wage, employment and the nominal short-
term interest rate. Prior distributions of the parameters are set following the parameters for Smets and Wouters (2007).

Based on the results of the posterior distributions and impulse response functions, we can find that the monetary policy shock does have significant effects on China’s output and inflation. This result is consistent with the literature. However, based on the results of variance decomposition, I find that the monetary policy shocks didn’t play significant role in China’s business role. Hence, the monetary policy might not be the major driver for China’s economic growth. The reason of the ineffectiveness of China’s interest rate policy might be the imperfect financial market and interest rate control in China. Besides, I find that the mean of the standard error of the shock to the productivity process is significantly higher than our expectation. This implies China has experienced and is experiencing an intense technological revolution. In the future study, I will focus on the comparison of the effect of different shocks on China’s economy and analyze the major driver for economic growth.

3.6 References


Table 3.1 Statistical Description of Data

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<td>7311.74</td>
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<td>1554.4</td>
<td>19968</td>
</tr>
<tr>
<td>Wage</td>
<td>92</td>
<td>10552.2</td>
<td>6602.64</td>
<td>2125.5</td>
<td>28844</td>
</tr>
<tr>
<td>Employment</td>
<td>92</td>
<td>13217.32</td>
<td>1907.47</td>
<td>10825</td>
<td>18375.94</td>
</tr>
</tbody>
</table>

Note: The data are Chinese data and are on a quarterly basis. The data sources are the World Bank database, Statistical Yearbook of China and the central bank of China. The sample period is from 1992 to 2014. The consumer price index (CPI) is the index of the level of inflation. For my data, the year of 2005 is the base year. The interest rate (R) is measured by 6-month short run interest rate offered by People's Bank of China. The data are from People’s Bank of China. The investment is measured by quarterly fixed-asset investment in China. The data for consumption is measured by quarterly per capita consumption. The wage is measured by per capita disposable income. The employment is measured by the number of employed people.
Table 3.2 Prior and Posterior Distribution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Prior Distribution</th>
<th>Prior Mean</th>
<th>Prior S.D.</th>
<th>Posterior Mean</th>
<th>Posterior S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_c ) Int. Sub.</td>
<td>Normal</td>
<td>1.5</td>
<td>0.37</td>
<td>1.28</td>
<td>0.00</td>
</tr>
<tr>
<td>( h ) Habit Form.</td>
<td>Beta</td>
<td>0.7</td>
<td>0.1</td>
<td>0.84</td>
<td>0.00</td>
</tr>
<tr>
<td>( l_w ) Wage Index</td>
<td>Beta</td>
<td>0.5</td>
<td>0.15</td>
<td>0.53</td>
<td>0.16</td>
</tr>
<tr>
<td>( l_p ) Price Index</td>
<td>Beta</td>
<td>0.5</td>
<td>0.15</td>
<td>0.18</td>
<td>0.05</td>
</tr>
<tr>
<td>( F ) Fixed Cost</td>
<td>Normal</td>
<td>1.25</td>
<td>0.12</td>
<td>1.67</td>
<td>0.00</td>
</tr>
<tr>
<td>( r^c ) Inf. Policy</td>
<td>Normal</td>
<td>1.5</td>
<td>0.25</td>
<td>1.87</td>
<td>0.05</td>
</tr>
<tr>
<td>( \rho ) Coeff. Lag</td>
<td>Beta</td>
<td>0.75</td>
<td>0.1</td>
<td>0.88</td>
<td>0.01</td>
</tr>
<tr>
<td>( r^y ) Output Policy</td>
<td>Normal</td>
<td>0.125</td>
<td>0.05</td>
<td>0.126</td>
<td>0.01</td>
</tr>
<tr>
<td>( r^b ) ( \Delta Y ) Policy</td>
<td>Normal</td>
<td>0.125</td>
<td>0.05</td>
<td>0.116</td>
<td>0.00</td>
</tr>
<tr>
<td>100(( \beta^{-1} - 1 ))</td>
<td>Gamma</td>
<td>0.25</td>
<td>0.1</td>
<td>0.11</td>
<td>0.05</td>
</tr>
<tr>
<td>( \gamma ) Trend</td>
<td>Normal</td>
<td>0.4</td>
<td>0.1</td>
<td>0.52</td>
<td>0.00</td>
</tr>
<tr>
<td>( \alpha ) Capital Share</td>
<td>Normal</td>
<td>0.3</td>
<td>0.05</td>
<td>0.21</td>
<td>0.01</td>
</tr>
<tr>
<td>( \sigma_a ) Std. Dev.</td>
<td>Inv-gamma</td>
<td>0.1</td>
<td>2</td>
<td>0.50</td>
<td>0.00</td>
</tr>
<tr>
<td>( \sigma_b ) Std. Dev.</td>
<td>Inv-gamma</td>
<td>0.1</td>
<td>2</td>
<td>0.39</td>
<td>0.00</td>
</tr>
<tr>
<td>( \sigma_i ) Std. Dev.</td>
<td>Inv-gamma</td>
<td>0.1</td>
<td>2</td>
<td>0.57</td>
<td>0.00</td>
</tr>
<tr>
<td>( \sigma_r ) Std. Dev.</td>
<td>Inv-gamma</td>
<td>0.1</td>
<td>2</td>
<td>0.24</td>
<td>0.004</td>
</tr>
<tr>
<td>( \rho^a ) Shock</td>
<td>Beta</td>
<td>0.5</td>
<td>0.2</td>
<td>0.98</td>
<td>0.00</td>
</tr>
<tr>
<td>( \rho^b ) Shock</td>
<td>Beta</td>
<td>0.5</td>
<td>0.2</td>
<td>0.17</td>
<td>0.00</td>
</tr>
<tr>
<td>( \rho^c ) Shock</td>
<td>Beta</td>
<td>0.5</td>
<td>0.2</td>
<td>0.61</td>
<td>0.00</td>
</tr>
<tr>
<td>( \rho^r ) Shock</td>
<td>Beta</td>
<td>0.5</td>
<td>0.2</td>
<td>0.20</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Note: \( \sigma_a \) and \( \rho_a \) are the parameters for productivity shocks. \( \sigma_b \) and \( \rho_b \) are the parameters for risk premium shocks. \( \sigma_i \) and \( \rho_i \) are the parameters for investment shocks. \( \sigma_r \) and \( \rho_r \) are the parameters for monetary policy shocks.
Table 3.3 Variance Decomposition (in percentage)

<table>
<thead>
<tr>
<th></th>
<th>Monetary</th>
<th>Productivity</th>
<th>Risk Prem</th>
<th>Wage</th>
<th>Price</th>
<th>Invest.</th>
<th>Govt. Spending</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>5.02</td>
<td>12.50</td>
<td>35.04</td>
<td>7.72</td>
<td>1.25</td>
<td>12.30</td>
<td>26.17</td>
<td>100</td>
</tr>
<tr>
<td>Inflation</td>
<td>0.34</td>
<td>0.42</td>
<td>0.04</td>
<td>13.07</td>
<td>86.05</td>
<td>0.04</td>
<td>0.04</td>
<td>100</td>
</tr>
<tr>
<td>Cons.</td>
<td>6.00</td>
<td>5.37</td>
<td>73.83</td>
<td>13.17</td>
<td>0.81</td>
<td>0.15</td>
<td>0.67</td>
<td>100</td>
</tr>
<tr>
<td>Invest.</td>
<td>5.17</td>
<td>5.86</td>
<td>11.71</td>
<td>5.64</td>
<td>1.42</td>
<td>68.06</td>
<td>2.14</td>
<td>100</td>
</tr>
<tr>
<td>Interest R.</td>
<td>0.77</td>
<td>0.40</td>
<td>0.42</td>
<td>13.07</td>
<td>86.95</td>
<td>0.25</td>
<td>0.16</td>
<td>100</td>
</tr>
</tbody>
</table>

Note: this table reports the forecast error variance decomposition of output, inflation, consumption investment and interest rate in infinite horizon.

Table 3.4 Conditional Variance Decomposition (in percentage) of Monetary Shocks

<table>
<thead>
<tr>
<th></th>
<th>Output</th>
<th>Inflation</th>
<th>Consumption</th>
<th>Investment</th>
<th>Interest Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>3.29</td>
<td>2.23</td>
<td>3.97</td>
<td>4.38</td>
<td>61.60</td>
</tr>
<tr>
<td>Q2</td>
<td>4.48</td>
<td>3.01</td>
<td>5.72</td>
<td>4.93</td>
<td>51.25</td>
</tr>
<tr>
<td>Q4</td>
<td>4.66</td>
<td>3.80</td>
<td>6.06</td>
<td>4.90</td>
<td>33.88</td>
</tr>
<tr>
<td>Q10</td>
<td>4.65</td>
<td>4.08</td>
<td>5.58</td>
<td>4.93</td>
<td>15.53</td>
</tr>
<tr>
<td>Q40</td>
<td>5.04</td>
<td>2.72</td>
<td>6.06</td>
<td>5.18</td>
<td>7.76</td>
</tr>
</tbody>
</table>

Note: this table reports the forecast error conditional variance decomposition of monetary policy shocks to output, inflation, consumption investment and interest rate in different horizons.(Q1=after one quarter, Q2=after two quarters, Q4=after one year, Q10=after ten quarters, Q40=after ten years)
Note: The data are Chinese data and are on a quarterly basis. The data sources are the Statistical Yearbook of China and the central bank of China.

Figure 3.1 Plots of Output and Inflation in the Sample Period
Note: The estimated impulse responses of four key macro-economic variables to monetary policy shocks.

Figure 3.2 IRF to Monetary Policy Shock
APPENDIX

The DSGE model in this paper is made up of final goods firms, intermediate goods firms, households, and the central bank. Households supply labor to intermediate goods firms and consume the final goods. The intermediate goods firms produce a homogenous intermediate good by combining labor and capital. Final goods firms purchase intermediate goods from intermediate producers in a competitive market, and transform them into composite final goods. There are bonds which can be traded between households and firms. The government conducts monetary and credit policies, collects taxes and makes government purchases.

The government expenditure is met by the lump sum taxation on the households, and bond issuing. The government budget constraint is given by $P_t G_t + B_{t-1} = T_t + \frac{B_t}{R_t}$, where $T_t$ is the nominal taxes which also appear in the household budget constraint, $G_t$ is the government spending, and $B_t$ is the bond issuing by government.

The resource constraint is given by $Y_t = C_t + I_t + G_t + a(Z_t) K_{t-1}$. This constraint represents the equilibrium in the final goods market, which is production equals demand by households for consumption and investment and the government spending.

The amount of capital that households can rent to firms is $K_t^j = Z_t^j K_{t-1}^j$, where $Z_t^j$ is the utilization rate of installed capital. This constraint represents the equilibrium in the capital rent market.

After solving the model, we can derive the steady state equations. We take the first order conditions with respect to $K_t^i$ and $L_t^i$ for intermediate goods producers’ Cobb-Douglas production function, which obtain the cost minimization conditions. We
combine the first order conditions for these two variables. Then, we can get the following capital-labor ratio: \( K_t^i = \frac{\alpha W_t L_t}{1 - \alpha} k_t^i \). Substituting the optimal ratio of capital to labor into production function, then we can obtain the marginal cost of the intermediate firm. After log-linearization, we can get the steady state equation of marginal cost as \( \dot{m}_t = (1 - \alpha) \dot{w}_t + \alpha \dot{r}_t^k - \dot{Z}_t \), where \( \dot{w}_t \) is the aggregate nominal wage rate and \( \dot{r}_t^k \) is the rental rate on capital, \( \dot{Z}_t \) is the utilization rate of installed capital. Besides, by the optimal ratio of capital to labor, we can obtain the equation of capital and labor as \( \dot{k}_t = \dot{w}_t - \dot{r}_t^k + \dot{L}_t \), where \( \dot{L}_t \) is the labor supply.

For the households, the capital accumulation equation which is given by:

\[
K_{t+1}^j = (1 - \delta) K_{t}^j + \delta^i I_{t+1}^j \left[ 1 - S \left( \frac{I_{t+1}^j}{I_{t}^j} \right) \right] I_{t+1}^j ,
\]

where \( \delta \) is the depreciation rate, \( K_{t}^j \) is the capital services used in production, \( S(\cdot) \) is the adjustment cost function, and \( \delta^i \) is a stochastic shock to the price of investment relative to consumption goods follows the following process: \( \ln \delta^i = \rho_i \ln \delta^i_{t-1} + \eta^i_{t-1} \), \( \eta^i, \eta^\ast \sim (0, \sigma_i) \). After log-linearization, we can obtain the steady state equation of the capital accumulation equation for household is given by: \( \dot{k} = (1 - \delta) \dot{k}_{t-1} + \delta \dot{i}_t \).

For the central bank sector, the monetary policy responds to deviation of inflation and output from their target levels. After log-linearization, the monetary policy reaction function is: \( R_t = \rho_R R_{t-1} + (1 - \rho_R) (r_x \dot{\pi}_t + r_y \dot{y}_t + \dot{\pi}_{t-1} + \dot{y}_{t-1}) - r_d \dot{y}_t + \dot{\epsilon}_t \), where \( \rho_R \) is the degree of interest rate smoothing, \( r_x \) is inflation coefficient, \( r_y \) is output
gap coefficient, \( r_{\text{dp}} \) is inflation growth coefficient, \( r_{\text{dy}} \) is output growth coefficient, and 

\( \varepsilon_t' \) is monetary policy shock follows the process: 

\[
\ln \varepsilon_t' = \rho_t \ln \varepsilon_{t-1} + \eta_{t}^\varepsilon, \eta_{t}^\varepsilon \sim (0, \sigma_{\varepsilon})
\]

After log-linearization, the steady state equation of Cobb-Douglas production function is:

\[
\hat{y}_t = \frac{y_s + F}{y_s} [\alpha k_t + (1 - \alpha) L_t + \varepsilon_t^a], \text{ where } F \text{ is fixed cost, and } \varepsilon_t^a \text{ is productivity shock}
\]

\( \varepsilon_t^a \) follows the process: 

\[
\ln \varepsilon_t^a = (1 - \rho_{\varepsilon}) \ln \varepsilon_{t-1} + \rho_{\varepsilon} \ln \varepsilon_{t-1} + \eta_{t}^\varepsilon, \eta_{t}^\varepsilon \sim (0, \sigma_{\varepsilon})
\]

The goods market equilibrium condition is given by 

\[
y_t = C_t + I_t + G_t + a(Z_t)K_{t-1}.
\]

After log-linearization, it can be written as:

\[
y_t = (1 - \delta k_y g_y) \varepsilon_t + \delta k_y i_t + g_y \varepsilon_t^g, \text{ where } k_y
\]

is the steady state capital-output ratio, and \( g_y \) is the steady state government spending – output ratio. \( \varepsilon_t^g \) is government spending shock which follows the process:

\[
\ln \varepsilon_t^g = \rho_t \ln \varepsilon_{t-1} + \eta_{t}^\varepsilon, \eta_{t}^\varepsilon \sim (0, \sigma_{g})
\]