Capital Constraints, Bank Risk-Taking and Monetary Policy

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A thesis submitted to Macquarie University
for the degree of Doctor of Philosophy
Department of Economics
December 16, 2016

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Except where acknowledged in the customary manner, the material presented in this thesis is, to the best of my knowledge, original and has not been submitted in whole or part for a degree in any university.

Abstract

In this thesis, the New Keynesian model is tested, extended and estimated using Chinese data. In particular, the New Keynesian Phillips Curve is tested for the weak identification problem. The empirical results reveal that both forward- and backward-looking behaviour exist in the pattern of Chinese inflation. The forward behaviour is quantitatively larger than the backward looking behaviour, but the latter is not negligible in the quantitative sense.

We empirically test whether China was able to achieve monetary policy autonomy under capital controls by estimating a Vector Error Correction Model (VECM), and theoretically examine the possible consequences of capital controls by constructing an open economy New Keynesian model with capital controls. It is found that China has indeed achieved monetary policy autonomy of under a partially opened capital account and an exchange rates regime, in general, pegged to the US dollar. In the modelling section, the appropriateness and consequences of capital controls are examined using an open economy New Keynesian model. Capital controls transform dramatic and immediate changes in deposit portfolios into a prolonged and gradual adjusting process. The appropriateness of capital controls depends largely on the sources of shocks. Capital controls can reduce output fluctuations under a foreign demand shock, but can only increase the volatility of the economy under a foreign interest rate and an inflation shock.

We build an open economy model with a banking sector and estimate it using Chinese data in order to analyse the effects of the monetary and macroprudential policies. Banks in the model can increase their leverage ratios quickly through greater reliance on short-term financing sources. Four different policy sets, including different combinations of a standard Taylor rule, a loan-to-value ratio extended Taylor rule, and a macroprudential tool, are assessed based on a central bank loss function. It is found that the extended Taylor rule has no dominant role among the four combinations of policies. The extended Taylor rule with macroprudential policy has lower losses compared with other policy sets.

Acknowledgements

It is not easy to write a thesis, but I am lucky that I had so much help from those who make this thesis possible.

I would like to express my deepest gratitude to my supervisor Prof. Jeffrey Sheen for his patience, motivation, immense knowledge, and insightful comments. His intuitive interpretation of models inspired and guided me, and I became interested in New Keynesian models. He provided great help with developing my models, coding, and writing. He corrected so many spelling and grammar errors I have made. The two-semester tutor experience with him was extremely helpful to practicing my English. I doubt that I will ever be able to convey my appreciation fully, but I owe him my eternal gratitude.

I would like to express my sincere gratitude to Prof. Qingquan Lin. His guidance and support helped me to complete my thesis. I have been amazingly fortunate to have him encourage me to explore my own topic.

I would like to thank my co-supervisor Dr. Ben Wang. His knowledge about modeling and coding saved me a lot of time in dealing with technical problems. His encouragement and hard questions guided me to understand the weaknesses of my model.

I would like to thank Selma Huang who helped a lot in teaching. I would like to thank Kagiso Mangadi who is very nice to me and spent a lunchtime discussing thesis writing with me.

I would like to thank my roommates in Valewood Marsfield. They are so friendly and showed me the cliff walks and jungle walks. The amazing nature made me feel small, and encouraged me to see more beautiful places.

I would like to thank Xiao Sun, my sister, my mother, and my father. Their love made me strong and gave me the courage to bravely face all the difficulties.

There is still a long journey ahead and I will do my best to know the wonderful world.

Contents

Chapter 1

Introduction

Monetary policies immediately prior to the financial crisis in 2008 primarily focused on the stabilisation of output and inflation. Formally or informally, a Taylor principle was adopted by central banks in developed and emerging economies. Although Taylor (2009) claims that the recent financial crisis could have been avoided if the US central bank strictly followed the Taylor rule, it seems that the original Taylor principle might not suffice to protect the economy from a crisis.

Curdia and Woodford (2010) argue that the augmented Taylor rule shows better performance than the conventional Taylor rule in stabilising the economy. However, Faia and Monacelli (2007) find that marginal welfare gains by embedding asset prices in the standard Taylor rule will disappear if the reaction of policy interest rates to inflation becomes substantially large. Rubio and Carrasco-Gallego (2014) find that the mix of monetary and macroprudential policy can increase the overall welfare of the economy. Should we extend the monetary policy to stabilize the financial system, or use a mix of mix of monetary and macroprudential policy?

The current versions of DSGE models do not provide an analytical framework to analyse systemic stability. There are several disadvantages to the basic versions of DSGE models, which include no meaningful financial frictions (Bean, 2009), no accumulation and burst of financial booms (De Bandt, Hartmann, and Peydr, 2009), and an implicit assumption of no bankruptcies (Goodhart, Osorio, and Tsomocos, 2009). In order to provide a more elaborate analysis of monetary and macroprudential policy, it is necessary to overcome these shortcomings.

To deal with these, two types of modifications has been developed. The first one considers credit constraints on non-financial borrowers, such as in the work of Curdia and Woodford (2009), Christiano, Trabandt, and Walentin (2011), Gerali et al. (2010), etc. The second one considers frictions within the financial sector. These models are widely used to examine the role of bank capital in the policy transmission channel, for example in Gerali et al. (2010). Using these extended DSGE models, the effects of an extended Taylor rule and macroprudential policy are widely discussed. Researchers usually find the extended Taylor rule and macroprudential policy useful, especially when the shocks come from the financial sector (Gilchrist and Zakrajšek, 2011).

Nevertheless, these models are limited in their liability to examine the risk-taking behaviour of banks. Banks still play a trivial role in current versions of dynamic stochastic general equilibrium (DSGE), which does not provide an analytical framework to analyse financial stability. In addition to these modelling considerations, the features of Chinese economy are important when applying DSGE model to analyse monetary and macroprudential policies. China follows a gradualist approach to reforming its central planning economic regime to a market oriented economic regime. In this process, China keeps learning from developed economies and tries to avoid large economic and financial instabilities using fiscal, monetary, and financial policy tools. Capital controls are adopted by China to smooth out international capital surges.

This study examines the monetary policy implications of the risk-taking behaviour of banks in an open economy environment. In order to investigate this monetary policy issue, a macroeconomic model with an elaborated banking system is developed. In particular, multiple interest rates with a risk-free policy rate, deposit rate, and loan rate should be embedded into the DSGE model. Banks' risk-taking behaviour is modelled using a more elaborate balance sheet structure. On the asset side, there are bank loans and cash reserves. On the liability and equity side, there are deposits from households, financial bonds from the interbank market, and bank capital. Several features of China's economy are considered in this study: the forward- and backward- looking behaviours in the New Keynesian Phillips Curve (NKPC), capital controls, and the risk-taking behaviour of banks.

In Chapter 2, we discusses the causes, consequences and recognition of, and robust statistics for, the weak identification problem. An NKPC is tested using the Cragg-Donald F statistic for the weak identification problem, and we find it exists. We then estimate the relevant parameters of this NKPC using weak identification robust statistics and construct size-correct confidence intervals using conditional likelihood ratio (CLR) statistics. The empirical results reveal that both forward- and backward-looking behaviours exist in the pattern of Chinese inflation, and the forward-looking behaviour is quantitatively larger than the backward behaviour, which nevertheless is not negligible in the quantitative sense. The subsample test results hint that backward behaviour of inflation tends to be stronger. This implies a tendency to more inflation inertia. The central bank should consider past inflation paths together with the impact of future real GDP gaps on current inflation.

In Chapter 3, we empirically test whether China was able to achieve monetary policy autonomy under capital controls by estimating a Vector Error Correction Model (VECM). We theoretically examine the possible consequences of capital controls by constructing an open economy New Keynesian model with capital controls. It is found that China has indeed achieved monetary policy autonomy under a partially opened capital account and exchange rate regime, in general pegging against the US dollar. In the modelling section, the appropriateness and consequences of capital controls are examined using an open economy New Keynesian model. It is found that capital controls transform dramatic and immediate changes in deposit portfolios into a prolonged and gradually adjusting process. The appropriateness of capital controls depends largely on the sources of shocks. Capital controls can reduce output fluctuations under a foreign demand shock, but can only increase the volatility of the economy under a foreign interest rate and an inflation shock.

In Chapter 4, we build an open economy model with a banking sector and estimate it using Chinese data, in order to analyse the effects of monetary and macroprudential policies from the view point of China. The banks in the model have an elaborated balance sheet structure, through which they can increase their leverage ratio quickly. Four different policy sets, including different combinations of a standard Taylor rule, a loan to value ratio extended Taylor rule, and a macroprudential tool, are assessed based on a central bank loss function. It is found that the extended Taylor rule has no dominant role among the four combinations of policies. The extended Taylor rule with macroprudential policy has lower losses compared with other policy sets. However, the macroprudential tool can generate a marginal reduction in losses for the central bank.

Chapter 2

An Estimated New Keynesian Phillips Curve for China

2.1 Introduction

Weak identification usually results in inconsistent point estimates and wrongly-covered confidence intervals for GMM statistics based on large sample properties. This paper discusses the causes, consequences and recognition of, and robust statistics for, the weak identification problem. The NKPC is tested for the weak identification problem using Cragg-Donald F statistic , and we find that it exists. We then estimate the relevant parameters of NKPC using weak identification robust statistics, and construct size-correct confidence intervals using CLR statistics. The empirical results reveal that both forward- and backward-looking behaviour exist in the pattern of Chinese inflation, and that the forward-looking behaviour is quantitatively larger than the backward-looking behaviour which, nevertheless, is not negligible in the quantitative sense. Subsample test results hint that backward-looking behaviour of inflation tends to be stronger.

2.2 Literature Review

DSGE (Dynamic Stochastic General Equilibrium) models are now the workhorse for monetary policy analysis. The basic New Keynesian DSGE model typically comprises three equations for the New Keynesian Phillips Curve (NKPC), the dynamic IS curve and a monetary policy rule. The NKPC can be estimated using full information estimation methods, such as likelihood ratio estimation or Bayesian estimation, together with other equations in the DSGE model. It can also be estimated using the limited information method as a single equation. The limited information estimation method includes the Generalized Method of Moments (GMM), and Limited Information Likelihood Estimates (LILM). The estimations and statistical inferences of GMM are usually based on the large sample assumption and the relevant asymptotic properties. However, the number of observations in macro-economic research is usually small, which may render the large sample assumption invalid. Lagged variables are usually used as the instruments for the endogenous variables, which leads to a weak identification problem in the estimation of the NKPC. The weak identification problem is found widely in small sample empirical work. Another cause of weak identification is the difficulty of predicting changes to inflation[1], which results in a weak relationship between the endogenous variable and the instrument variables (Mavroeidis, Plagborg-Møller, and Stock, 2014). The weak identification test and relevant weak identification robust estimates will be reviewed for the empirical application of the NKPC.

The NKPC is one of the three functions comprising the basic New Keynesian model, which is a DSGE model with the features of sticky prices and wages. Under the Calvo (1983) assumption of sticky prices, only a portion of producers can change to their optimal price when facing the demand of con-

[1]Stock and Watson (2007) find it becomes harder to forecast changes in US inflation.

sumers in a specific period, while the remaining producers have to keep their price unchanged. Based on this specification, the NKPC with a forward-looking component can be derived. However, because of the wide empirical evidence on inflation inertia, the pure forward-looking NKPC does not fit the data well. Because of this, a backward-looking component is embedded by assuming that a portion of producers follows a rule of thumb, i.e., just keeping prices unchanged in each period. The resulting NKPC thus has both a forward- and a backward-looking component. This type of NKPC is usually referred to as the hybrid NKPC. In the following, the hybrid NKPC and NKPC will be used interchangeably if no confusions occur.

$$\pi_t = \lambda x_t + \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + u_t \tag{2.1}$$

In the work of Galí and Gertler (1999), the NKPC is derived as (2.1). In equation (2.1), π_t is the inflation rate at time t, and $E_t\pi_{t+1}$ is the expectation of π_{t+1} at time t. x_t is the driving variable at time t, such as the output gap or the marginal production of labor. λ, γ_f and γ_b are the coefficients of the driving force, the forward-looking coefficient and the backward-looking coefficient of the NKPC. The parameters γ_f and γ_b represent the rational expectation and adaptive expectation elements that determine inflation. u_t is the regression error perhaps reflecting the unobservable part related to production cost shocks.

Under the rational expectation assumption, the mean of the regression error or unobservable part is zero, i.e. $E_{t-1}u_t = 0$. In other words, u_t is unpredictable and uncorrelated with all variables up to time $t-1$. Because expected inflation $E_t\pi_{t+1}$ is unobservable, it is replaced by the actual inflation π_{t+1} in GMM estimation, which can lead to measurement error and thus an endogeneity problem. Using π_{t+1} to replace $E_t\pi_{t+1}$, the equation (2.1) can be rewritten as (2.2).

$$\pi_t = \lambda x_t + \gamma_f \pi_{t+1} + \gamma_b \pi_{t-1} + \tilde{u}_t \tag{2.2}$$

In equation (2.2), $\tilde{u}_t = u_t + \gamma_f(E_t\pi_{t+1} - \pi_{t+1})$ is the new regression error term. Based on the property of conditional expectation, the new regression error still has a zero mean, i.e. $E_{t-1}\tilde{u}_t = 0$. Suppose Z_t is a valid instrument set, the moment condition of GMM can be written as $E(\tilde{u}_t Z_t) = 0$. The property of conditional expectations can guarantee that all the variables observable till time $t-1$ belong to Z_t.

2.2.1 Forward- or Backward-Looking NKPC

There is some controversy about the weights of the forward- and backward-looking parts of the NKPC. Some assert that the forward-looking part of the NKPC has a dominant role, implying that pricing behaviour is in general rational. For example, using the change of GDP deflator as a measurement for inflation and the ratio of labour income to GDP as the driving force variable, Galí and Gertler (1999) estimate the forward-looking and backward-looking NKPC based on the quarterly data from quarter 1, 1960 to quarter 4, 1997. They use four-period lagged inflation, ratio of labour income to GDP, spread between short and long-term interest rates, output gap, wage inflation, and commodity inflation are used as the instrument variables. They find that the backward-looking coefficient γ_b is significant, ranging from 0.22 to 0.38. The forward-looking coefficient γ_f is significant as well, ranging from 0.59 to 0.77. If the change of the non-agriculture deflator index is used as the measurement for inflation, the estimated backward coefficient γ_b is 0.085 and thus even smaller than before. The estimated forward-looking coefficient is 0.871 and thus even larger than before. Based on this result, Galí and Gertler (1999) conclude that although it is statistically significant, the backward-looking behaviour is not important quantitatively. The pure forward-looking NKPC is thus sufficient to describe inflation behaviour.

Galí, Gertler, and Lopez-Salido (2001) estimate the NKCP using GMM based on European and US data. The results based on US data are basically similar to the results of Galí and Gertler (1999). However, the results based on European data exhibit a stronger forward-looking feature. The estimated γ_b and γ_f are 0.27 and 0.69 respectively. Gali, Gertler, and Lopez-Salido (2005) estimate the NKPC using US data once again and find similar results to that of Galí and Gertler (1999). The work of Gali, Gertler, and Lopez-Salido (2005) is mainly due to challenges from Rudd and Whelan (2005), and Lindé (2005) who argue that the estimation method of Galí and Gertler (1999) is problematic. Rudd and Whelan (2005) argue that an omitted variable which is related to both π_{t+1} and its instruments may lead to upward bias of estimated γ_f. Lindé (2005) criticizes GMM in general because it is biased towards finding inflation inertia given inertias in aggregate demand and the interest rate.

Ravenna and Walsh (2008) extend the work of Galí and Gertler (1999) by considering the impact of unemployment on inflation. Using GMM based on the US data, Ravenna and Walsh (2008) find the estimated γ_f is about 0.66 while the estimated γ_b is only 0.22 in the unemployment-rate version of the NKPC. This result is similar to and thus supportive of Galí and Gertler (1999). Krause, Lopez-Salido, and Lubik (2008) use the probability of a worker finding a job as another measurement for the driving force variable, replacing the real marginal cost of the labour force. The GMM estimation results suggest that the estimated γ_f is 0.59 while the estimated γ_b is 0.40. Although the difference between γ_f and γ_b is smaller than that in Galí and Gertler (1999), the forward-looking part is still dominant.

However, some other scholars find different results using a similar method to Galí and Gertler (1999) to estimate the NKPC. They claim that both the estimated γ_b and γ_f are significant, but that the forward-looking part does not necessarily dominate the backward-looking part. Benigno and Lopez-Salido (2006) claim that there might be heterogeneity for inertia across different economies. They estimate the NKPC of five main countries in the Euro area using quarterly data from 1970 to 1997. It is found that the coefficient γ_b is not significant but γ_f is significant and above 0.7 in Germany. The estimated coefficients in France and Norway are similar. The estimated γ_b is 0.3 and the estimated γ_f is 0.6, and both of them are significant. The estimated γ_b and γ_f for Italy and Spain are both around 0.5 and significantly. The output level of German is about 35 per cent of the entire output of the Euro area. The next four countries have 56 per cent of the entire output of the Euro area. It therefore cannot be concluded that the forward-looking part of the NKPC is dominant for the entire Euro area. Thus, using similar data and G-MM estimation, Benigno and Lopez-Salido (2006) get a result different from Galí, Gertler, and Lopez-Salido (2001).

Chowdhury, Hoffmann, and Schabert (2006) estimate the short-term interest rate of extended NKPC using the percentage change of the GDP deflator as the measure of inflation. They find that in Canada and Japan the estimated γ_b and γ_f are 0.2 and 0.7 respectively. The forward-looking coefficient is obviously larger than the backward-looking coefficient. The estimated γ_b and γ_f in Germany, France, and the UK are roughly the same. The estimated γ_b ranges from 0.3 to 0.4 and the estimated γ_f is about 0.5. In the case of the UK and Italy, the estimated backward-looking coefficient is larger than the estimated forward-looking coefficient. The estimated γ_b and γ_f in the US are 0.53 and 0.39 respectively and the γ_b and γ_f in Italy are 0.50 and 0.48 respectively. Therefore, Chowdhury, Hoffmann, and Schabert (2006) produce an opposite empirical result to that of Galí and Gertler (1999). The estimated γ_b and γ_f for Germany are different from those in Benigno and Lopez-Salido (2006) as well.

Blanchard and Galí (2007) estimate the NKPC using the quarterly data after World War II. The percentage change of the GDP deflator is used to measure the inflation rate, and the real price of the non-produced inputs is used as the driving variable in NKPC. Moreover, the impact of the unemployment rate on inflation is considered as well. GMM results show that the estimated γ_b is 0.66 while the estimated γ_f is 0.42. However,Blanchard and Galí (2007) do not provide explanations for why the forward-looking coefficient is smaller than the backward-looking coefficient.

2.2.2 Weak Identification of NKPC

Kleibergen and Mavroeidis (2009) argue that one possible reason for these controversial empirical findings is the weak identification problem for the instrument variables in GMM large sample estimation. In the seminal work of Hansen and Singleton (1982), GMM is proposed as a general method to estimate a rational expectation equation, such as the Euler equation, from the optimisation problem of a household. The Euler conditions of households and firms have a similar structure[2]. Thus, GMM is widely used as the estimation method for the NKPC.

The main idea of GMM is to minimise the constructed target function, which is usually the weighted quadratic sum of the moment condition. The parameter values can be found by solving a set of first order conditions for the target function. Suppose the moment condition for GMM is $Ef_t(\theta) = 0$, where $f_t(\cdot)$ is a function of parameter θ to be estimated. The parameter θ can be identified if and only if $\theta = \theta_0$; then $Ef_t(\theta_0) = 0$, where θ_0 is the true parameter value. If for any $\theta \in \Theta$, $Ef_t(\theta) = 0$ where Θ is a non-empty set, usually a continuum set, parameter θ cannot be identified because there is more than one value satisfying the moment condition. Weak identification refers to a case between identification and under-identification. Suppose Θ_{θ_0}

[2]See explanations by Fuhrer and Olivei (2010)

is a neighborhood area of θ_0. When $\theta \neq \theta_0$ and $\theta \in \Theta_{\theta_0}$, $Ef_t(\theta)$ is not zero but is very small. In this case, GMM target function is quite flat and forms a plateau in the area of θ_0. In this case, the parameter of the target function can only be weakly identified because only an area can be identified, and it is therefore difficult to identify the exact value of θ_0 (Stock and Wright, 2000).

In the case of NKPC estimation, lagged variables are all valid instrument variables under the rational expectation hypothesis. However, these instrument variables might be not strong enough to use as a proper instrument, because an instrument variable requires both relevance and validity. The weak identification problem thus can also be interpreted as a weak correlation between the instrument and endogenous variable. Because it is usually very difficult to forecast changes to inflation, the instrument variables for inflation expectation are usually accompanied by the weak identification problem (Mavroeidis, Plagborg-Møller, and Stock, 2014).

Although the weak identification problem is common in GMM estimation for the NKPC, its importance has received limited attention. The earliest work in the area is Ma (2002), which analyses the weak identification problem in estimating NKPC using GMM. Ma (2002) uses a continuously-updating estimator (CUE) to estimate the NKPC. The CUE is based on the following target function: $Q(\theta) = Tf_T(\theta)'V_{ff}(\theta)^{-1}f_T(\theta)$, where T is the sample size. In large sample estimation, it is usually assumed that the weight matrix $V_{ff}(\theta)$ does not change with parameter θ. However, in the CUE, the target function is a continuous function of θ.

The CUE is used in the case of weak identification because it is sensitive to the weakly-identified moment condition. It is robust to the weak identification problem. The CUE therefore can be used in GMM with weak instruments (Stock, Wright, and Yogo, 2002). By using the CUE, Ma (2002) finds that there is no large difference between the forward-looking and backward-looking parts of the NKPC. The estimated γ_b and γ_f are 0.43 and 0.52 respectively. However, because GMM target function is quite flat over an interval, the weak instrument robust confidence interval is [0,3] for the backward-looking parameter γ_b. In this sense, the estimation for γ_b is far from accurate and there is a severe weak identification problem in GMM estimations for NKPC. Therefore the common GMM estimation for γ_b and γ_f cannot convey useful information about the relative importance between the backward- and forward-looking parts of the NKPC.

The controversial empirical results likely result from the flat area of GMM target function. Kleibergen and Mavroeidis (2009) use the MQLR statistic to test GMM parameters for the presence of the weak identification problem. The MQLR statistics is based on the S statistics of Stock and Wright (2000) and the Lagrange Multiplier (LM) statistics of Kleibergen (2002)[3]. Kleibergen and Mavroeidis (2009) suggest that the MQLR statistics are more effective than the statistics of Stock and Yogo (2005), based on the minimum rank of covariance of the instrument variables. Kleibergen and Mavroeidis (2009) estimate the NKPC using the CUE and construct a confidence interval using the MQLR statistic. It is found that there is obvious forward-looking behaviour in the US inflations but the confidence interval is very wide. In particular, the estimated γ_b and γ_f are 0.230 and 0.773 respectively. The confidence interval are [-0.062, 0.451] and [0.531, 1.091] respectively. This result shows that the low bound of the γ_f is larger than the upper bound of the γ_b based on the weak instrument robust statistics.

In the work of Dufour, Khalaf, and Kichian (2006), the LM test provided by Kleibergen (2002) is used to estimate the NKPC for the US. It is found that the estimated γ_b and γ_f are 0.39 and 0.6 respectively. However, the estimated confidence interval is wide. They are [0.1, 0.6] for γ_b and [0.35,

[3]See further explanations for the MQLR statistic and S-statistic in Kleibergen and Mavroeidis (2009).

0.9] for γ_f. This result is not as strong as that in Kleibergen and Mavroeidis (2009) but still reveals a roughly dominant role for the forward-looking part of the NKPC in the US. Nason and Smith (2008) use the AR statistic to test the parameters of the NKPC[4]. However, they find that the forward-looking behaviour of the NKPC is not significant. In the work of Dufour, Khalaf, and Kichian (2006), the confidence interval is derived from the AR statistic while in the work of Nason and Smith (2008), the relevant parameters are tested based on the AR statistic directly. It is argued that a wide confidence interval usually corresponds to a rejection of the hypothesis about the dominant forward-looking behaviour of NKPC. In general, the weak identification problem is a severe issue in GMM estimation for the NKPC and must therefore be considered in the estimation process based on GMM.

For China, some scholars have estimated the NKPC using GMM. However, these works do not consider the impact of weak identification on the estimated parameters. For example, Guo, Ai, and Zheng (2013) estimate the NKPC based on GMM and find that the adaptive expectation component is stronger than the rational expectation one when using the CPI rate as the measurement for inflation. If the RPI rate is used as the measurement for inflation, the forward-looking part rather than the backward-looking part is dominant. Based on GMM, Yang (2009) finds that inflation has both a forward- and backward-looking part. If inflation is measured by CPI, the forward-looking part in NKPC is dominant. If it is measured by RPI, the backward-looking part is dominant. The works of Guo, Ai, and Zheng (2013) and Yang (2009) are both based on GMM, and using different samples they get opposite empirical results. This might be due to the weak identification problem reviewed above.

The difference between the forward- and backward-looking NKPC is im-

[4] AR statistic is from Anderson and Rubin (1949) and is an invariant statistic used to eliminate influences from nuisance parameter. See Anderson and Rubin (1949) and Kleibergen and Mavroeidis (2009) for further details.

portant because the policy implicationsfor these two types of Phillips curve are entirely different. The forward-looking part of NKPC results from the rational expectations of producers while the backward-looking part results from their adaptive expectations. For the rational expectation case, inflation is determined by producers expectations about the output gap in the future. More precisely, the current inflation is the sum of the discounted output gap in the future. However, in the case of adaptive expectation, the current inflation is determined by the shocks to the economy in history. From the perspective of monetary policy, the central bank has to consider the impact of monetary policy on output in the future. However, if the NKPC is forward-looking, the government should focus on expectation management rather than considering the impact of historical policies and shocks. In this way, expectation management will be of great importance in the work of the central bank.

Based on the review above, we note that the NKPC has been estimated widely using GMM for the industrial economies. China is now an important player in the global economy and understanding of its inflation behaviour will be beneficial to both economic research about the China economy and policy makers of countries which have close economic relationship with China. The weak identification problem of NKPC estimation is widely documented using Europe and the US data. In the case of Chinese data, however this problem is not thoroughly examined. Thus, this study thus aims to examine the possible outcome of weak instruments in estimating the NKPC, based on which the NKPC will be estimated using weak instrument robust statistics.

2.3 Test For Weak Instruments

2.3.1 Weak Identification and Hypothesis Test

Based on the shape of GMM target function, weak identification means the target function is relatively flat around the true value of the parameter. When the moment condition is linear, GMM and GIV (generalised instrument variables) estimates are equivalent. For instrument variables, there are two requirements: validity and relevance. Validity means that instrument variables must be exogenous, i.e. not correlated with the regression error term. Relevance refers to the correlation between instrument variables and endogenous variables. If the correlation is high, the instrument variables are strong. Otherwise, the instrument variables are weak. The following example is from Mavroeidis (2005) and will be used to explain the impact of a weak instrument.

$$y_1 = Y\beta + X_1\gamma + u \tag{2.3}$$

$$Y_2 = X_2\Pi + X_1\bar{\Gamma} + v \tag{2.4}$$

In equation (2.3) and (2.4), y_1 is the observed $T \times 1$ dimension dependent variable. Y_2 is the observed $T \times 1$ dimension endogenous variable. $X \equiv [X_1, X_2]$ is the observed $T \times K$ dimension instrument variables in which X_1 contains the exogenous variables in equation (2.3) and X_2 contains the exogenous variables used as additional instrument variables in equation (2.4). For analytical convenience, suppose $X_1 = 0$: that is, there are no exogenous variables in equation (2.3). u and v are the regression errors. Both of them are normally independent and identically distributed. That is, $[u_t \ v_t] \sim N(0, \Sigma)$ for $t = 1, \ \ldots \ , T$. Σ is a symmetric matrix with diagonal elements σ_u^2 and σ_v^2. The left bottom element of Σ is σ_{uv}. Define $\rho \equiv \sigma_{uv}/(\sigma_u\sigma_v)$.

The weakness or strength level of the instrument variables can be measured by what is known as the concentration parameter. If the concentration parameter is higher than zero, the parameters can be identified. If the concentration parameter is zero, the parameters can only be identified partially, or cannot be identified (Mavroeidis, 2005). In this example, the concentration parameter μ can be defined as $\mu^2 \equiv \Pi' X' X \Pi / \sigma_v^2$.

In this definition of the concentration ratio, the numerator is the variance explained by the instrument variables while the denominator is the variance of the residuals. A strong instrument variable implies a small regression residual and thus a large concentration parameter μ. The two-stage least square (2SLS) estimator β^{2SLS} can be written as $\beta^{2SLS} = (Y_2' P_X y_1)/(Y_2' P_X Y_2)$, where $P_X = X(X'X)^{-1}X'$ is the projection operator. Put $Y_2' P_X y_1$ and $Y_2' P_X Y_2$ into $\beta^{2SLS} - \beta$ and expression (2.5) for the concentration parameter can be derived.

$$\mu(\beta^2 SLS - \beta) = \frac{\sigma_u}{\sigma_v} \frac{x_u + S_{uv}/\mu}{1 + 2x_v/\mu + S_{vv}/\mu^2} \tag{2.5}$$

In (2.5), $x_u = (\Pi' X' u)/(\sigma_u \sqrt{\Pi' X' X \Pi})$, $z_v = (\Pi' X' v)/(\sigma_v \sqrt{\Pi' X' X \Pi})$, $S_{uv} = (v' P_X u)/(\sigma_u \sigma_v)$, and $S_{vv} = (v' P_X v)/\sigma_v^2$. If the instrument variables are not random, the two newly defined variables x_u and x_v are two standard normally-distributed random variables. S_{uv} and S_{vv} have a quadratic form based on identity matrix P_X. Because the x_u, x_v, S_{uv} and S_{vv} are all independent of the sample size T, the sample size can only influence the distribution of the two-stage least squares estimator $\beta^2 SLS$ through the concentration parameter μ.

Based on the definition, it can be seen that the concentration parameter is an increasing function of the sample size T. When μ becomes relatively large, μ^2 will be even larger. Moreover, it can be found that $\mu \in [0, \infty)$. Therefore, the two-stage least squares estimator can generate consistent estimates if the sample is large enough or the instrument is strong enough. The impact of S_{uv}, S_{vv}, and x_v will decrease gradually with the increase of the concentration parameter μ. Finally, $\mu(\beta^{2SLS} - \beta)$ will retreat to a normal distribution $N(0, \sigma_u^2/\sigma_(v)^2)$. Therefore, when the concentration parameter is large, i.e. when the instrument is strong or the sample is large enough, the inference based on the large sample asymptotic normal distribution is valid. However, when μ^2 is small, the distribution of $\mu(\beta^{2SLS} - \beta)$ will deviate away from normal distribution such that the asymptotic normal distribution will not be valid anymore. In fact, neglecting the quadratic term S_{uv} and S_{vv}, the $\mu(\beta^{2SLS} - \beta)$ follows a Cauchy distribution which has no limited mean (Hansen, 2016). When μ^2 is 0, then $\Pi = 0$, and $E(\beta^{2SLS} - \beta) = \text{plim}(\beta^{OLS} - \beta) = \sigma_u Y/\sigma_Y^2$. Define $E(\beta^{2SLS} - \beta)/\,\text{plim}(\beta^{OLS} - \beta)$ as the relative bias of the two-stage least square[5].

In the case of under-identification, the relative bias is 1. Thus, the two-stage least squares estimator cannot provide any improvement compared to the OLS estimator. The endogeneity implies that $\sigma_u Y \neq 0$, which means that both the OLS and the two-stage least squares estimator cannot provide a consistent estimation of β in the case of under identification. In the case of weak identification, the instrument estimation approaches the OLS estimator in the limit. Therefore, GMM, General Instrument Variable (GIV), and two-stage least square estimators in fact approach the OLS estimator under the condition of weak instruments. Moreover, under weak identification, because the asymptotic distribution of the estimators is not normal, the constructed t statistic and relevant confidence interval is not reliable (Mikusheva, 2013).

2.3.2 Test for Weak Identification

As illustrated above, the weak identification problem leads to inconsistent estimation and unreliable confidence intervals, based on the concept of the

[5] plim is the probability limit operator.

concentration parameter μ. Econometrically, we need to determine a critical value for μ above which the instrument variables are strong, otherwise the instrument variables will be weak.

In general, there are two methods of determining the critical value for μ. The first method is based on the relative bias between the 2SLS estimator and the OLS estimator,$E((\beta^{2SLS} - \beta)/\operatorname{plim}\beta^{O}LS - \beta$. For example, if the relative bias is larger than 10 per cent, the instrument variable is deemed to be weak. The 10 per cent here is quite arbitrary because it depends on researchers' tolerance for bias. The second method of determining the critical value is through the size of the test, i.e. the probability of rejecting the true hypothesis. In a regression satisfying all classical assumptions, the significance level implies a probability of rejecting the true hypothesis.

However, a weak instrument will distort the probability of rejecting the true hypothesis. In particular, a weaker instrument usually implies a larger type I error in the regression with endogenous variables. The second method of determining the critical value of the weak instrument variable is thus based on the concept of type I errors. In particular, if the significance level is 5 per cent, a 10 per cent type I error might be acceptable while a 15 per cent or 20 per cent type I error might imply that the instrument variables are too weak. Stock and Yogo (2005) prove that a certain level of μ^2/K corresponds to a 10% relative bias for the first method and a 10% test size for the second method, where K is the number of the instrument variables.

For GMM with only one endogenous variable, the F Statistic in the first stage regression depends only on μ^2/K and K. Thus, in the case of a single endogenous variable, the weak instrument test can be conducted based on the F Statistic. This F Statistic is proposed by Cragg and Donald (1993) and constructed based on the idea of examining the minimum rank of the covariance matrix between endogenous and instrument variables, given the exogenous variables. For different values of K, Stock, Wright, and Yogo (2002) propose the critical values of μ^2/K and the F statistic, as in Table 2.1.

Table 2.1: Critical Value for Weak Instrument Test in 2SLS

K	Relative Bias >10%		Actual Test Size > 15%	
	μ^2/K	F Statistic	μ^2/K	F Statistic
1			1.82	8.96
2			4.62	11.59
3	3.71	9.08	6.36	12.83
5	5.82	10.83	9.20	15.09
10	7.41	11.49	15.55	20.88
15	7.94	11.51	21.69	26.80

K is the number of instrument variables. Actual Test Size > 15% is calculated under 5% significance level. F statistic in the third column refers the critical value of first stage F statistic in 2SLS used to test the null that μ^2/K is less than or equal to the value in the second column against the alternative that μ^2/K exceeds that value. The final two columns present the analogous weak-instrument thresholds and critical values when weak instruments are defined so that the usual nominal 5% 2SLS t test of the hypothesis $\beta = \beta_0$ has size potentially exceeding 15%. This table is from Stock, Wright, and Yogo (2002).

In Table 2.1, the first column is the number of the instrument variables K. The second column is the critical value for a relative bias no higher than 10 per cent for different values of K. As the F Statistic depends only on the value of μ^2/K and K, the third column gives the critical value for F corresponding to the μ^2/K and K. As the F Statistic in the first stage regression can be easily calculated and is usually reported in most econometric software, the F Statistic criteria is more convenient. When the F Statistic is higher than the critical value, it can be inferred that the instrument variables in the first stage regression are strong. Otherwise, it can be inferred that the instrument variables are weak. In the third and fourth columns, the relevant critical values for μ^2/K and corresponding F Statistic are listed.

For example, when there are five instrument variables in the first stage regression, an estimated F value larger than 10.83 implies no weak instrument problem with a relative bias smaller than 10 per cent. However, if the estimated F value is smaller than 10.83, this is a sign of weak instrument.

Nevertheless, if based on the actual test size larger than 15 per cent under $\alpha = 5\%$, to reject the null hypothesis of a weak instrument the estimated F value should be larger than 15.09 . Stock, Wright, and Yogo (2002) proposed a rule of thumb. That is, if the F statistic is higher than 10% in the first stage regression, it can be concluded that there is no weak instrument problem.

In the examples above, the case of a single endogenous variable is considered. If there is more than one endogenous variable, the Cragg-Donald F statistic can be used to conduct the weak instrument test. The Cragg-Donald F statistic is an extension of the first Stage F statistic in 2SLS and is based on the correlation between the instrument variables and the endogenous variables. This statistic is constructed based on the minimum rank of the covariance matrix between the endogenous variables and the additional exogenous variables in the second stage regression. Further discussion of Cragg-Donald F can be found in Stock and Yogo (2005). The main purpose of this study is to examine the endogeneity problem of expected inflation in the NKPC. Thus, the single endogeneity variable case will be discussed in this study. Moreover, in the following empirical part of this study, it is found that the driving force variable is not endogenous, based on a formal test for endogeneity.

2.3.3 Weak Identification Robust Statistics

The weak identification problem distorts the size of the test, leading to inaccuracy of the Wald and likelihood ratio tests. The relevant confidence interval that is constructed based on these tests is also unreliable. The main reason for the distortion of the Wald and likelihood ratio statistics is that these tests will be influenced by other parameters besides those to be tested. These parameters are called nuisance parameters. Thus, the point of weak identification robust statistics is to construct a statistic related only to the parameters to be tested. These statistics are called pivotal statistics.

Put equation (2.7) into (2.6) and define $Y = [y_1, Y_2]$, $M_X = 1 - X(X'X)^{-1}X'$, and $Z = M_{X_1}X_2$. Then equations (2.3) and (2.4) can be rewritten as (2.6) and (2.7) respectively.

$$y_1 = Z\Pi\beta + X_1\delta + u_1 \tag{2.6}$$

$$Y_2 = Z\Pi + X_1\Gamma + v \tag{2.7}$$

In equations (2.6) and (2.7), $\Gamma = \bar{\Gamma} + (X_1'X_1)^{-1}X_1'X_1\Pi$, $\delta = \Gamma\beta + \gamma$. By construction, $[Z, X_1]$ is a pair of orthogonal variables. The independently and identically distributed regression error vector $V = [v_1, V_2]$ has a covariance matrix $\Omega = [\omega_{i,j}]$. As Ω is unobservable, it is replaced using its consistent estimator $\Omega = Y'M_ZY/(T-K)$ (Stock, Wright, and Yogo, 2002). As Z and X_1 are orthogonal, the parameter $[\gamma, \Gamma]$ and $[\beta, \Pi]$ can be determined by the distribution of $X_1'Y$ and $Z'Y$ respectively.

In this case, the main focus is to test the null hypothesis of $\beta = \beta_0$. However, in equation (2.6), the parameter β shows up in the regression coefficient together with Π. Thus, it is difficult to conduct a hypothesis test for β directly. The main idea here, as mentioned above, is to find a statistic which is sufficient for β without the influence of the nuisance parameter Π.

Using a linear transformation of X_1, the impact of $[\gamma, \Gamma]$ in the estimation can be eliminated to construct a statistic which is only related to $[\beta, \Pi]$ (Moreira, 2009). Define $S_\beta \equiv Z'Yb_0$ and $T_\beta \equiv Z'Y\Omega^{-1}a_0$, where $b_0 = (1, -\beta_0)'$ and $a_0 = (\beta_0, 1)'$ is a pair of orthogonal vector. Under the null hypothesis of $\beta = \beta_0$, S_β and T_β are a pair of independent normally distributed variables. Moreover, S_β is independent from Π while T_β depends on Π. Therefore, the invariance sufficient statistic $Z'Y$ for $[\beta, \Pi]$ has been partitioned into two parts. Under the null hypothesis of $\beta = \beta_0$, a sufficient statistic for Π can be constructed. Based on the conditional Π, relevant tests can be constructed which are pivotal and do not depend on the nuisance parameter Π. Based on this idea, several statistics robust to the weak identification problem have been proposed including the Anderson and Rubin (1949) AR statistic, Kleibergen (2002) LM statistic, and the Moreira (2003) conditional likelihood ratio (CLR) statistic.

Anderson and Rubin (1949) propose the AR statistic to test the null hypothesis of $\beta = \beta_0$. The AR statistic is constructed as $AR(\beta_0) = S'_\beta S_\beta$. Under the null hypothesis, the AR statistic follows a χ^2 distribution with k degree of freedom. Moreira (2003) proves that AR is the optimal statistic when GMM is exactly identified. However, the rejection of the AR statistic can result either from $\beta \neq \beta_0$ or the failure of the orthogonal condition. Thus, when the AR statistic is significantly different from zero, it is necessary to check the orthogonal condition before rejecting the null hypothesis. Moreover, when GMM is over-identified, the AR statistic is not optimal because the degrees of freedom for χ^2 are larger than the number of parameters tested (Moreira, 2003).

Kleibergen (2002) proposes an LM statistic to improve the AR statistic. It is defined as $LM(\beta_0) = (S'_\beta T_\beta)^2/(T'_\beta T_\beta)$. In the case of $K = 1$, the AR test and the LM test are equivalent. Kleibergen (2002) proves that $LM(\beta_0)$ follows a χ^2_1 distribution regardless of whether the instrument variables are strong or weak. The conditional likelihood ratio statistic is proposed by Moreira (2003), and defined as (2.8).

$$
\begin{aligned}
&CLR(\beta_0) = \\
&\frac{1}{2}\Big(S'_\beta S_\beta - T'_\beta T_\beta + \sqrt{(S'_\beta S_\beta + T'_\beta T_\beta)^2 - 4[(S'_\beta S_\beta)(T'_\beta T_\beta) - (S'_\beta T_\beta)^2]}\Big)
\end{aligned} \tag{2.8}
$$

The distribution of $CLR(\beta_0)$ is not a standard one and Moreira (2003) suggests using simulation to find the critical values. Because of the low efficiency of the simulation, Andrews, Moreira, and Stock (2006) propose another more efficient approach to find critical values. For the AR, LM, and CLR statistics, the type I errors equal the significance levels. Thus, the confidence interval can be correctly constructed based on these statistics. In particular, the AR statistic is robust to model misspecification and can be used to test over-identification. The LM statistic is less efficient than the CLR statistic, which implies a wider confidence interval. Moreover, the probability of type II errors in the CLR statistics is smaller than those of the AR and LMtest (Mikusheva and Poi, 2006). Thus, the CLR statistic is more powerful. In the following empirical research on the NKPC, the CLR statistic will be used for hypothesis testing and confidence interval construction.

2.4 Weak Instrument Test and Estimation of NKPC

2.4.1 Data and Regression Model

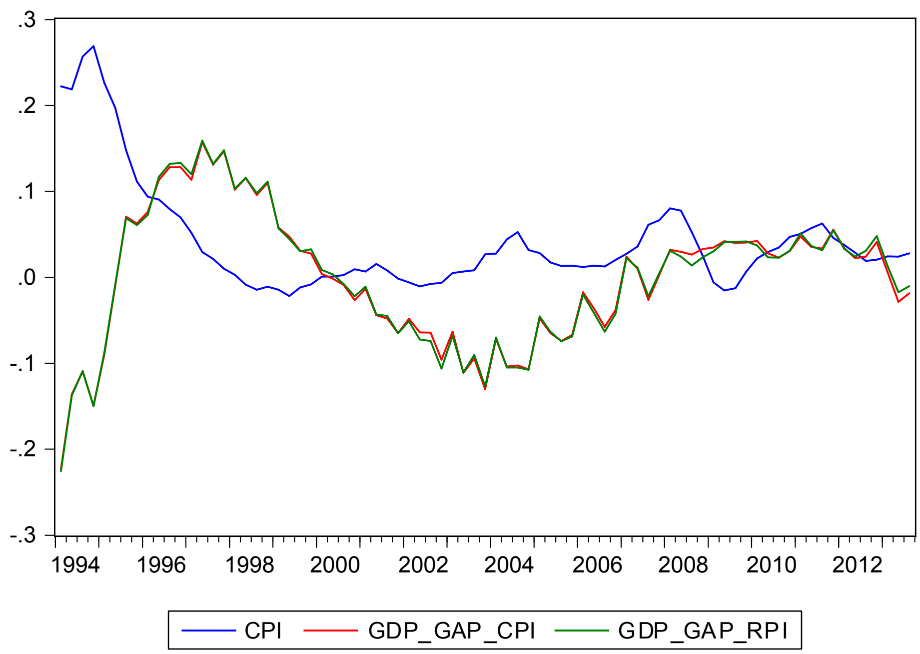
In this study, quarterly data from Quarter 1 1994 to Quarter 3 2013 are used to estimate the NKPC, covering 79 observations. The variables include nominal GDP, CPI, and RPI. All the data are from the Statistic Bureau of China (SBC henceforth) [6]. The main reason for using Quarter 1 1994 as a starting point for the sample is that there was a large scale economic reform launched at the end of 1993 and in early 1994. There were economic reforms in areas including monetary policy, the exchange rate regime, and the tax system. Because of the influences of these reforms, a structural change is likely. A longer sample period from 1994 is used to check for possible changes before and after 2001. Moreover, there were no large monetary policy reforms launched after 1994. Subsample estimation can used to test for possible changes in the parameter estimations.

[6] http://www.stats.gov.cn/

Implicit and explicit price controls have prevailed in China, especially before 1994 when the Chinese government officially admitted the socialist market economy system. Price controls may cause at least two distortions of the estimation results. First, the measurement errors for expectation may be larger because of price controls. Second, the price controls may impose influences on the price expectation itself. Thus, the pre-1994 data sample is not used in this study. Nevertheless, some forms of price controls still existed after 1994. These control prices were usually biased above or below their fair price for a sustainable time. For example, there were consistently subsidies for agricultural products. These persistent biases may have limited influence on overall price levels because the subsidies were relatively stable over time. Thus, we expect that the influences will not be systematic because in general most of the prices are determined by the market, at least officially.

Nominal GDP has a seasonal feature and should be adjusted. The method used in this study is to introduce seasonal dummies to eliminate the seasonal effects. This method was also adopted by Guo, Ai, and Zheng (2013) and Xie and Luo (2002). In the calculation of real GDP, the GDP deflator should be used in general. However, the SBC does not publish relevant data for the GDP deflator. Once again, this study follows the method of Guo, Ai, and Zheng (2013) and Xie and Luo (2002) by using the CPI or RPI to change the nominal GDP into the real GDP.

The specific treatment for the GDP data is as follows. The CPI-based real GDP is defined as $\mathrm{GDP}^{\mathrm{c}} = \mathrm{GDP}^{\mathrm{n}}/\mathrm{CPI}$, and RPI-based real GDP is defined as $\mathrm{GDP}^{\mathrm{r}} = \mathrm{GDP}^{\mathrm{n}}/\mathrm{RPI}$, where $\mathrm{GDP}^{\mathrm{n}}$ is the nominal GDP. After calculating the real GDP, three seasonal dummy variables are defined. The real GDP is regressed on these three dummy variables and a polynomial time trend. The residuals are deemed the GDP or output gap. Mavroeidis, Plagborg-Møller, and Stock (2014) emphasize the importance of data availability when estimating the NKPC. Alternative measures of output gap can include labour income share in the non-farm business sector, as in the work of Galí and Gertler (1999). In China, the seasonal data for the non-farm business sector are only available from 2005 Q1, and annual data are available before 2005. This restricts the use of labor income share in the non-farm business sector as a measure of the output gap unless a shorter sample period is used. A mixed data sampling method may be used to cover this issue and this is a possible direction for future work.



Data are complied from National Bureau of Statistics of China. All variables are in percentage terms.

Figure 2.1: Inflation and Output Gaps

CPI and RPI are the price indices for consumers and retail products in the economy. The data provided by the CSB has a monthly frequency. The quarterly data of the CPI and RPI is the arithmetic average of the three-month CPI or RPI within the quarter. The measure used for the CPI and

RPI is the ratio of the relevant price at a given month in one year to the price level at the same month in the previous year. In the regression, the CPI and RPI measures are expressed in percentage terms and deducted by 100. For example, if the CPI is 106.5, 6.5 will be used in the regression. Figure 2.1 gives the plot of the inflation and output gaps.

Table 2.2: ADF Test Results

Series	Prob.	Lag	Max Lag	Obs
CPI	0.0085	5	11	73
RPI	0.0109	5	11	73
GDP gap(CPI)	0.0067	5	11	73
GDP gap(RPI)	0.0060	5	11	73

In order to test for a unit root of the GDP gap, CPI and RPI, the ADF statistic is used. The ADF test results are presented in Table 2.2. The relevant p value of the ADF statistic for the GDP gap, CPI and RPI are all smaller than 1 per cent. It is suggested that the CPI, RPI, and GDP gaps adjusted using CPI and RPI are all stationary. The PP test results for unit root are similar and thus not presented here. Using these data, equation (2.9) will be regressed.

$$\pi_t = \lambda gdp_t + \gamma_f E(\pi_{t+1}) + \gamma_b \pi_{t-1} + \tilde{u}_t \tag{2.9}$$

In equation (2.9), gdp_t is the real output gap calculated based on CPI or RPI. The inflation rate π_t is measured using CPI or RPI. $\tilde{u}_t$ is the regression error which is white noise under the rational expectation hypothesis. It should be noticed that the sum of the forward looking and backward looking weights should be less than one. Otherwise, there will be a problem of unit root.

In the regressions, expected inflation $E(\pi_{t+1})$ is replaced by actual inflation π_{t+1} which leads to the problem of endogeneity, as explained above. The moment condition for GMM is $E\tilde{u}_t Z_t = 0$ where Z_t is the set of instrument variables. If inflation is measured using the CPI (or RPI), the instrument variables include the CPI (or RPI) lagged in three periods and the relevant GDP lagged in three periods. For example, the instrument variables set is $\{\pi_{t-1},\ \pi_{t-2},\ \pi_{t-3},\ gdp_t,\ gdp_{t-1},\ gdp_{t-2},\ gdp_{t-3}\}$. The reason for choosing the three-period lagged instrument rather than the four-period one, as in Galí and Gertler (1999), will be discussed below.

Compared to the work of Guo, Ai, and Zheng (2013), this study is different in two aspects. Firstly, this study adopts fewer instrument variables. There are many more instrument variables in the work of Guo, Ai, and Zheng (2013), which might lead to a problem of too many instrument variables (Hansen, Hausman, and Newey, 2012). The number of observations in the sample is also relatively small, which might lead to a high estimation error in regression. Secondly, there is only a one-period lag of inflation shown in equation (2.2). That is, only π_{t-1} is included. Nason and Smith (2008)) suggest that higher lagged inflation will lead to a more severe weak identification problem because the instrument variables will have an even smaller relation to the endogenous variable. Moreover, in the estimations of Guo, Ai, and Zheng (2013), it is found that the two-period lagged inflation has a significant but very small coefficient. Thus, the hybrid NKPC in this study adopts only one period of lagged inflation.

2.4.2 Weak Identification Test and Estimation

In the section, the full sample data will be used for the weak identification test and robust estimation. In Table 2, the second and third columns give the Sargan statistic for testing over-identification. The estimated statistics for CPI and RPI are 2.864 and 5.139 respectively. The relevant p values are 0.4131 and 0.1619. The null hypothesis for the Sargan test is that the over-identified instrument variables are not related to the regression error. If the four-period lagged inflation is included in the instrument variables set, the p value for the Sargan test is smaller than 1 per cent, implying a rejection of the null hypothesis. Thus, four-period lagged inflation is related to the regression error and is an invalid instrument. If one-, two-, three-, and five-period lagged inflation are included in the instrument variables set, the p values are higher than 10 per cent. This confirms that four-period lagged inflation is correlated with the regression error of equation (2.6). One explanation for this correlation is that there might be still some seasonal effect of the GDP even after the seasonal adjustment procedure described above. This over-identification test result is different from that seen in Guo, Ai, and Zheng (2013) where the four-period lagged inflation is used as the instrument variables as well. Because the four period lagged inflation is not a valid instrument, only three-period lagged inflations are used as instrument variables.

In Table 2.3, the Cragg-Donald F statistics are reported to examine the possible weak identification problem. The fourth row gives the estimated Cragg-Donald F statistics, which are 8.282 and 8.183 for CPI and RPI respectively. From the sixth row to the last row of Table 2.3, the critical values of the Cragg-Donald F statistic are reported for different levels of relative bias and test size. The critical values for 5 per cent,10 per cent, 20 per cent and 30 per cent relative bias are provided in the rows from the sixth to the ninth. It is found that the estimated Cragg-Donald F is between the critical value of 20 per cent and 10 per cent, for both the case of CPI and RPI. This suggests that the instrument variable estimation for NKPC will generate an estimated γ_f with a relative bias larger than 10 per cent but smaller than 20 per cent, for both the case of CPI and RPI. The critical value for 10 per cent, 15 per cent, 20 per cent and 25 per cent test size are provided in the rows from the tenth to the last. It can be found that the estimated Cragg-Donald F statistic is lower than the critical value of 25 per cent test size, for both the case of CPI and RPI. This suggests that the instrument variable estimation for NKPC will generate an estimated γ_f with a type I regression error higher than 25 per cent, for both the case of CPI and RPI. In particular, under the significance level of 5 per cent, the confidence interval only has a probability less than 75 per cent to cover the true value of γ_f.

Table 2.3: Weak Identification Test for GMM Estimation of NKPC, 1994Q1 -2013Q3

Inflation Measurement	CPI	RPI
Sargan Over-identification Statistic	2.864	5.139
p value	0.413	0.162
Cragg-Donald F Statistics	8.282	8.183
Critical Values		
At Most 5% Relative Basis		16.85
At Most 10% Relative Basis		10.27
At Most 20% Relative Basis		6.71
At Most 30% Relative Basis		5.34
At Most 10% Test Size		24.58
At Most 15% Test Size		13.96
At Most 20% Test Size		10.26
At Most 25% Test Size		8.31

Critical Values of Cragg-Donald F statistics are from Stock and Yogo (2005).

Thus, based on these two methods of testing the weak instrument problem, it can be concluded that there is a weak identification problem in NKPC estimation using GMM for this Chinese data. The confidence interval constructed by Guo, Ai, and Zheng (2013) using 2SLS might be unreliable. Following this section, we will estimate the NKPC using the continuous-updating estimator (CUE) of GMM and construct a confidence interval for γ_f based on the CLR statistic which is robust to the weak instrument problem.

Table 2.4 gives the estimation results using CUE. Because CUE is sensitive to a weak instrument, it can provide a robust point estimation for the parameter. In Table 2.4, the last row of the panel for CPI and RPI empirical

Table 2.4: CUE for NKPC, Sample of 1994Q1-2013Q3

	Value	Std Error	t	p-value	95% CI
γ_f^{CPI}	0.672	0.074	9.031	0.000	[0.526,0.818]
γ_b^{CPI}	0.403	0.053	7.562	0.000	[0.299,0.508]
λ^{CPI}	-0.003	0.011	-0.29	0.771	[-0.026,0.019]
Cragg-Donald F Statistic					8.282
γ_b^{RPI}	0.642	0.076	8.402	0.000	[0.492,0.791]
γ_b^{RPI}	0.426	0.054	7.821	0.000	[0.319,0.533]
λ^{RPI}	-0.549	1.207	-0.451	0.642	[-2.915,1.817]
Cragg-Donald F Statistic					8.183
Critical value for at most 10% Type 1 Error					5.44

Critical Values of Cragg-Donald F statistics are from Stock and Yogo (2005). CI refers to confidence interval. Superscripts CPI and RPI refer to the case using CPI and RPI measured inflation respectively.

results give the Cragg-Donald F statistics under CUE. The estimated value is 8.282 and 8.183 for CPI and RPI respectively, which are both higher than the critical value at the 10 per cent test size. Thus, under the null hypothesis and the 5 per cent significance level, the type I error of the relevant confidence interval will be no higher than 10 per cent. Thus, the relevant interval can cover the true value of γ_f at a probability of 90 per cent.

Table 2.5: Confidence Interval for γ_f based on CLR Statistic

	Value	p-value	95% CI
γ_f^{CPI}	0.672	0.000	[0.516,0.877]
γ_f^{RPI}	0.642	0.000	[0.471,0.854]

CI refers confidence interval. Superscripts CPI and RPI refer the case using CPI and RPI measured inflation respectively.

In the case of CPI as the measurement for inflation, the estimated forward-looking and backward-looking parameters are 0.672 and 0.403 respectively[7]. The confidence intervals are [0.526,0.818] and [0.299,0.508].

[7]Unfortunately, we cannot provide a formal statistical test about which coefficient of the forward- and backward looking part is larger. In fact, we just compare the estimated

Based on this result, it is clear that the forward-looking part is much higher than that of the backward-looking parameter in NKPC. Moreover, the lower bound of the interval for γ_f is higher than that for γ_b . Thus, the forward-looking parameter has a dominant role in the NKPC based on these estimation results. Moreover, as the size is 10 per cent, this conclusion is reliable. However, the backward-looking coefficient is 0.4 with a lower bound of 0.299. This implies that the backward-looking parameter is still relevant.

Table 2.6: Weak Identification Robust Estimation using Subsamples

	1994Q1-2003Q4			2004Q1-2013Q3		
	Value	p-value	95% CI	Value	p-value	95% CI
γ_f^{CPI}	1.044	0.000	[0.492,13.670]	0.578	0.000	[0.450,0.713]
γ_b^{CPI}	0.127	0.413	[-0.178,0.433]	0.544	0.000	[0.450,0.640]
γ_f^{RPI}	1.431	0.000	$(-\infty,+\infty)$	0.605	0.000	[0.469,0.761]
γ_b^{RPI}	-0.143	0.619	[-0.705,0.420]	0.551	0.000	[0.451,0.652]

CI refers to confidence interval. Superscripts CPI and RPI refer to the case using CPI and RPI measured inflation respectively.

In the case of RPI measurement for inflation, the estimated forward-looking and backward-looking parameters are 0.642 and 0.426 respectively. The confidence intervals are [0.492, 0.791] and [0.319,0.533]. Compared with the results in the case of CPI measurement for inflation, the difference between the point estimates of γ_f and γ_b is smaller. Moreover, there is a small overlap between the intervals for the two coefficients. Therefore, it cannot be concluded that γ_f is dominant. However, a conclusion that forward-looking behaviour is the major part of the NKPC is still reasonable. Similar to the case of CPI measurement for inflation, the backward-looking component is still relevant.

Based on the results in the CPI and RPI case, these empirical results

values of forward- and backward coefficients informally as Galí and Gertler (1999).

are quite different from Guo, Ai, and Zheng (2013) who find that backward-looking component is stronger. However, because the work of Guo, Ai, and Zheng (2013) may suffer from the problem of the weak identification, the results in this study are more robust.

In Table 2.4, the size of the confidence interval provided does not equal the significance level because of distortions from the weak instrument variables. Although the type I error is not larger than 10 per cent, a more accurate confidence interval can be constructed based on the weak identification robust statistics. As mentioned above, AR statistics are optimal in the exact identification case but not if the model is over-identified. In this study, the instrument variables exceed the number of endogenous variables. Thus, the AR statistics are not optimal.

The CLR statistic will be used because it is more efficient than the LM statistic, as an improved version of the AR statistics for over-identified models. In Table 2.5, the relevant point estimates and confidence intervals are presented. It can be found that the point estimates for γ_f are the same as those in Table 2.4. However, the 95 per cent confidence interval is wider. This wider interval is mainly due to the robust reason to cover the true value of the forward-looking parameter. It can be found that the modified confidence interval inverted from the CLR statistic is [0.516,0.877] at the confidence level of 95 per cent for the case of CPI measured inflation. The lower bound of the modified interval is 0.5168, which is still higher than the upper bound of the interval for γ_b in Table 2.4. Thus, for the case of the CPI measured inflation, the forward-looking behaviour is still in the dominant position.

As to the RPI measured inflation, it can be seen in Table 2.5 that the interval inferred from the CLR statistic is [0.471, 0.854] at a confidence level of 95 per cent. The lower bound for this interval is 0.471, which is lower than the upper bound of the correspondent γ_b in Table 2.4. The exact difference between these two bounds is 0.06, which is about 1/6 the size of the confidence interval for γ_f. Therefore, the conclusion for RPI is similar to that for CPI in that forward-looking behaviour does not dominate.

The empirical results from the CLR inferred confidence interval are similar to the results derived from the CUE estimator. However, the analysis based on the CLR inverted confidence interval is more robust because it is not influenced by nuisance parameters.

If the full sample is split into two samples at Q1 2004, the first and second will have 40 and 39 observations respectively. Using CUE to estimate the NKPC and construct the confidence interval based on CLR, the empirical results are summarized in Table 2.6. It can be found that in the first subsample, the forward-looking feature is obviously dominant. In particular, for the case of CPI, the estimated γ_f is 1.044, with a robust confidence interval of [0.492,13.670]. This confidence interval is very wide but something can still be inferred from the value of the lower bound, 0.492, which is higher than the upper bound of the backward-looking behaviour coefficient γ_b. This means that forward-looking behaviour is dominant in this period.

For the case of RPI, the point estimates are similar but the CLR inferred confidence interval for γ_f is $(-\infty, +\infty)$. The main reason for this is that the construction of the CLR interval is based on the solution of a quadratic function. In some cases, the quadratic function might have no solution, which results in a confidence interval like $(-\infty, +\infty)$. This kind of interval implies that the sample does not have enough information to provide proper inferences about the value of the parameter.

In the second subsample, the values of the estimated γ_f and γ_b have a more mixed pattern. That is, the forward- and backward-looking parts both play an important or roughly similar role in determining the inflation dynamics. The CUE point estimated γ_f is still higher than the estimated γ_b, but the CLR inverted confidence intervals for these two parameters overlap almost completely. Moreover, the cases for CPI and RPI measures are quite similar.

There are several issues about the subsample estimation results. Firstly, the inflation dynamics are not stable over time if the subsample estimation results are not robust. In the first half of the sample period, the inflation dynamics exhibit a strong forward-looking feature while in the second half, the forward-looking behaviour feature starts to retreat and adaptive expectation starts to play an important role in determining inflation. Based on historical monetary policy and inflation over the full sample period, it can be seen that in the first half sample period, the inflation fluctuations were very large. Under these conditions, it might be beneficial for producers to form rational expectation rather than just using the adaptive expectation.

In the second half of the sample period, China experienced a more stable economic environment with inflation fluctuations that were much smaller than in the previous subsample period. In this case, adaptive inflation might be enough to form inflation expectations because inflation in general is more stable. Secondly, the regression results for the full sample period are still meaningful because they can be used for comparison purposes with the previous studies, as explained in detail above. Thirdly, the subsample might suffer some econometric problems because the sample size is too small, which might lead to insufficient information for econometric tests and inferences.

Based on the weak identification test and estimation results, it is found that the NKPC in China has an obvious forward-looking feature. Moreover, the forward-looking behaviour is stronger than the backward-looking behaviour which is, however, not negligible. From the view of monetary policy, both the rational and adaptive expectations are important in the pricing process of producers. The central bank must not only consider for monetary policy on the future output gap but also on the past inflation trend. If the inflation trend in the recent past is high, more expansionary monetary policy will lead to few real effects. Only when the economy is in a status of low inflation for a period, will the expansionary monetary policy works because the adaptive expectation will generate inertia to inflation. The subsample empirical results suggest that adaptive expectations start to take the place of rational expectation in periods with lower inflation fluctuations.

2.5 Conclusion

This study mainly discusses the influences of the possible weak identification problem on the NKPC estimation using Chinese data. The relevant reasons for and influences of the weak identification problem are reviewed. Weak identification robust statistics were analyzed as well. Based on these reviews, the NKPC in China is tested and estimated using quarterly data. The weak identification problem mainly refers to the fact that the correlation between instrument variables and endogenous variables is weak. Because the change of inflation in NKPC is usually difficult to predict, the weak instrument problem is thus common in estimating the NKPC using GMM. The main consequences of the weak identification problem is that the relevant point is inconsistent and the confidence interval cannot cover the true value of the parameters at the given confidence level. The Cragg-Donal F statistic can be used to test the weak identification problem, and Stock and Yogo (2005) proposed a relevant critical value using simulation method. By partitioning the endogenous and exogenous variables, the relevant AR, LM and CLR statistics can be constructed and these statistics are robust to the weak identification problem. By inverting these statistics, the relevant confidence interval can be constructed. The size of the confidence interval equals to the confidence level, which solves the problem of distorted type I error implied by the confidence level in large sample GMM estimation.

In the empirical part, this study adopted quarterly Chinese data from Q1 1994 to Q3 2014, covering 79 observations. The CPI and RPI are used as measurements for inflation, and the GDP gap is used for the driving force variable in NKPC. The three-period lagged inflation and GDP gaps are used as the instrument variables. The Cragg-Donal F statistic estimated suggests that there is a weak identification problem when using the large GMM estimation. To solve this problem of weak identification, the CUE is used and relevant CLR inverted confidence intervals are constructed. The full sample empirical results suggest that the inflation dynamics in China have both a forward-looking feature and backward-looking one, and that while the forward-looking part is the major one, the backward-looking part is not negligible. The subsample results suggest that the backward-looking behaviour in the first ten years of the sample is not significant but the forward-looking part is significant. In the second ten years, the forward- and backward-looking behaviours are quite similar. This implies a tendency to more inflation inertia. This can be explained by a more stable inflation environment. The inflation fluctuation in the first decades is relatively larger than that in the second decade. The central bank should therefore consider past inflation paths together with the impact of future real GDP gaps on the current inflation.

Chapter 3

Chinese Capital Controls in a New Keynesian Model

3.1 Introduction

In November 2015, the International Monetary Fund (IMF) decided to include the Chinese Yuan (Renminbi, the RMB) in the Special Drawing Right (SDR) basket[1]. There are two criteria for the SDR basket currencies: the export criterion and the free use criterion. The free use criterion is closely related to capital account liberalization, although the IMF clarified that "*the concept of a freely usable currency, ... , is different from whether a currency is either freely floating or fully convertible*"[2]. In fact, the IMF rejected the inclusion of the RMB in the SDR basket in 2010, claiming that the RMB did

[1]The inclusion of the RMB in the SDR basket will push forward the reform schedule of the Chinese government. The relevant implications of this event for Chinese capital controls are discussed in my recent article published in the Foreign Affairs Review 2016, named "*China, the IMF and the Two-way Socialization of the Capital Account Liberalization*".

[2]IMF (2016) Review of the Special Drawing Right (SDR) Currency Basket, `https://www.imf.org/external/np/exr/facts/sdrcb.htm`

not satisfy the free use criterion[3].

The inclusion of the RMB in the SDR basket confirms the increasing convertibility of the RMB on the one hand, and indicates reflection on the full capital account openness advocated by the IMF since the Washington Consensus in 1989 on the other hand. In the 1990s, the full convertibility of the RMB in China was proposed as a reform target, while recently the central bank of China (People's Bank of China, PBC) seems to have switched from the full convertibility target to the managed convertibility target. The reform target of full capital account openness was modified to a managed convertibility in capital account, as proposed by the president of PBC, Xiaochuan Zhou, in the Thirty-First Meeting of the International Monetary and Financial Committee in April 2015[4].

Given this background, this study aims to empirically test whether China was able to achieve monetary policy autonomy under capital controls by estimating a Vector Error Correction Model (VECM), and theoretically examine the possible consequences of capital controls by constructing an open economy New Keynesian model with capital controls.

In the empirical section, it is found that China indeed achieved monetary policy autonomy, under a partially opened capital account and exchange rates regime in general pegging on the US dollar[5]. Using FDI inflows, the Shanghai Interbank Offered Rate (Shibor), the Federal effective rate, and the nominal the RMB/USD exchange rate, a VECM is tested and estimated, based on monthly data over the sample period from October 2006 to June 2015. It

[3] IMF (2010) IMF Executive Board Completes the 2010 Review of SDR Valuation, `https://www.imf.org/external/np/sec/pn/2010/pn10149.htm`

[4] Statement by the Honorable Zhou Xiaochuan Governor of the IMF for China to the Thirty-First Meeting of the International Monetary and Financial Committee

[5] See IMF(2006)De Facto Classification of Exchange Rate Regimes and Monetary Policy Framework, and IMF (2014) Annual Report on Exchange Arrangements and Exchange Restrictions

is found a long-run relationship exists between FDI inflows and interest rate differentials. The policy interest rates were not significantly influenced by the long-run relationship, while the exchange rates and capital inflows were significantly influenced by the long-run relationship. This means that PBC was able to choose levels of interest rates autonomously, but at capital inflows and exchange rates were mainly disciplined by the market.

These finding contradict the advocates of a strictly binding impossible trilemma, such as Fisher (2001) who claims that middle point exchange regimes, including the fixed pegging exchange regime, adjustable pegging exchange regime and narrow band exchange regime are not sustainable because of attacks from international capital. Empirical findings based on historical data imply the possibility of choosing some middle point of the impossible trilemma, but we still may have no clues about the appropriateness of choosing a middle point such as the managed currency convertibility proposed by Xiaochuan Zhou.

In the modelling section, the appropriateness and consequences of capital controls are examined using an open economy New Keynesian model. It is found that capital controls transform dramatic and immediate changes in deposit portfolios to a prolonged and gradually adjustment process. The appropriateness of capital controls depends largely on the source of shocks. Capital controls can reduce output fluctuations under a foreign demand shock, but can only increase the volatility of the economy under a foreign interest rate and inflation shock. Moreover, there is an optimal capital control level if the weight of output volatility in the central banks loss function is high enough. This indicates that the proposition of Xiaochuan Zhou may be appropriate if the central bank places a strong emphasis on output gaps.

3.2 Literature Review

One of the main conclusions of the Mundell-Fleming model is that the impossible trinity restricts policy choice to two of monetary policy autonomy, a stable exchange regime, and capital account openness. Based on the model of Mundell (1963) and Fleming (1962), a central bank will lose its monetary independence when a country opens its capital account entirely under a fixed exchange rate regime. This conclusion was then referred as the trilemma, i.e., the conflict confronted by a county which cannot achieve the three policy goals simultaneously (Hausmann, 1999).

Under the framework of the impossible trinity, a polarized regime was popular in the 1990s, and some scholars in China are supportive of this polarized regime choice. The claim is that, given monetary policy independence, the central bank should choose either the combination of a fixed exchange rate and closed capital account, or a floating exchange regime and open capital account. In practice, based on the IMF report, 62 percentage of the countries in the world chose some middle point of the exchange regime in 1991. That is, they chose soft pegging of the exchange rate, combining with a certain level of capital control without total openness. However, this ratio reduced to 34 percentage in 1999. The ratio of the countries adopting a fixed exchange rate increased from 16 percentage in 1991 to 24 percentage in 1999. The ratio of the countries adopting the floating exchange regime increased from 23 percentage in 1991 to 42 percentage in 1999. Fischer (2001) claims that this is because the middle point exchange regime, which includes the fixed pegging exchange regime, adjustable pegging exchange regime, and a narrow band exchange regime is not sustainable because of attacks from international capital. Fischer (2001) also classifies some exchange regimes, such as the managed floating exchange rate regime, as sustainable exchange regimes.

In recent years, the advantages of the middle point exchange regime have been discussed because of the successful experiences of emerging economies in dealing with the financial crisis. Aizenman and Ito (2012) claims that there are still many countries adopting the middle point exchange regime in the first decades of the 21st century, even though the polarized regime choice was widely discussed and recommended.

There are at least two reasons for emerging economies to adopt a middle point exchange regime rather than a floating exchange regime. Firstly, emerging economies mainly specialised in labour-intensive products whose profits are very sensitive to the changes in the exchange rate (Mohan and Kapur, 2009). Therefore, a fixed exchange regime can reduce the uncertainties facing exporters. Secondly, the financial and capital markets of emerging economies are usually under-developed. The financial system is vulnerable to international capital attacks under an open capital account, as shown by the experience of the Asian financial crisis in the late 1990s. Jin and Zhou (2014) constructed an index to measure the dispersion level from the corner of the impossible trinity and found that there is a trend of moving away from the corner of the trinity based on the data of 29 emerging economies over the recent 30 years. This trend is beneficial to economic growth and stability based on the empirical findings. Moreover, the middle exchange regime is usually combined with a certain level of capital control. Farhi and Werning (2014) find that some capital account control is good for the economy even under a pure floating exchange rate regime. Capital controls can smooth the capital flow between countries and thus increase the welfare of the domestic country. In fact, the experience of the recent financial crisis reveals that the constraints on short-term international capital flow can mitigate the rush to deleverage the economy, which can reduce the adverse effects of the country.

Based on the experience of policy practices and the relevant theoretical research, there are controversies among scholars in China about the choice between the monetary policy target, the exchange regime, and the openness of the capital account. In 1994, China adopted the exchange regime of pegging its currency to the US dollar and started mandatory exchange settlement. In 2005, however, China started to peg to a basket of currencies rather than the US dollar only. Because of the de facto pegging exchange regime and the mandatory exchange settlement, the central bank of China passively injected much money into the economy, which has contributed to high inflation in recent decades (He, 2007). From this point of view, policy independency was influenced substantially by the exchange rate regime. However, some adopt the opposite view, which is that the independence of monetary policy has not been influenced by the capital account openness, accumulation of foreign reserves, or the international interest rate environment (Wang and Wang, 2011).

Can China maintain monetary policy independence and a fixed exchange rate regime under the limiting capital account constraints? The impossible trinity under the Mundell-Fleming model implies that this is not possible. However, as claimed by Sun (2006), China's policy seems successful in the sense that its monetary policy is independent given the pegging exchange regime and soft capital account controls. In fact, in the work of Zhou (2012), the president of China's central bank expressed his preference for the middle point regime, claiming that China can adopt a managed floating exchange regime under capital account openness. However, the regime adopted by China yielded many criticisms worldwide. Krugman (2010) and Laffer (2015) criticize China for manipulating the exchange rate for a long time. Bernanke (2005, 2007) claims that the undervaluation of China's exchange rate is one of the main reasons for the huge international surplus and exchange reserves, which led to the global saving glut and finally helped cause the global financial crisis. Nevertheless, there are other opinions about the increasing international surplus and exchange reserves. Zhao (2007) believes that the surplus increase is due to low consumption demand, which results from savings being higher than investment for a long time. Song et al (2012) suggest that the increasing surplus is due to low investment because of the financial stress of privately-owned companies. Nationally-owned companies are less efficient but have easy access to bank loans, while private companies are more efficient but are financially stressed since they cannot get loans easily from banks. With the retreat of the state-owned companies and an increasing proportion of private companies, investment is thus continuously lower than savings. McKinnon and Schnabl (2012) and McKinnon (2010) suggest that China's exchange reserve accumulation is mainly for exchange stability purpose. Schroder (2015) finds that mercantilism accounts for only less than 10 per cent exchange reserve accumulation, while precaution motivation and other factors are the major causes.

3.2.1 Monetary Policy and Interest Rate Differentials

The short-term interest rate is increasingly used as a monetary policy instrument both in developed countries and emerging market economies. Aggregate demand can be influenced by various channels which are related to the short-term interest rates. The Federal Reserve uses the short-term interest rate as the benchmark for long-term interest rates. In the years before the global financial crisis, the US maintained a sustained low interest rate environment. However, a persistent low interest rate environment can foster systemic instability in the economy. Monetary policies using short-term interest rates are usually consistent with transparent rules, such as the Taylor rule, either explicitly or implicitly.

The Taylor rule, which is proposed by Taylor (1993), has proved both sufficient and necessary to ensure an equilibrium of the economy under certain parameter restrictions, at least in a New Keynesian model (Woodford, 2001). Usually, the effectiveness of monetary policy in the New Keynesian model is based on price or wage stickiness, which is used to embed a positive output gap pressure on inflation. In this way, the shift of aggregate demand induced by a change in interest rates can move the equilibrium of the e-conomy along an upward sloping aggregate supply curve in the short-run. However, this equilibrium will return to the natural level which is associated with the natural level of interest rates, unemployment rates, and output in the medium run. In this sense, short-term interest rate can only be effective in the short-run. Persistent deviations from the medium run level of interest rate will cause distortions of the economy leading to booms and bursts. Years of a lasting gap between the actual policy interest rate and the interest rate implied by the Taylor rule before the recent financial crisis was one of the main reasons of the boom in the U.S. housing market (Taylor, 2009). Because of the inappropriate low-interest rate environment and sluggish return to the natural interest rate level, the US adjusted in the form of crisis.

Interest rate differentials are one of the most important factors driving the surges in capital flow under the current global backdrop of financial integration. Calvo, Leiderman, and Reinhart (1996) identify the low interest rate environment in developed countries as one of the main causes for surges in capital inflow in the Latin American countries. By late 1992, the short-term interest rate in the US reached its lowest level since the 1960s. However, in early 1994, it began to rise, reducing the attractiveness of the investment in these Latin Americans, and contributing to capital flight there. Ahmed and Zlate (2014) examine the determinant factors for surges in net private capital inflows to emerging market economies. They find that interest rate differentials are one of the most important determinants of net private capital inflows to emerging market economies since 2002, together with growth rate differentials and the global risk appetite. The global risk factor is emphasized in the work of Forbes and Warnock (2012). Extreme capital flows are divided into four episodes including surges, stops, flights and retrenchment. It is found that global factors, especially global risk, are the main driving forces of extreme capital flow episodes. However, the coefficients of world interest rates are not significant in all the regression results for different stages of international capital flows. Rey (2013) emphasizes the importance of global risk factor as well but provides a link between the global risk premium and the monetary policies of centeral banks. It is argued that the change in the VIX[6], which is a measurement of global risk appetite, is due to the change in US government policies (Rey, 2013).

The short-term interest rate will eventually return to the medium- and long-run levels which depend on real factors in both developed and emerging economies. A persistent low interest rate will lead to adjustments because various economic pressures eventually lead to a sudden collapse of investment confidence, with a shooting up of risk premiums in the markets. Therefore, eventually, a full pattern of international capital flow including surges, stop, flights, and retrenchments can be induced by the deviations and reversals of the short-term interest rate from its long-run level in the central country.

Sustained deviations of the short-term interest rate from the medium-run level in a centeral country can export its monetary policies to other peripheral countries (Rey, 2013). Some early studies hold the view that the floating exchange rate would enable monetary policy independence Obstfeld and Taylor (2004). Under a fixed change rate, the peripheral countries need to adjust their exchange rates passively and thus lose their monetary policy autonomy. Thus, the floating exchange rate is a necessary condition for a country to have an independent monetary policy under capital account openness. However, it is suggested that monetary policy in the peripheral countries cannot lose its independence in the long-term even under a floating exchange rate regime. In the short-run, emerging market economies' central banks can set their interest rate independently from the US Federal rate, but in the long-run, the interest rates will tend to converge. This view is sup-

[6]VIX is the Chicago Board Options Exchange Market Volatility Index. It is a measure of the implied volatility of S&P 500 index options.

ported by the work of Goodhart and Turner (2014), and Bernanke (2013). Obstfeld (2015) suggests that interest rate linkages are a potent mechanism through which the monetary policies and financial cycles are transmitted to emerging market economies. Short-term autonomy but high long-term correlations existed between emerging market economies and central economies. It is claimed that one of the most important channels for the transmission of international monetary and financial policy is through the long-term interest rate (Obstfeld, 2015).

3.2.2 Capital Inflows Surges and Financial Stability

Surges mainly refer to sharp increases in global capital inflows to an economy. Free international capital inflows will benefit the global economy through a similar mechanism to free international trade. Global capital inflow can improve the welfare of emerging economies by mitigating funding shortages, diversifying investment risks, facilitating inter-temporal trade, and improving the financial market. (Ostry et al., 2010). However, global capital inflows can also lead to some unfavorable results. Sharp changes in international capital inflows have a relatively small impact on developed countries but will usually trigger financial instabilities in emerging economies.

Ostry et al. (2010) analyse the influences of capital inflow and possible policy responses. The direct response to a capital inflow is an appreciation of the domestic currency. However, if this is not desirable because the currency has been overvalued already, the central bank can choose to maintain the exchange rate and allow capital inflow by means of buying foreign funds. The reserves will increase, which may increase inflation pressure if no sterilisation is used. However, the sterilisation may be related to further capital inflow and eventually the central bank will need to abandon it and allow the exchange rate to appreciate or adopt a lower interest rate environment. In some cases, an overheated economy can be handled by contractionary fiscal policy. However, monetary policy may not be available due to political considerations and nor will fiscal policy due to its lagged effects. In this case, capital controls can be used. Nevertheless, these may lose their effectiveness over time and need to be strengthened, leading to further distortions.

The consequences of surges in capital inflows can be an increase in credit leverage and asset price bubbles. Capital inflows into emerging market economies can be divided into four stages: surges, stops, flights and retrenchments (Forbes and Warnock, 2012). These capital flows may influence the relationship between domestic and foreign interest rates because they will lead to changes in the demand for domestic bonds, which may lead to changes in domestic interest rates (Obstfeld, 2015). In particular, these countries usually suffer bursts of credit boom with negative real effects on the economy. Capital surges can cause several problems. The first is capital outflow after a continuous period of inflow, resulting in sharp devaluation of the domestic currency. The second relates changes in asset prices due to the capital inflows. This may foster asset price booms. This kind of capital feast and famine will increase the vulnerability of an financial system (Obstfeld, 2015).

Different types of capital inflows have different impacts on the financial stability of emerging market economies. The impacts of the non-financial FDI and liability outflows on economic growth are not the same. Countries with higher liabilities and financial FDI inflows suffer higher growth reduction in a financial crisis. However, countries with higher nonfinancial FDI suffer relative less growth reduction (Ostry et al., 2010). Different types of capital inflow thus have different implications for financial fragility. Compared with debt financing, equity capital inflow allows more risk-sharing between the creditors and borrowers. Based on these considerations, there is a pecking order of capital flows regarding their levels of riskiness. For each category, short-term capital flows are more risky than long-term ones. The pecking order is foreign-currency debt, consumer-price-indexed local currency debt, local-currency debt, portfolio equity investment, and foreign direct investment, ordered by decreasing impact on financial instability (Ostry et al., 2010).

3.2.3 Validity of Trilemma and Capital Controls

Under an open capital market environment, monetary policies in emerging economies can achieve autonomy in the short-run but will lose their independence in the long-term because of the convergence between short- and long-term interest rates. Permanent controls on the inflow or outflow sides are a choice but the experiences of low income countries can be subject to specific characteristics (Klein, 2012). Temporary capital controls are possible as well in the booming period. The central bank can also use macro prudential policies to reduce the incentives for banks to finance from external resources if the domestic interest rate is high.

However, in the work of Obstfeld (2015), it is claimed that the trilemma is still valid. Obstfeld (2015) agrees with Rey (2013) that interest rate linkage is one potent mechanism through which monetary policies and financial cycles are transmitted to emerging market economies. There exists short-term autonomy, but high long-term correlation is exhibited between emerging market economies and central economies. It is claimed that one of the most important transmission channels for international monetary and financial policy is the long-term interest rate. The policy proposed by Obstfeld (2015) is to enhance capital controls, by means of which an economy can experience both a current account surplus and capital account surplus, as in the case of China. It is suggested that the costs and benefits of capital controls should be examined in the presence of several trade-offs of capital flows. Financial integration is beneficial for gross debt expansion and international risk sharing. Some of the historical capital controls are consistent with these policy suggestions. Obstfeld (2015) advocates the trend from debt to equity finance, which makes domestic policy more effective and raises the welfare of the nation. Monetary policy is a vital tool to temper these kinds of capital surges though other tools are necessary as well.

A comprehensive policy package was employed to handle capital inflows in countries which managed their capital flows successfully. In particular, these countries distinguish between short- and long-term inflows. The short-term inflows usually deal with sterilisation transactions to maintain the exchange rate unchanged. The sterilisation effort will be scaled back if the inflows persist. The resulting appreciation of the nominal and real exchange rates can be accompanied by an overheating of the economy, which may need relevant contractionary fiscal policies. Moreover, relevant polices such as increasing exchange rate flexibility and control methods to curb inflows are used to moderate size and lengthen investment maturities (Calvo, Leiderman, and Reinhart, 1996). Obstfeld (2015) suggests that a policy mix of persistent sterilization, heavy intervention in the foreign exchange market, and no controls on short-term capital movement may be less effective.

In the recent financial crisis, China played an important role as a global stabilisation factor, as advocated by McKinnon and Schnabl (2012). In a high-growth economy, capital demand is somehow constrained by the sterilization action of the central banks. McKinnon and Schnabl (2012) claim that China used window guidance to guide capital to export-related industries. A hard peg may not lead to misalignment because the central bank will let the money supply change passively. The export sector price reduces while keeping the non-tradable price stable. As a result, there is a relative increase in the tradable price compared to the non-tradable price. Without sterilization, the price level of domestic goods will increase because of the increased money supply, which shifts the demand for domestic goods to foreign goods. However, with sterilization, the price level of domestic goods can be kept roughly unchanged, preventing a shift from domestic goods to foreign goods. By reducing inflation, the real appreciation of China's exchange rate is prevented, and the export sector investment falls. In the Asian financial crisis, one problem was the high interest rate environment, which encouraged saving but not investment. In general, the Chinese surplus resulted from the export-led economy regime. McKinnon and Schnabl (2012) claim that the distortions in China resulted from low interest rate policies in the US and the stabilisation effort in China. A possible solution was to increase the interest rate level in the US.

Overinvestment is induced when the interest rate is lower than the natural interest rate in the up phase of the economy. The capital inflow to emerging market economies occurs mainly because the global nominal interest rate environment is lower than that in emerging economies, which was a possible cause of the over-investment in China.

Since the early years of this millennium, the economy of China has exhibited a feature of dual deficits in both the current account and the capital account. As one of the largest trade partners of China, the US experienced a savings deficit. It is suggested that this kind of global savings investment imbalance should not be solved by appreciating the Chinese Yuan against US dollar (McKinnon and Schnabl, 2012). One possible solution is to reduce the consumption level in US and increase consumption in China. Obviously, this is a long-run solution to the savings glut problem. If China chooses to appreciate the currency, this will lead to a reduction of investment because the investment costs will increase as a result of currency appreciation (McKinnon, 2010). McKinnon and Schnabl (2012) suggest that the use of the exchange rate to adjust international trade is kind of cliché, which worked only in the era when capital controls were universal. However, in the current backdrop of financial globalisation, the idea of using the exchange rate to adjust international trade is misleading. The main reason here is that investment would adjust more quickly than international trade, which makes the exchange rate policy ineffective.

Several tools can be used to manage surges in capital inflow, including fiscal policy, monetary policy, exchange rate policy and capital controls. Capital controls can be justified if the economy is close to its potential level and lacks any other distortions, as the short-run capital flow surges can cause fluctuating costs but nothing else. Capital controls can be effective if the resulting costs of the flows are higher than the expected returns without controls. The empirical evidence suggests that emerging economies will gain capital control benefits by reducing their reliance on risky external liabilities. Ostry et al. (2010) examine the merits and effectiveness of capital controls. One of the possible results for surges of capital inflow is the appreciation of the exchange rate, which may undermine the competitiveness of the export sector. Another possible result is excessive borrowing and the foreign currency exposure. Capital controls may be justified even from a multilateral perspective. The unremunerated reserve requirement may discourage foreign exchange borrowing. A capital inflow tax can be used to decrease the differentials between long-term and short-term interest rates. A direct minimum stay requirement can be used as well to increase the maturity of foreign liabilities.

There are several concerns about capital controls. The first is their effectiveness (Ostry et al., 2010). For countries with extensive controls, it may be easier to strengthen controls in bad times. The more complicated case is for relatively open countries to find a proper method to control the capital account without further distortions. The second concern about controls on outflows. The effect of capital outflow liberalisation is not clear because the inflow can increase because the country is more attractive as an investment destination, or decrease because of the increasing outflow. There are two main reasons for imposing capital controls, including for an undervalued currency or a stable financial system (Ostry et al., 2010). The temporary capital inflow surges should be controlled because they can only bring fluctuations in exchange rates and relevant prices. Persistent capital inflow may be due to some other, more fundamental reasons and should therefore be treated by some other, more fundamental policies. The effectiveness of capital controls depends on the extensiveness of the controls and the efforts of investors to circumvent them.

3.3 Interest Rate Parity: Empirical Evidence

Uncovered interest parity is closely related to international capital flows which are forces to arbitrage away mispricings. If the capital account is strictly controlled, one economy can freely choose its interest rate and exchange rate levels without worrying about arbitrage pressures from the international capital market. For a country with partially capital account openness like China, arbitrages may be costly and not profitable if the interest parity relation is not binding in the short term. However, the arbitrage may be profitable if the interest rates and exchange rates are persistently away from the parity relation. Persistent capital flows thus play a crucial role in maintaining the uncovered interest parity relation.

If there are no capital controls, it will cost nothing for investors to arbitrage away even very small interest rate differentials between domestic and foreign interest rates under a fixed exchange rate regime. In this case, capital flows only play the role of threatening to arbitrage possible deviations from the equilibrium relations, and have no direct relations to interest rate differentials and exchange rates, as in the conventional interest rate parity. If there are some capital controls, interest rate differentials can deviate a small amount away from the binding interest rate gap under fixed exchange rate regime, because it will be costly for investors to arbitrage small deviations. In this case, the capital flows, especially the long-term and persisting capital flows, will play an error correction mechanism for large and persisting deviations from interest rate parity relation. This section is thus to test whether there is a long-run relationship among interest rate gaps, exchange rates, and FDI inflows, and whether the interest rate differentials and exchange rates exhibit an error correction mechanism, based on monthly data of China.

It is usually difficult to decide, in equation (3.25), which should be the dependent variable and which should be the explaining variables. The VAR (Vector Autoregressive) model avoids this issue by estimating a system of endogenous variables where each is regressed on the others. The VAR is for stationary time series, i.e. $I(0)$, yet many economic variables are not necessary stationary, usually $I(1)$. For a vector of $I(1)$ time series, the VAR model can be estimated and meaningful if the regression errors are $I(0)$. In this case, a VECM can be built to describe the long-term stable relationship among I(1) variables which leads to a stationary error.

3.3.1 Variables, Data and Sample Selections

In this section, three variables will be used: the interest rate differentials between the US and China, the RMB to US dollar exchange rate, and capital inflows to China. The US is treated as a special country because it is the central country in the global financial system. The monetary policies of the Federal Reserve Board have spillover effects on other countries. The experiences of China can shed light one the situation for other peripheral countries.

This study uses the fluctuations in FDI inflows to capture the pressure on deviations from the interest parity relation. As reviewed in the literature, surges in capital inflows can improve welfare but also can foster financial instabilities in emerging economies. Therefore, capital inflows play a critical role in emerging market economies [7]. In China, capital inflows are relatively less restricted by the Chinese Government but capital outflows are highly regulated (Jin, 2013). Fluctuations in capital outflows are driven more by official administrative factors than by the market factors. Moreover, only quarterly capital outflows data are available for recent years. Thus, this study uses FDI inflows to capture the arbitrage pressure on deviations from the interest parity relation.

The interest rate differentials are the differences between the US and Chinese benchmark interest rates (Chinese interest rates minus US interest rate). In the US, the Federal funds effective rate is an overnight interest rate that is used as the benchmark interest rate. This study uses a monthly average of these daily overnight interest rates from the website of the Federal Reserve[8]. In China, there are still no widely accepted benchmark interest rates. Many empirical studies have analysed different types of interest rates and suggest that the Shibor (Shanghai Inter Bank Offered Rate), the fixing repo rate in the interbank market, and the benchmark deposit interest rate are the potential benchmark interest rates in China.

The terms of Shibor cover from overnight to one year, including eight different types. The central bank of China wants to foster Shibor as the benchmark interest rate in the future, and the overnight Shibor is the one most after referenced in both academia and industry. However, the Shibor is not currently based on real trades among banks. The seven days fixing repo rates, among three different terms of fixing repo rates including the overnight, seven days, and fourteen days, are the most actively traded and are believed to have the features of a benchmark interest rate. The fixing repo rates in the interbank market are real trade based and widely accepted

[7] Other determinants of FDI can be added into the VAR model as exogenous variables. However, this complicates the model specifications and increases the parameters to be estimated.

[8] http://www.federalreserve.gov/releases/h15/data.htm

as benchmark interest rates in the financial market. The one-year deposit interest rate is important because of its historically pivotal position in the interest rate system. China has adoptted a gradual approach to reforming the interest rate system and in the more centralized era[9], one year deposit interest rates are the most important in the financial system, determining the overall financing costs of financial institutions. The one-year benchmark deposit interest rates are set by the central bank at irregular intervals. The central bank in China may change the benchmark deposit rate within a quarter, but in some periods the same benchmark interest rate has been maintained for a couple of years. The monthly frequency data are a mathematical average of these benchmark interest rates within the calendar month.

The data for seven days fixing repo rate is available from January 2004, and for Shibor only from October 2006 when it was first reported. The available sample period of benchmark deposit interest rates is much longer than the other two market interest rates, beginning in the early 1990s. The Shibor data come from its website[10], and these seven-day fixing repo rate data are from the RESSET data base[11], and the data on the benchmark deposit interest rate are from the website of China's central bank[12].

Different measures for international capital flows can be used based on the emphases of a particular study. In this research, capital inflows will be used because capital outflows from China to foreign countries are still quite restricted. The FDI inflow data are from the National Bureau of Statistics of China[13]. The exchange rates between RMB and USD are monthly averages of the daily exchange rates of RMB/USD and from the website of Federal

[9]In the years between 1952 and 1978, China government adopted the centrally planned economy regime.
[10]http://www.shibor.org/
[11]http://www.resset.cn/
[12]http://www.pbc.gov.cn/publish/zhengcehuobisi/631/index.html
[13]http://www.stats.gov.cn/

Reserve Bank of St. Louis[14].

The earliest data on Shibor is from October 2006. Thus the sample for this study is from October 2006 to June 2015, covering 105 monthly observations for interest rate differentials, FDI inflows, and exchange rates.

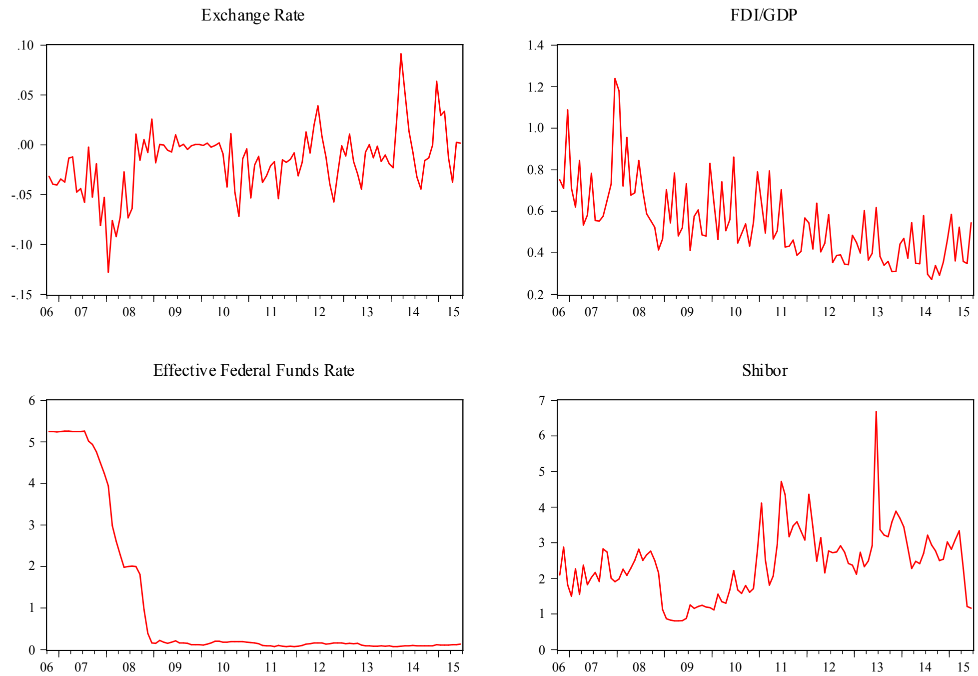
3.3.2 Descriptive Statistics and Unit Root Test

In Figure 3.1, variables used in the estimation are plotted, including the log differences of the exchange rate, FDI/GDP ratio, effective Federal funds rate, and Shibor. In Table 3.1, a positive correlation between interest rate gaps and percentage changes of the exchange rate can be observed. According to the interest parity relation, the nominal exchange rate of RMB/USD should appreciate, and thus decrease given positive interest rate differentials, because of more investment demands for assets denominated in RMB. Thus, this positive correlation cannot be explained merely by the conventional interest parity relation.

Percentage changes in exchange rates are negatively related to the FDI/GDP ratio, suggesting positive FDI inflows may impose pressures on the appreciation of RMB, which is consistent with arguments about extended interest rate parity. The interest rate differentials are negatively related to the FDI/GDP ratios. Positive interest rate differentials can cause more capital inflows, yet persistent inflows may impose pressure on the central bank to reduce policy interest rates. This negative relationship implies the latter may dominate the relationship between FDI inflows and interest rate differentials. The low correlation between Chinese and the US interest rates indicate relatively independent monetary policy choices for these two countries.

In Table 3.2, the means and variances are listed. In general, different interest rates including Shibor, the fixing repo rate and the deposit rate share

[14] https://research.stlouisfed.org/fred2/series/DEXCHUS



Data are complied from National Bureau of Statistics of China, Federal Reserve Bank of St. Louis, RESSET data base, and People's Bank of China. Exchange rate is expressed in the log difference form to approximate the percentage change, defined as $\log(\mathcal{E}_t/\mathcal{E}_{t-1})$, where is $\mathcal{E}_t$ is nominal RMB/USD exchange rate at month t. All variables are in percentage terms.

Figure 3.1: Interest Rates, Capital Inflows, and Exchange Rates

a similar pattern overtime. However, in the empirical part of this Chapter, the interest rate differentials calculated using fixing repo rate and deposit rate will not be used because of the possible term premium. The average interest rate differentials between Shibor and the effective Federal Funds rate is 1.3686 over the past decades, as shown in Table 3.2. This indicates that the interest rate level in China was in general higher than that in the US, which is consistent with the relatively higher expected returns in China because of rapid economic growth, or the higher risk premium because of a less developed financial market. The average of FDI/GDP is 0.5468 with a variance of 0.1851. The average of $\log(\mathcal{E}_t/\mathcal{E}_{t-1})$ is -0.0165 with a variance of

Table 3.1: Correlations among Variables

	$\log(\mathcal{E}_t/\mathcal{E}_{t-1})$	FDI/GDP	IRD*	Shibor	EFFR**
$\log(\mathcal{E}_t/\mathcal{E}_{t-1})$	1.0000	-0.3622	0.3439	-0.0561	-0.4415
FDI/GDP	-0.3622	1.0000	-0.5648	-0.2516	0.5410
IRD	0.3439	-0.5648	1.0000	0.5606	-0.8964
Shibor	-0.0561	-0.2516	0.5606	1.0000	-0.1355
EFFR	-0.4415	0.5410	-0.8964	-0.1355	1.0000

Data are complied from National Bureau of Statistics of China, Federal Reserve Bank of St. Louis, RESSET data base, and People's Bank of China. $\mathcal{E}_t$ is the nominal RMB/USD exchange rate at month t. All variables are in percentage terms. *IRD refers to the interest rate differentials between Shibor and the effective Federal Funds rate. **EFFR refers to the effective Federal Funds rate.

Table 3.2: Descriptive Statistics

	Mean	Std. Dev.	Observations
$\log(\mathcal{E}_t/\mathcal{E}_{t-1})$	-0.0165	0.0316	105
FDI/GDP	0.5468	0.1851	105
IRD*	1.3686	2.1347	105
Shibor	2.4075	0.9548	105
EFFR**	1.0389	1.7843	105

Data are complied from the National Bureau of Statistics of China, Federal Reserve Bank of St. Louis, RESSET data base, and People's Bank of China. $\mathcal{E}_t$ is the nominal RMB/USD exchange rate at month t. All variables are in percentage terms. *IRD refers to the interest rate differentials between Shibor and the effective Federal Funds rate. **EFFR refers to the effective Federal Funds rate. Std. Dev. refers standard deviation.

0.0316. This means RMB is on average experiencing appreciation over the sample period.

Table 3.3 gives the augmented Dickey−Fuller (ADF) test results for relevant variables. The second and third columns in Table 3.3 are the p-values and numbers of lags chosen for the ADF test to level variables. The fourth and fifth columns are the p-value and number of lags for ADF test to first difference variables. The information in Table 3.3 implies that the interest rate gaps and FDI/GDP are $I(1)$ variables, and $\log(\mathcal{E}_t/\mathcal{E}_{t-1})$ is $I(0)$. This suggests that FDI/GDP and the interest rate gaps are random walks.

However, two random walks may share common patterns over time. This is the co-integration relationship.

Table 3.3: ADF Test for Unit Roots

	Level		1^{st} Difference	
	Prob.	Lag	Prob.	Lag
$\log(\mathcal{E}_t/\mathcal{E}_{t-1})$	0.0000	0	0.0000	0
IRD*	0.1285	0	0.0000	2
FDI/GDP	0.5161	12	0.0016	11

Lags are selected based on SIC (Schwarz information criterion).$\mathcal{E}_t$ is the nominal RMB/USD exchange rate at month t. *IRD refers to the interest rate differentials between Shibor and the effective Federal Funds rate. Individual intercept and trend are included in the test equation. In the ADF test for level variables, only individual intercepts are included.

The results of a Phillips-Perron(PP) unit root test are listed in Table 3.7 in Appendix 3.A.1, showing that the PP test results are the similar to the ADF test results, except for the FDI/GDP. In order to examine the unit roots of FID/GDP ratio, more tests are conducted. The Kwiatkowski-Phillips-Schmidt-Shin unit root test for FDI/GDP rejects the null hypothesis of a stationary time series at a significant level of 10 per cent, but cannot reject the null hypothesis at the significance level of 5 per cent. Elliott-Rothenberg-Stock tests for unit roots with respect to FDI to GDP ratio cannot reject the null hypothesis of unit root at the significance level of 1 per cent. All of these tests suggest that the differenced FDI/GDP ratio is stationary. Based on these results, this study consider the non-FDI to be a $I(1)$.

The inclusion of a stationary exchange rate is not technically necessary from the view of VECM estimation because this stationary variables only act as one additional explaining variable in the model. However, it is theoretically important because we aim to map the empirical relationship among interest rate, exchange rate, and capital flows to the extended interest rate parity relationship, as in equation (3.25).

3.3.3 VECM Estimation

Interest parity relation determines changes to nominal exchange rates in the short-term, yet it does not necessarily bind stringently because of various market imperfections such transaction costs, risk premium, etc. However, large and persistent deviations of the exchange rate from its equilibrium level will incur continuing capital flows and even political pressures to devaluate or revaluate the currency. For example, because of the influence of the Asian financial crisis in 1997, the PBC adopted a de facto fixed exchange rate pegging to the US dollars thereafter. In 2003, Masajuro Shiokawa, the Japanese Finance Minister, challenged the pegging exchange regime in the G7 finance ministers' meeting, saying that China's low RMB exchange rate was one of the main reasons for global deflation (McKinnon and Schnabl, 2003). Masajuro Shiokawa demanded that China cancel the de facto pegging of the exchange rate to the US dollar. In 2005, the peggged exchange rate regime was relaxed to a floating foreign exchange regime pegged to a basket of currencies rather than the US dollar, to allow the appreciation of the RMB to the US dollar. In the early 2000s, China suffered huge pressure to sterilising its increasing foreign reserves from continuing capital inflows. Thus, the capital inflows in fact play an important role in correct the persistent deviations of interest rate parity relations from their long-run equilibrium level.

The onshore RMB/USD exchange rate is managed and subject to a daily trading band that has varied during the sample period. This bounded exchange rate may have limited influence on estimations because these bands are exogenously determined by the central bank. The possible effect can be captured by adding a dummy variable for this period. Moreover, a narrow band may enforce the interest rate and FDI co-integration relationship, as suggested by Shambaugh (2004).

In an emerging economy with few capital controls, such as Thailand in the 1997 Asian crisis, surges in capital inflows attacked the nominal exchange rates quickly and hard, and this induced financial instabilities. Capital controls can slow down capital flights and surges such that small and temporary deviations of exchange rates from equilibrium level will not lead to fierce fluctuations in capital inflows.

In this study, as revealed above, the interest rate gaps and FDI/GDP are $I(1)$ variables, and $\log(\mathcal{E}_t/\mathcal{E}_{t-1})$ is $I(0)$. If these two $I(1)$ variables are cointegrated, it can be claimed that there is a long-run relationship between interest rate gaps and FDI/GDP. The deviations from this long-run relationship can act as an error correction mechanism on other variables and draw them to the equilibrium level. This section is thus to test whether there is a long-run relationship between interest rate gaps, exchange rates, and FDI inflows, and whether the interest rate differentials and exchange rates exhibit an error correction mechanism because of deviations from the long-run relationship, based on monthly data from China.

The Johansen test will be used to examine the possible long-run equilibrium relationship between three sets of variables. This study follows the cointegration test procedure suggested by Sjö (2008). In equations (3.1), (3.2), and (3.3), x_t is a vector of endogenous variables including FDI/GDP, interest rate differentials, and $\log(\mathcal{E}_t/\mathcal{E}_{t-1})$. Γ_i are coefficients for lagged Δx_{t-i}, up to k lags.

Suppose $\alpha\beta = \Pi$. Then Π represents the co-integration relationship among the elements in vector x_t. If there is no co-integration, the elements of each row in Π should be not significantly different from zero. However, if there is at least one co-integration among the elements in vector x_t, some parameters in Π should not be equal to zero. In particular, if $rank(\Pi) = 0$, there is no co-integration relationship. If $rank(\Pi) > 0$, there should be at least one co-integration relationship. $\beta_i, i = 1, 2, 3, \ldots,$ are the coefficients of the i^{th} con-integration relationship while $\alpha_j, j = 1, 2, 3, \ldots,$ are the relevant impacts of this relationship on Δx_t.

Nested equation (3.1), (3.2), and (3.3) are mainly used to test different trends, allowing for constants in the cointegrating vectors, deterministic trend in x_t and constants in the cointegrating vectors, and constants and deterministic trends in the cointegrating vectors respectively (Sjö, 2008). Parameter μ_0 in equation (3.1), and (3.2) represents the mean value of the co-integration vectors. Compared with equation (3.2), equation (3.1) sets $\mu_0 = 0$ but embeds a constant item in the co-integration vectors. Equation (3.3) relaxes 3.2 by introducing a time trend in the co-integration vectors, which may be useful in this study because the FDI/GDP seems to have a time trend in the decade, as shown in Figure 3.1.

$$\Delta x_t = \sum_{i=1}^{k} \Gamma_i x_{t-i} + \alpha[\beta, \beta_0][x_{t-1}, 1]' + \varepsilon_t \tag{3.1}$$

$$\Delta x_t = \sum_{i=1}^{k} \Gamma_i x_{t-i} + \alpha\beta x'_{t-1} + \mu_0 + \varepsilon_t \tag{3.2}$$

$$\Delta x_t = \sum_{i=1}^{k} \Gamma_i x_{t-i} + \alpha[\beta, \beta_0, \beta_0][x_{t-1}, 1, t]' + \varepsilon_t \tag{3.3}$$

To select the most appropriate model, the Johansen test will begin with an hypothesis of zero integration and check the test statistic for equation (3.1), (3.2), and (3.3) sequentially. If zero integration hypotheses are all rejected, an hypothesis of one integration will be tested across the model sequentially, and so on. This process stops when the null hypothesis cannot be rejected, and the correspondent equation will be selected as the appropriate model.

In particular, the Johansen test will begin with equation (3.1),testing zero cointegration relationship. If the Johansen test rejects the null hypothesis of zero cointegration relationship, it will be performed for equation (3.2) and then equation (3.3). If zero cointegration relationships are all rejected for equations (3.1), (3.2), and (3.3), the Johansen test will be performed to test at most one cointegration relationship for equations (3.1), (3.2), and (3.3) sequentially. This procedure will be continued until the null hypothesis cannot be rejected.

The Johansen test results to x_t for equations (3.1), (3.2), and (3.3) are presented in Table 3.4. Following the procedure explained above, the hypothesis test begins with equation (3.1), then equation (3.1), and then equation (3.1), under the null hypothesis of none cointegration. The results in Table 3.4 indicate that the hypothesis of none cointegration is rejected for all three equations. Moreover, the null hypothesis of one cointegration is all rejected for all three equations as well. The first null hypothesis that cannot be rejected is the hypothesis of two cointegration relations for equation (3.1). Thus, the Johansen test stops and model (3.1) is selected, indicating a constant in the cointegrating vectors and without any trend in cointegration vectors or in x_t.

In the unit root test subsection, it is found that $\log(\mathcal{E}_t/\mathcal{E}_{t-1})$ is $I(0)$ is stationary. Thus, the second cointegration relationship must exist between interest rates differentials and FDI/GDP, implying a long-run equilibrium relationship between these two variables. In the following, the selected model (3.1) will be estimated to examine how the error correction mechanism can influence the changes in FDI/GDP, interest rate differentials, and $\log(\mathcal{E}_t/\mathcal{E}_{t-1})$ is $I(0)$.

In Table 3.5, the estimated equation (3.1) is presented, in which the term Cointegration 1 and 2 represent the two cointegration relations identified

Table 3.4: Johansen Test Results for Equation (3.1), (3.2), and (3.3)

Equation	No. of CE(s)	Eigenvalue	Trace Statistic	Prob.**
(3.1)	None *	0.3124	69.7685	35.1928
	At most 1 *	0.2294	32.3079	20.2618
	At most 2	0.0606	6.2501	9.1645
(3.2)	None *	0.3091	68.1143	29.7971
	At most 1 *	0.2248	31.1371	15.4947
	At most 2 *	0.0552	5.6776	3.8415
(3.3)	None *	0.3223	75.1101	42.9153
	At most 1 *	0.2621	36.2094	25.8721
	At most 2	0.0564	5.8099	12.5180

Note: * denotes rejection of the hypothesis at the 0.05 level. ** MacKinnon-Haug-Michelis (1999) p-values. CE is short for cointegration equation.

using the Johansen test. These estimated cointegration relations are in Table 3.8 in Appendix 3.A.1. Each of these two cointegration relations is normalized, and thus the coefficients for $\Delta \log(\mathcal{E}_t/\mathcal{E}_{t-1})(-1)$ and ΔFDI/GDP(-1) in cointegration equation 1 and 2 constitute a 2×2 identity matrix.

In the cointegration equation 1, the coefficient of $\Delta \log(\mathcal{E}_t/\mathcal{E}_{t-1})(-1)$ is 1 and the coefficient of ΔFDI/GDP(-1) is 0. Thus, the cointegration equation 1 represents the cointegration relation for stationary variable $\Delta \log(\mathcal{E}_t/\mathcal{E}_{t-1})$. In the cointegration equation 2, the coefficient of $\Delta \log(\mathcal{E}_t/\mathcal{E}_{t-1})(-1)$ is 0 and the coefficient of ΔFDI/GDP(-1) is 1. Thus, the cointegration equation 2 represents the cointegration relation between the remaining two $I(1)$ variables, interest rate gap and FDI/GDP.

In equation (3.1), the error terms of the cointegration relations 1 and 2 in period $t-1$ are used to explain Δx_t. A significantly negative coefficient of the error term implies that Δx_t will decrease given a positive error term. In Table 3.5, the coefficient of the error terms of cointegration equation 2 is significantly negative when the dependent variable is ΔFDI/GDP, yet are not significant when the dependent variables are $\Delta \log(\mathcal{E}_t/\mathcal{E}_{t-1})$ and ΔIRD. This means that the error term of a long-run relationship between FDI/GDP and interest rate gaps imposes an error correction mechanism on ΔFDI/GDP, but not on $\Delta \log(\mathcal{E}_t/\mathcal{E}_{t-1})$ and ΔIRD.

Table 3.5: Equations (3.1) Estimation Results

	$\Delta \log(\mathcal{E}_t/\mathcal{E}_{t-1})$	ΔFDI/GDP	ΔIRD*
	-0.4987	-1.1083	-1.7599
Cointegration 1	(-0.1006)	(-0.5773)	(-3.0523)
	[-4.9574]	[-1.9200]	[-0.5766]
	-0.0316	-0.7713	-0.4072
Cointegration 2	(-0.0216)	(-0.1241)	(-0.6560)
	[-1.4615]	[-6.21747]	[-0.62070
	-0.0894	1.3711	1.0970
$\Delta \log(\mathcal{E}_t/\mathcal{E}_{t-1})(-1)$	(-0.0948)	(-0.5441)	(-2.8770)
	[-0.9423]	[2.5198]	[0.3813]
	-0.0120	-0.0675	0.5553
ΔFDI/GDP(-1)	(-0.0173)	(-0.0990)	(-0.5233)
	[-0.6948]	[-0.6818]	[1.0611]
	-0.0045	0.0154	-0.1858
ΔIRD(-1)	(-0.0034)	(-0.0195	(-0.1031)
	[-1.3175]	[0.7922]	[-1.8025]

Standard errors in ( ), and t-statistics in [ ]. The lags are chosen based on the SIC. *IRD is short for interest rate differentials between Shibor and the effective Federal Funds rate. There are 103 observations for estimating this model and the number of coefficients is 19. The two-side 5 per cent critical value for the student t distribution is 1.9886.

There are three empirical findings based on the results of the Johansen test and VECM estimation. First, there is a long-run relationship existing between the FDI/GDP and interest rate differentials. The Johansen test implies that there is a long-run relationship for these two variables. If there are no capital controls, interest rate differentials will be arbitraged away. In this case, the long-run relations should not exist. If there are some capital controls, interest rate differentials can be maintained even under a fixed exchange rate regime, accompanied by with a persisting capital flows. The persistent interest rate differentials and capital flows finally lead to a long-run relation between them. Thus, the Johansen test results confirm the augment that interest rate differentials and capital inflows exist in the long-run rather than in the short-term, because of the capital controls.

Second, it is clear that interest rate differentials and exchange rates in general exhibit no error correction patterns. This implies that the deviation from the long-run relationship between capital inflows, interest rate differentials, and exchange rates will not impose a significant influence on monetary policies and the exchange rate. In particular, the interest rate differential are not influenced by deviations in the market. The cointegration term in the model represents deviations from the long-run relationship. Given the deviations, interest rates and exchange rates exhibit no reverting adjustments and only the FDI reacts to this deviations. Therefore, this can be interpreted as the monetary policy independence in China and the US from the capital inflows to China. The central bank of China indeed can maintain a non-zero interest rate even under a pegged exchange rate. Moreover, the RMB/USD exchange rates are independent of these deviations. This finding is consistent with the results of Cheung, Tam, and Yiu (2008). However, this policy independence should be deemed as monetary policy independence in the short run, rather than the long-term. The long-run relationship is governed by the FDI interest rate co-integration relationship, which is consistent with the empirical findings of Frankel, Schmukler, and Servén (2002).

Third, the evolution capital inflows exhibit an error correction pattern with respect to the long-run relationship between FDI/GDP and interest rate differentials. Deviations from the long-run relationship in the previous period can impose a negative pressure on the FDI inflows in the current period. The deviation of FDI capital inflows from the long-run trend will thus be corrected. This suggests that capital flows is the variable adjusting passively to adapting market forces and different policy environments. Market forces will react to the interest rate and exchange rate environment by flowing into or out of the economy. This implies that the maintenance of a pegged exchange rate cannot prevail over the long term.

In general, the empirical findings are consistent with the impossible trilemma which asserts that, under a fully open capital account, it is not possible to maintain a fixed exchange rate if the central bank does not give up monetary policy independence. The no arbitrage condition between short-term interest rates and exchange change rates can be summarized using the interest parity relation. The interest parity relation is widely tested and it has been found that the covered interest parity in general holds, but the uncovered interest parity usually has the wrong signs. There are several factors that cause the rejection of the uncovered interest parity, including a constrained capital account, inefficient foreign exchange markets, imperfect substitutions between domestic and foreign assets, and transaction costs. In the case of Chinese foreign exchange market, these factors play roles in slowing down the error correction mechanism towards the equilibrium relationship between exchange rates and interest rates. However, the empirical test results above indicate that there is a long-run equilibrium relationship existing between FDI/GDP and interest rate differentials. Deviations will not last for too long and will be smoothed out over time.

3.4 A Small Open Economy Model with Capital Controls

In the empirical section, it is found that PBC can determine the interest rate and exchange rate autonomously, but not capital inflows. These findings imply that the central bank of China can choose some middle point of the impossible trilemma under capital account controls. However, the appropriateness of capital controls is still under doubts from a normative perspective because they may induce some adverse effects in the economy, despite ensuring the monetary policy autonomy. In this section, a capital control mechanism will be introduced into an open economy New Keynesian model to normatively examine the appropriateness and possible consequences of capital controls.

In particular, the model of Gali and Monacelli (2005) is extended in two directions by including an Iacoviello (2005) type collateral constraint and a capital control extended budget constraint for households. The capital control mechanism is introduced by imposing additional quadratic costs on households for deviations from the steady state position of foreign deposit or bonds. Therefore, households will choose the foreign deposit position closer to the steady state level under capital controls, compared to the case without capital controls.

This additional cost of capital controls has two consequences. First, nominal returns to domestic and foreign deposits will be influenced by the position of foreign deposits. This implies an additional term to the uncovered interest parity between the domestic interest rate, foreign interest rate, and nominal exchange rate. In an economy without capital controls, the nominal exchange rate is determined by the uncovered interest parity given the interest rates in domestic and foreign countries. If there are capital controls, the nominal exchange rate depends on the domestic and foreign interest rates, and the change of foreign deposit position. This extended uncovered interest parity relation enables the central bank to move away from the binding interest rate gap under a fixed exchange rate regime. This explains how China managed to achieve monetary autonomy as revealed in the empirical section.

Second, capital controls transform dramatic and immediate changes in deposit portfolios to a prolonged and gradual adjustment process, and real variables are influenced by the changes in purely nominal foreign variables.

If these are no capital controls, non-zero interest rate differentials under a fixed exchange rate regime will lead to dramatic and immediate changes in deposit portfolios. If there are capital controls, different nominal returns imply a necessity for households to adjust their deposit portfolios, but only through a gradual process because of high costs incurred by dramatic change. However, this will influence the domestic credit market and asset prices. In this way, capital controls mitigate the ability of the nominal exchange rates to absorb foreign nominal shocks and establish a link between foreign interest rates and domestic real variables.

By changing the level of capital controls, it is possible to compare the impulse responses of model variables to different shocks. In particular, by comparing cases with and without capital controls, the consequences of capital controls can be assessed. Using the collateral constraint, a positive relationship between credit expansion and asset prices can be introduced. Given foreign interest rates or other shocks, credit cycles in the economy may be different because of different capital controls.

The participants in the economy include households, entrepreneurs, retailers, capital producers, and the central bank. The world economy consists of a continuum of countries on the $[0, 1]$ interval. One of these countries, $H \in [0, 1]$, is treated as the domestic country and other countries, $i \in [0, 1]$ *and* $i \neq H$, as the foreign countries.

3.4.1 The Goods and Prices in the Economy

The goods in the economy include intermediate goods, retail goods, domestic goods, and final goods. The intermediate goods are homogeneous and can be produced by entrepreneurs both in domestic and foreign countries. There is a continuum of retailers over the interval [0,1]. Each of these retailers buys intermediate goods from entrepreneurs at the price P_t^W and differentiates them into retail goods. The retail goods are heterogeneous, thus the demand function for the retail goods is downward-sloping because of customers preference for goods diversity. The downward sloping demand curve implies a certain level of market power on which retailers can rely to price the domestic goods. In particular, the consumers consume a basket of retail goods, named as final goods C_t which is defined in equation (3.4).

$$C_t \equiv \left((1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \tag{3.4}$$

The parameter α represents the preference of domestic consumers for foreign goods. $C_{H,t}$ and $C_{F,t}$ represent domestic goods and foreign goods respectively. $C_{H,t}$ consists of a basket of domestic retail goods and $C_{F,t}$ consists of a basket of imported final goods from other countries. In particular, these two type of goods are defined as (3.5) and (3.6), where $C_{i,t}$ and $C_{i,t}(j)$ are imported goods and retail goods j from country i as defined in equation (3.7) .

$$C_{H,t} \equiv \left(\int_0^1 C_{H,t}^{\frac{\varepsilon-1}{\varepsilon}}(j)\, dj \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{3.5}$$

$$C_{F,t} \equiv \left(\int_0^1 C_{i,t}^{\frac{\gamma-1}{\gamma}}\, di \right)^{\frac{\gamma}{\gamma-1}} \tag{3.6}$$

$$C_{i,t} \equiv \left(\int_0^1 C_{i,t}^{\frac{\varepsilon-1}{\varepsilon}}(j)\, dj \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{3.7}$$

It can be observed that the final goods C_t, domestic goods $C_{H,t}$, foreign goods $C_{F,t}$, and imported goods from country i $C_{i,t}$ are all defined in the form of constant elasticity of substitution. Based on the work of Green (1964), this implies that the optimisation problem faced by consumers can be solved in two stages. In the first stage, the demand for final goods C_t can be calculated by considering the optimisation problem of consumers. In the second stage, the demands for domestic goods $C_{H,t}$ and foreign goods $C_{F,t}$ can be calculated given the level of final consumption goods.

$$P_t = \left((1-\alpha)\, P_{H,t}^{1-\eta} + \alpha P_{H,t}^{1-\eta}\right)^{\frac{1}{1-\eta}} \tag{3.8}$$

$$P_{H,t} = \left(\int_0^1 P_{H,t}^{1-\varepsilon}(j)\, dj\right)^{\frac{1}{1-\varepsilon}} \tag{3.9}$$

$$P_{F,t} = \left(\int_0^1 P_{i,t}^{1-\gamma} di\right)^{\frac{1}{1-\gamma}} \tag{3.10}$$

$$P_{i,t} = \left(\int_0^1 P_{i,t}^{1-\varepsilon}(j)\, dj\right)^{\frac{1}{1-\varepsilon}} \tag{3.11}$$

The constant elasticity of substitution form for the final consumption goods will be sufficient to ensure that the solution from the two-stage budgeting procedure is exactly the same as that from directly solving the optimisation conditions for the demands of domestic and imported goods. Using this two-stage budgeting procedure, the corresponding price indexes for final goods, domestic goods, foreign goods, and imported goods from country i can be defined as equations (3.8), (3.9), (3.10), and (3.11) respectively.

Moreover, the demand functions for domestic goods, foreign goods, and imported goods from country i are expressed respectively as equations (3.12), (3.13),and (3.14) from the two-stage budgeting procedure. The demands for goods j from the domestic and foreign country i are expressed in equations (3.15) and (3.16).

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \tag{3.12}$$

$$C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{\eta} C_t \tag{3.13}$$

$$C_{i,t} = \left(\frac{P_{i,t}}{P_{F,t}}\right)^{-\gamma} C_{F,t} \tag{3.14}$$

$$C_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\varepsilon} C_{H,t} \tag{3.15}$$

$$C_{i,t}(j) = \left(\frac{P_{i,t}(j)}{P_{i,t}}\right)^{-\varepsilon} C_{i,t} \tag{3.16}$$

After some substitutions, the demand for the retail goods j produced by the domestic country and by country i can be expressed in terms of the consumption demand for final goods C_t and the relevant price indexes. The consumption demands for goods j from the domestic country and foreign country i are a linear function of the demand for final goods C_t, which confirms the validity of the two-stage budgeting procedure. For a given price level for each retail goods, the consumption demand for each retail good, either from the domestic country or from any other country i, will increase proportionally with final goods demand C_t. Moreover, this nexus is the same for investment demands using final goods C_t as an input. In particular, the investment demand for retail goods j produced by domestic country and by country i can be expressed analogously in terms of the investment demand for final goods I_t, as in equations (3.17) and (3.18).

$$I_{H,t}(j) = (1-\alpha)\left(\frac{P_{H,t}(j)}{P_{H,t}}\right)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} I_t \tag{3.17}$$

$$I_{i,t}(j) = \alpha\left(\frac{P_{i,t}(j)}{P_{i,t}}\right)^{-\varepsilon}\left(\frac{P_{i,t}}{P_{F,t}}\right)^{-\gamma}\left(\frac{P_{F,t}}{P_t}\right)^{\eta} I_t \tag{3.18}$$

3.4.2 Decisions of Households and Entrepreneurs

There are two types of consumers in the economy on the interval [0,1] totaling a mass of 1. Households and entrepreneurs comprise portions $\gamma^{\mathfrak{h}}$ and $\gamma^{\mathfrak{e}}$ respectively[15]. Following the work of Iacoviello (2005), it is assumed that entrepreneurs are less patient than households and thus have a smaller time discount parameter. This implies that households save and entrepreneurs borrow in the steady state. Households provide labour to entrepreneurs to earn wages which are used to support consumption. Labour leads to disutility of households, and thus there is a tradeoff between labour supply and consumption. In particular, a typical household maximizes the utility function as in (3.19), subject to the budget constraint (3.20).

$$\max_{C_t^{\mathfrak{h}}, L_t^{\mathfrak{h}}, D_t, D_{i,t}} E_0 \sum_{t=0}^{\infty} {\beta^{\mathfrak{h}}}^t \left(\frac{{C_t^{\mathfrak{h}}}^{1-\sigma}}{1-\sigma} - \frac{{L_t^{\mathfrak{h}}}^{1-\phi}}{1-\phi} \right) \tag{3.19}$$

In the utility function of households (3.19), $C_t^{\mathfrak{h}}$ is the consumption of final goods and L_t is the labour supply of households. $\beta^{\mathfrak{h}}$, σ and ϕ are the time discount parameter, inter-temporal substitution parameters for consumption and labour supply respectively. The real budget constraint of households is as shown in (3.20).

$$\begin{aligned} \int_0^1 P_{H,t}(j) C_{H,t}^{\mathfrak{h}}(j)\, dj + \int_0^1 \int_0^1 P_{i,t}(j) C_{i,t}^{\mathfrak{h}}\, dj\, di + D_t^{\mathfrak{h}} + \int_0^1 \mathcal{E}_{i,t} D_{i,t}\, di \\ \leq W_t L_t + (1 + r_{t-1}^D) D_t + \int_0^1 \mathcal{E}_{i,t} (1 + r_{i,t-1}) D_{i,t-1}\, di \\ - \frac{\kappa_D}{2} \int_0^1 \left(1 - \frac{D_{i,t}}{D_i}\right)^2 \mathcal{E}_{i,t} D_i\, di \end{aligned} \tag{3.20}$$

[15] Symbols $\mathfrak{h}$ and $\mathfrak{e}$ indicate parameters or variables for households and entrepreneurs respectively in this thesis.

On the left-hand side of this budget constraint is the spending of households in period t. The household pays for both domestic and foreign retail goods. On the right-hand side of the budget constraint is the wage income of the household in period t and proceeds of deposits held from period $t-1$ to period t. D_t and $D_{i,t}$ are domestic deposits and foreign deposits held by households. D_i is the long-run equilibrium level of foreign deposit holdings. The stock of $D_{i,t}$ can be negative and regarded as borrowing from foreigners. In China, households cannot invest in foreign bonds directly. However, as claimed by Song, Storesletten, and Zilibotti (2011), the central bank invests foreign exchange income into foreign bonds, which can be considered as indirect households' investment in the foreign bonds. China's government is now gradually lifting the restriction on domestic residents' investment in foreign bonds. Thus, the specification in this budget constraint can match the reality of the capital and financial account of China. $\mathcal{E}_{i,t}$ is the nominal exchange rate faced by domestic investors, where $P_{i,t}$ is the final goods price index for country i expressed in domestic currency. r^D_{t-1} and $r_{i,t-1}$ are the nominal interest rates for domestic and foreign bonds respectively received at time t. W_t is the nominal wage.

The last item on the right-hand side of this budget constraint is the adjustment cost incurred in changing the investment size of foreign bonds. This is introduced to capture the restrictions on financial and capital accounts in China. In particular, the parameter $\kappa_D \in [0, \infty)$ describes the level of capital restriction. When $\kappa_D = 0$, there are no restrictions on financial and capital accounts. When $\kappa_D > 0$, the last item on the left-hand side of this budget constraint is positive if $D_{i,t} \neq D_i$ for any i. This means that changes in the previous level of bonds holding from any country will lead to additional costs besides the price for the bonds. Compared with the approach of Farhi and Werning (2012, 2014) where the interventions in the financial and capital market are introduced by assuming a subsidy from the government, the adjustment cost approach to introducing capital constraints in this study is more suitable for the management practices of the financial and capital account in China. Moreover, China mainly restricts portfolio investment rather than foreign direct investment. Within the portfolio investment category, long-term investments are preferred but short-term capital flows are highly restricted by the government.

Similar specification of capital controls can be found in the work of Chang, Liu, and Spiegel (2015). In their work, the cost of foreign capital flows is associated with the deviations from an exogenous ratio between domestic and foreign asset holding by households. In this study, the costs of foreign capital flows are determined by the speed of the flows rather than the absolute level. The setting in this study will make more sense considering the well documented sudden-stop effect, such as in Aguiar and Gopinath (2007).

This additional adjustment cost means that short-term and more volatile capital flows will lead to higher transaction costs within a given time. The adoption of the adjustment costs gives a good description of the policy orientation of the Chinese government, which focuses on short-term capital flows rather than long-term ones. Moreover, by using this adjustment cost form, an explicit solution for the Backus-Smith condition[16] can be derived similar to Gali and Monacelli (2005), where as only an implicit solution can be derived in the work of Farhi and Werning (2012, 2014). The explicit solution will facilitate an analytical discussion about the effects of relevant monetary, financial and capital account policies because this explicit form of the Backus-Smith condition can be used to establish the relationship between capital flows and consumption demands. Based on the definition for the final goods index (3.4) and the corresponding final goods price index (3.8),

[16]The Backus-Smith condition is the theoretical positive correlation between relative consumption and the real exchange rate. The Backus-Smith puzzle refers to the empirical zero or negative relationship between relative consumption and the real exchange rate, see Backus and Smith (1993).

the budget constraint of the household can be rewritten as (3.21).

$$
\begin{aligned}
P_t C_t &+ \int_0^1 \int_0^1 P_{i,t}(j) C^{\mathfrak{h}}_{i,t}\, dj\, di + D^{\mathfrak{h}}_t + \int_0^1 \mathcal{E}_{i,t}(j) D_{i,t}\, di \\
&\leq W_t L^{\mathfrak{h}}_t + (1 + r_{t-1}) D_t + \int_0^1 \mathcal{E}_{i,t}(j)(1 + r_{i,t-1}) D_{i,t-1}\, di \\
&- \frac{\kappa_D}{2} \int_0^1 \left(1 - \frac{D_{i,t}}{D_i}\right)^2 \mathcal{E}_{i,t} D_i\, di \qquad (3.21)
\end{aligned}
$$

Given this budget constraint and the optimisation problem of the household, the first-order necessary conditions for final goods consumption $C^{\mathfrak{h}}_t$, labour supply $L^{\mathfrak{h}}_t$, domestic bonds D_t and foreign currency deposits from country i are as follows:

$$
\frac{{L^{\mathfrak{h}}_t}^{\phi}}{{C^{\mathfrak{h}}_t}^{\sigma}} = \frac{W_t}{P_t} \qquad (3.22)
$$

$$
1 = \beta^{\mathfrak{h}}(1 + r^D_t) E_t \left[\frac{P_t}{P_{t+1}} \frac{{C^{\mathfrak{h}}_{t+1}}^{-\sigma}}{{C^{\mathfrak{h}}_t}^{-\sigma}} \right] \qquad (3.23)
$$

$$
1 + \kappa_D \Big(\frac{D_{i,t}}{D_i} - 1 \Big) = \beta^{\mathfrak{h}}(1 + r_{i,t}) E_t \left[\frac{P_t}{P_{t+1}} \frac{{C^{\mathfrak{h}}_{t+1}}^{-\sigma}}{{C^{\mathfrak{h}}_t}^{-\sigma}} \frac{\mathcal{E}_{i,t+1}}{\mathcal{E}_{i,t}} \right] \qquad (3.24)
$$

Equation (3.22) describes the tradeoff between the labour supply and consumption demand in period t. Equation (3.23) is the Euler equation for the households which represents the intertemporal choice between the consumption and saving in the form of domestic deposits. Equation (3.24) is an Euler equation as well, where the only difference is the use of foreign currency deposits rather than domestic deposits for saving[17]. It can be observed that there are only three first-order necessary conditions for four unknown variables. Using the budget constraint of the household, all these four unknown variables can be determined given the price level, domestic and foreign in-

[17] The Lagrange multiplier $\lambda_t = C_t^{-\sigma}/P_t$ for households is cancelled in equations (3.23) and (3.24).

terest rates, and changes in the exchange rate. By combining the first-order necessary conditions for domestic and foreign currency deposits, an extended interest parity relation under the capital constraint can be derived as (3.25).

$$1 + r_t = \frac{\mathcal{E}_{i,t+1}}{\mathcal{E}_{i,t}} \frac{1 + r_{i,t}}{1 + \kappa_D \hat{d}_{i,t}} \tag{3.25}$$

In equation (3.25), $\hat{d}_{i,t} \equiv D_{i,t}/D_i - 1 \approx \log(D_{i,t}/D_i)$ represents the percentage deviation of $D_{i,t}$ from its steady state level D_i [18]. The log linearised form of equation (3.25) is $\log(\mathcal{E}_{i,t+1}/\mathcal{E}_{i,t}) = r_t - r_{i,t} + \kappa_D \hat{d}_{i,t}$. If $\kappa_D = 0$, this extended interest parity retreats to the conventional form which connects the exchange rate, and domestic and foreign interest. It should be noted that the first-order condition for deposits from country i stands for all foreign countries $i \in [0, 1]$ *and* $i \neq H$. This extended interest parity relation creates additional space for the central bank to cope with external shocks by means other than relying solely on domestic interest rates. In particular, the impossible trinity may not bind all the time. In the conventional form of interest parity, domestic interest rates should always equal foreign interest rates if the exchange rate is fixed. This suggests that the domestic central bank loses its monetary policy autonomy because there is no space for it to move away from the foreign interest rates. If the domestic central bank favors monetary autonomy and fixed exchange rates, the only choice left is to break the interest parity relation by closing financial and capital accounts.

However, this extended interest parity under capital controls enables the central bank to achieve a certain, perhaps mild, level of monetary autonomy even under a fixed exchange rate regime. Under a fixed exchange rate regime, $\mathcal{E}_{i,t+1} = \mathcal{E}_{i,t}$. Assume the economy is in the steady state at period t. In this case, $\hat{d}_{i,t} = 0$. Then the central bank can indeed hold the exchange rate

[18] Other lower case letters with a hat can be interpreted similarly. Lower case letters represent the logarithm of the uppper case variable, for example, $p_t = \log P_t$.

unchanged and adopt an expansionary or contractionary monetary policy by changing the domestic bond interest rate. The speed of capital flows depends on the financial and capital openness parameter κ_D. It should be noted that the room for monetary policy change is mild because the fixed foreign exchange rate is not sustainable, as capital keeps flowing into or out of the country. Eventually the central bank will be forced to either increase the interest rate or decrease $\mathcal{E}_{i,t+1}$, i.e. appreciation gradually, to deal with continuing capital outflow. In fact, this was exactly the situation in China from 2005 to 2008 when the People's Bank of China decided to appreciate gradually. This extended interest parity creates room for the central bank to move away from the foreign interest rate and achieve monetary autonomy even under a fixed exchange rate regime, though conventional interest parity is still a benchmark which the central bank may have to bounce back to.

Entrepreneurs in the model consume and own firms to produce using capital accumulated and labour employed. The time discount parameter of entrepreneurs $\beta^{\mathfrak{e}}$ is smaller than that of the household $\beta^{\mathfrak{h}}$, implying entrepreneurs discount future consumption and income more. The optimisation problem for entrepreneurs is specified as in (3.26), subject to the real budget constraint (3.27) and the collateral constraint (3.28).

$$\max_{C_t^{\mathfrak{e}}, L_t^{\mathfrak{e}}, B_t, K_t^{\mathfrak{e}}} E_0 \sum_{t=0}^{\infty} \beta^{\mathfrak{e}t} \log C_t^{\mathfrak{e}} \tag{3.26}$$

On the right-hand side of the budget constraint (3.27) are the funds available for the entrepreneur at time t. Y_t is the output of the entrepreneur and $K_{t-1}^{\mathfrak{e}}$ is the capital level determined in period $t-1$ and used for production activities in period t. After production, a δ portion of the capital depreciates and thus the last item of the budget constraint is the value of the capital after depreciation, where Q_t^K is the real price for capital at period t. B_t is the loan demand of the entrepreneur at time t, following the specification of Iacoviello

(2005).

On the left-hand side of the budget constraint is the expenditure of the entrepreneur at period t including the consumption $C_t^{\mathfrak{e}}$, borrowing payment for bank loans B_{t-1}, wages for employed labour $L_t^{\mathfrak{e}}$, and capital $K_t^{\mathfrak{e}}$ for production in period $t+1$. $\pi_t \equiv P_t/P_{t-1} - 1$ is the final goods inflation rate. The capital level $K_t^{\mathfrak{e}}$ is determined at period t. The difference between $K_t^{\mathfrak{e}}$ and $(1-\delta)K_{t-1}^{\mathfrak{e}}$ is the new capital accumulated, which constitutes the demand side of the capital market. $L_t^{\mathfrak{e}}$ is the labour demand for the production in period t. The payment on borrowing is in nominal terms thus adjusted for inflation.

$$C_t^{\mathfrak{e}} + \frac{1+r_{t-1}^B}{1+\pi_t} B_{t-1} + W_t L_t^{\mathfrak{e}} + Q_t^K K_t^{\mathfrak{e}} \leq \frac{Y_t}{X_t} + B_t + Q_t^K (1-\delta) K_{t-1}^{\mathfrak{e}} \qquad (3.27)$$

$$B_t \leq \frac{\kappa^{EB} Q_{t+1}^K K_t^{\mathfrak{e}} (1-\delta)}{1+r_t^B} \qquad (3.28)$$

The credit constraint faced by entrepreneurs is specified as (3.28). It is assumed that the borrowing size in period t is a linear function of the value of capital after depreciation in period $t+1$. The parameter κ^{EB} measures the portion of the capital which can be pledged as collateral. However, it should be noticed that although the Q_{t+1}^k may drop too much, such that the value of capital after depreciation $Q_{t+1}^K(1-\delta)K_t^{\mathfrak{e}}$ is smaller than $B_t(1+r_t^B)$ in period $t+1$, the entrepreneur still has to pay all debts. The production function Y_t is in the Cobb-Douglas form dependent on the labour employed in period t and capital predetermined in period $t-1$, as in equation (3.29), where A_t is the technology used in production.

$$Y_t \equiv A_t {K_{t-1}^{\mathfrak{e}}}^{\xi} {L_t^{\mathfrak{e}}}^{1-\xi} \qquad (3.29)$$

Following the work of Andrés, Arce, and Thomas (2013), the entrepreneur's optimal choice of consumption and capital can be expressed as a function of net wealth NW_t, defined as in (3.30). In the definition of NW_t, $r_t^K \equiv \xi Y_t/(K_{t-1}^{\mathfrak{e}} X_t)$ is the marginal return to capital in production. $X_t \equiv P_t/P_{H,t}^W$ is the real price of entrepreneur output Y_t, where $P_{H,t}^W$ is the wholesale price of Y_t. $Q_t^K(1-\delta)K_{t-1}^{\mathfrak{e}}$ is the value of one unit of capital after depreciation. Following the specification of Iacoviello (2005), the borrowing constraint is assumed to always be binding because entrepreneurs discount more heavily than households. Defining $\chi_t \equiv \kappa^{EB} Q_{t+1}^K(1-\delta)/(1+r_t^B)$ as the loan to value ratio, the binding borrowing constraint can be expressed as $B_t = \chi_t K_t^{\mathfrak{e}}$. For a given lever of capital $K_t^{\mathfrak{e}}$, the borrowing increases as the loan to value ratio χ_t goes higher, while the latter depends on the expected asset price and current domestic nominal interest rate.

$$NW_t \equiv \left(r_{t-1}^K + Q_t^K(1-\delta) - \chi_{t-1} \frac{1+r_{t-1}^B}{1+\pi_t} \right) K_{t-1}^{\mathfrak{e}} \tag{3.30}$$

The last item of NW_t is thus the payment of principal and interest on borrowing in period $t-1$. Based on the definition, NW_t depends on two variables in period t, the asset price Q_t^K and the final goods inflation π_t, which are both taken as given by the entrepreneur. It can be verified that NW_t is an increasing function of Q_t^K. Inflation π_t has a positive impact on NW_t because of the debt deflation effect, following Fisher (1933). That is, deflation will have a negative impact on net wealth which can negatively influence the variables supported by net wealth, such as consumption and investment. Using the definition of NW_t, the first-order necessary conditions for consumption and capital can be written as (3.31) and (3.32) respectively.

$$C_t^{\mathfrak{e}} = (1-\beta^{\mathfrak{e}}) NW_t \tag{3.31}$$

$$K_t^{\mathfrak{e}} = \frac{\beta^{\mathfrak{e}}}{Q_t^K - \chi_t} NW_t \tag{3.32}$$

$$L_t = (1-\xi) \frac{Y_t}{X_t W_t} \tag{3.33}$$

As explained by Gambacorta and Signoretti (2014), these two conditions are key to understanding the collateral channel of monetary policy. Both consumption and capital are linear functions of net wealth, which depends on asset prices and inflation. As the asset price Q_t^K increases, consumption increases because the entrepreneur becomes wealthier. However, its impact on investment is ambiguous because there is a tradeoff between the wealth effect captured by NW_t and the substitution effect captured by the multiplier on NW_t. A higher inflation environment will encourage the entrepreneur's consumption and investment because of the debt deflation effect. The nominal interest rate can influence current capital or investment by changing the entrepreneur's loan to value ratio χ_t. The net wealth in the next period will be influenced as well because of the reduction in interest rate costs. The labour demand function of the entrepreneur is (3.33).

3.4.3 Capital Goods and Retail Goods

Capital producers in the economy buy domestic final goods and then transfer these goods into capital goods. The optimisation problem of the capital goods producer is specified as (3.34).

$$\max_{I_t} E_0 \sum_{t=0}^{\infty} \lambda^{\mathfrak{e}}{}_{0,t} \left(Q_t^K Y_t^K - I_t \right) \tag{3.34}$$

In (3.34), $\lambda^{\mathfrak{e}}{}_{0,t} = \beta^{\mathfrak{e}} C_t^{\mathfrak{e}} / C_{t+1}^{\mathfrak{e}}$ is the Lagrange multiplier for the entrepreneur in period t. I_t is the amount of final goods the capital producer has bought to produce the capital goods Y_t^K. The production function of the capital goods is $Y_t^K \equiv (1 - \kappa^I (I_t / I_{t-1} - 1)^2) I_t$, where $\kappa^I \geq 0$ is the capital installation cost parameter. The capital producer then chooses I_t to maximize the discounted sum of the real profits.

In the work of Brzoza-Brzezina and Makarski (2011), there are three types of retailers operating in the domestic, export and import retail markets. This means that retailers can decide the prices in all these three market. However, the exporters usually decide the price, not the importers. Therefore, in this study, retailers can determine the domestic and export prices but not the import price. The import price is determined exogenously by the foreign countries.

There are a mass of [0,1] retailers in the economy who buy homogeneous intermediate goods from entrepreneurs and differentiate them into retail goods. As the retail goods are heterogeneous, the substitution between different retail goods is not perfect. This leads to downward-sloping demand curves for each type of retail goods, implying the possibility of retailers determining the price rather than taking it as given. In order to make monetary policy nontrivial, this study uses a Calvo (1983) formalism to introduce sticky prices in the economy. In particular, each of the retailers (for example, retailer j differentiates intermediate goods into retail goods j) has an probability of $1-\theta$ to adjust the retail goods price in each period. Otherwise, the retailer will choose to keep the retail price unchanged. For domestic retail goods j, there are demands from both domestic and foreign countries. As the demand functions from the domestic and foreign countries are different, the optimal prices are different. The optimisation pricing problem of the domestic retail goods j in period t is specified as (3.35).

$$\max_{P^*_{H,t}(j)} \sum_{k=0}^{\infty} \theta^k E_t \Big(\lambda^{\mathfrak{h}}{}_{t,k} Y_{H,t+k}(j) \big(P^*_{H,t}(j) - P^W_{H,t+k} \big) \Big) \tag{3.35}$$

In this optimisation problem, $\lambda^{\mathfrak{h}}{}_{t,k} \equiv \lambda^{\mathfrak{h}}{}_{t+k}/\lambda^{\mathfrak{h}}{}_t$ is the discount factor of the household. $Y_{H,t+k}(j)$ is the size of the intermediate goods input and the retail goods output in period $t+k$. This optimisation function is in fact the discounted value of the future income from retail goods j by holding the price at $P^*_{H,t}(j)$ for all periods from period t. The retailer j faces the demand function (3.36) for the domestic retail goods j, where $C_{H,t+k} = C^{\mathfrak{h}}_{H,t+k} + C^{\mathfrak{e}}_{H,t+k}$

is the domestic consumption demands for domestic goods, and $C_{i,t+k}$ is the demands for domestic goods from country i.

$$Y_{H,t+k}(j) = \left(\frac{P_t^*(j)}{P_{H,t+k}}\right)^{-\varepsilon} \left(C_{H,t+k} + \int_0^1 C_{i,t+k}\, di\right) \tag{3.36}$$

The first order condition for the retailer's optimisation problem is (3.37). Defining the domestic goods inflation from period $t-1$ to period $t+k$ as $\Pi_{H,t-1|t+k} \equiv P_{H,t+K}/P_{H,t-1}$ and the relative price of intermediate goods to domestic goods in period $t+k$ as $X_{H,t+k} \equiv P_{H,t+K}/P^W_{H,t+k}$[19], and given the steady state real price of the intermediate goods as $X_H = \varepsilon/(\varepsilon-1)$, the first-order necessary condition (3.37) can be rewritten as (3.38).

$$\sum_{k=0}^{\infty} \theta^k E_t \left[C^{\mathfrak{h}}_{t+k} Y_{H,t+k}(j) \frac{1}{P_{t+k}} \left(P^*_{H,t}(j) - \frac{\varepsilon}{\varepsilon-1} P^W_{H,t+k}\right)\right] = 0 \tag{3.37}$$

$$\sum_{k=0}^{\infty} \theta^k E_t \left[C^{\mathfrak{h}}_{t+k} Y_{H,t+k}(j) \frac{P_{H,t-1}}{P_{t+k}} \left(\frac{P^*_{H,t}(j)}{P_{H,t-1}} - \Pi_{H,t-1|t+k} \frac{X_H}{X_{H,t+k}}\right)\right] = 0 \tag{3.38}$$

Equation (3.38) can be linearised around the steady state, leading to the New Keynesian Phillips curve (3.39) , where $\kappa^X \equiv (1-\theta)(1-\theta\beta^{\mathfrak{e}})/\theta$, $\pi_{H,t} \equiv \log \Pi_{H,t-1|t}$, and $\hat{x}_{H,t} = \log(X_{H,t}/X_H)$.

$$\pi_{H,t} = \beta^{\mathfrak{e}} E_t[\pi_{H,t+1}] - \kappa^X x_{H,t} \tag{3.39}$$

3.4.4 International Risk Sharing and Equilibrium

In a closed real economy model with no nominal frictions, aggregate output depends on the production function, and utility function based on which a tradeoff among consumption, investment, and labour can be established. These real variables do not depend on the price level because producers

[19] Note that $X_{H,t}/X_t = P_{H,t}/P_t$.

change prices to cope with different aggregate demands. In a closed economy New Keynesian model, aggregate output is determined by bringing the dynamic aggregate demand and supply together. In particular, consumption and investment are decided given the price and wage level. The aggregate price level is determined given aggregate demand. By combining aggregate demand and supply with a policy rule pinning down the interest rates, all the real and nominal variables in the model can be determined. In a canonical New Keynesian closed economy model, a positive relationship between output and price level is established through the New Keynesian Phillips curve. In the open economy, consumption and investment depend on the final goods price level. Given aggregate demand, only the domestic price level can be determined. Therefore, a relationship between the domestic price level and the final goods price level should be established to determine the variables in the economy.

By log-linearizing the final goods index (3.8), a relationship between the final price level and the domestic price can be established, $p_t = (1-\alpha)p_{H,t} + \alpha p_{F,t}$. In this relation, there is one additional item, $p_{F,t}$, linking the domestic and final goods prices. To combine aggregate demand and supply, the relative price S_t is used to substitute for the foreign goods price $p_{F,t}$. As the consumers prefer diversity of consumption goods, the differences between domestic and foreign goods prices do not lead to arbitrage. However, this relative price will influence the demand for domestic and imported goods. In particular, define the bilateral relative price between domestic country and country i as $S_{i,t} \equiv P_{i,t}/P_{H,t}$. The effective relative price is defined as (3.40).

$$S_t \equiv P_{F,t}/P_{H,t} = \left(\int_0^1 {S_{i,t}}^{1-\gamma} di \right)^{\frac{1}{1-\gamma}} \tag{3.40}$$

The log linear form of the definition of S_t can be written as $s_t = p_{F,t} - p_{H,t}$. This implies that the CPI inflation can be expressed as (3.41), combining with the logarithm form of the final goods index[20]. Equation (3.41) can be interpreted intuitively[21]. If the relative price $s_t = 0$, the CPI inflation equals domestic inflation. If $s_t > 0$, i.e. if foreign inflation is higher than domestic inflation, CPI inflation will be higher than domestic inflation. The difference is thus the product of the foreign goods portion and relative inflation in terms of the domestic currency. Equation (3.41) establishes a pass through effect of foreign country inflation one the domestic country. Based on this relationship, final goods inflation is the sum of domestic inflation and an α portion of s_t. To close the economy, the relative price S_t should be linked to other endogenous variables in the economy.

$$\pi_t = \pi_{H,t} + \alpha \Delta s_t \tag{3.41}$$

As S_t is defined as the relative price of domestic and foreign goods under the domestic currency, a link between S_t and the exchange rate should be established. In particular, assume that the law of one price holds for individual goods at all times, i.e. $P_{H,t}(j) = \mathcal{E}_{i,t} P^i_{i,t}(j)$. The relationship between the domestic price and foreign price can then be established using the nominal exchange rate. $P^i_{i,t}(j)$ is the price of goods j expressed in the country i's currency. Following the relationship between $P_{i,t}(j)$ and $P^i_{i,t}(j)$, it is obvious that $P_{i,t} = \mathcal{E}_{i,t} P^i_{i,t}$. Substitute $P_{i,t}$ into $P_{F,t}$, and log linearise $P_{F,t}$ around the steady state, and it can be found that $p_{F,t} = e_t + p^*_t$. By substituting $p_{F,t}$ using s_t and $p_{H,t}$, one can get (3.42) which pins down the nominal exchange rate.

$$e_t = s_t + p_{H,t} - p^*_t \tag{3.42}$$

At this stage, the relative price S_t is expressed using the exchange rate, foreign price level, and domestic price level. The foreign price level can be considered as exogenously determined, and thus we need to pin down the

[20] Note that $x_{H,t} - x_t = p_{H,t} - p_t = \alpha \Delta s_t$.

[21] Domestic inflation $\pi_{H,t}$ and foreign inflation $\pi_{F,t}$ are both in domestic currency. Thus, the effects of changes in nominal exchange rate are included.

nominal exchange rate. The bilateral real exchange rate with country i is $Q_{i,t} = \mathcal{E}_{i,t} P_t^i / P_t$, where P_t^i is the final goods price index for country i. The effective exchange rate in logarithm form is thus $q_t = e_t + p_t^* - p_t$. Therefore, a relationship between the real exchange rate and the nominal exchange rate is derived. By comparing the expression of q_t and s_t, it can be found that $q_t = (1 - \alpha) s_t$.

To summarise, the relationship between CPI inflation and domestic inflation is now combined through the relative price S_t which is determined by the equilibrium condition and international risk sharing condition. Given S_t and the relevant price levels, the nominal and real exchange rates can be determined. The international risk-sharing mechanism mainly considers the no arbitrage condition between the domestic and foreign Euler equations. In particular, the household's Euler equation in country i can be expressed as (3.43), where β^i, C_t^i, P_t^i, and r_t^i are the consumption demand of the household, final goods price, and nominal interest in country i at time t. Combining with the Euler equation of the domestic household, the Backus-Smith condition (3.44) can be derived.

$$\left(\frac{C_{t+1}^i}{C_t^i}\right)^{-\sigma} \frac{P_t^i}{P_{t+1}^i} = \frac{1}{1 + r_t^i} \tag{3.43}$$

$$\left(\frac{C_{t+1}^i}{C_t^i}\right)^{-\sigma} \frac{P_t^i}{P_{t+1}^i} = \left(\frac{C_{t+1}^{\mathfrak{h}}}{C_t^{\mathfrak{h}}}\right)^{-\sigma} \frac{P_t}{P_{t+1}} \frac{1 + r_t^D}{1 + r_t^i} \tag{3.44}$$

$$\left(\frac{C_{t+1}^i}{C_t^i}\right)^{-\sigma} \frac{P_t^i}{P_{t+1}^i} = \left(\frac{C_{t+1}^{\mathfrak{h}}}{C_t^{\mathfrak{h}}}\right)^{-\sigma} \frac{P_t}{P_{t+1}} \frac{\mathcal{E}_{i,t+1}}{\mathcal{E}_{i,t}} \frac{1}{1 + \kappa_D \hat{d}_{i,t}} \tag{3.45}$$

The Backus-Smith condition reflects the tradeoff between consumption and saving in both domestic and foreign countries. It can be found that this condition is irrelevant to time discount parameters in different countries. Thus, this condition holds for entrepreneurs as well. In this sense, the consumption here represents the aggregate consumption of households and entrepreneurs.

Using uncovered interest parity (3.25), the Backus-Smith condition can be rewritten as (3.45).

This new Backus-Smith condition (3.45) is an extension of the one in the work of Gali and Monacelli (2005). If the capital constraint parameter κ_D is equal to zero, this equation reverts to the normal case, as in Gali and Monacelli (2005). The introduction of this parameter implies that relative consumption may not change one to one with changes in the relative exchange rate. This extension can explain the Backus-Smith condition puzzle. Another advantage of this expression of Backus-Smith condition is that it can be solved explicitly. In the work of Farhi and Werning (2012, 2014), financial and capital account friction is introduced by adding a premium over the nominal interest rate. This can generate an extended Backus-Smith condition but no explicit solution for it can be easily derived.

$$C_t \left(1 + \frac{\kappa_D}{\sigma} \hat{d}_{i,t}\right) = \nu_i Q_{i,t}^{\frac{1}{\sigma}} C_t^i \tag{3.46}$$

Suppose equation (3.46) holds, where ν_i is a constant parameter. By bringing it into (3.45), it can be easily verified that the extended Backus-Smith condition is satisfied. Thus, equation (3.46) is indeed the solution to the extended Backus-Smith condition. The logarithm of (3.46) is (3.47).

$$c_t = q_{i,t} + c_t^i - \frac{\kappa_D}{\sigma} \hat{d}_{i,t} \tag{3.47}$$

$$c_t = (1-\alpha)s_t + c_t^* - \frac{\kappa_D}{\sigma} \hat{d}_t \tag{3.48}$$

Integrate (3.47) on both sides and substitute q_t using $(1-\alpha)s_t$, and the relationship (3.48) between consumption and the real exchange rate can be derived, given the changes in holding of the foreign currency deposits, where $c_t^* \equiv \int_0^1 c_t^i \, di$.

The final form of the Backus-Smith condition (3.48) provides a linkage between the domestic consumption demand, relative price, foreign consumption demand, and holdings of the foreign currency deposits. It can be seen that the holding of foreign currency deposits will negatively influence domestic consumption demand, if other variables are unchanged. This implies that capital controls may reduce the negative impact of the volatility of the foreign currency deposits holding on domestic consumption. If the capital constraint parameter κ_D equals zero, this equation above reverts to the case in Gali and Monacelli (2005). In the benchmark model of Gali and Monacelli (2005), a relationship between consumption and output can be established by considering the equilibrium condition. The main use of this condition is to link consumption demand and the relative price, and finally pin down the real exchange and relative price in the model.

There are several types of goods demanded in the domestic economy, including homogeneous intermediate goods, retail goods, domestic final goods, imported foreign goods, and final goods. For each of the retail goods j, the retail goods output equals the homogenous intermediate goods input. Thus, the demand for the retail goods can be summed up directly to get the demand for homogeneous intermediate goods. Let $Y_{W,t}$ represent the output of the intermediate goods. Thus, the equilibrium condition of the intermediate goods $Y_{W,t}$ is (3.49).

$$Y_{W,t} = \int_0^1 Y_{H,t}(j)\, dj \tag{3.49}$$

From the optimisation problem, it can be seen that consumers favor a variety of goods. They buy each item of the goods from the market separately and consume them as a bundle. Thus, equilibrium should be satisfied at the retail goods level. One question to ask is whether the holding of the retail goods equilibrium leads to the holding of the equilibrium in terms of final goods. There are several types of demand for the retail goods j, including domestic consumption, domestic investment, and exports in the model, as in (3.50). $X_{H,t}(j)$ is foreign demand for or exports of domestic goods j, defined as

$X_{H,t}(j) \equiv \int_0^1 X_{i,t}(j)\,di \equiv \int_0^1 \big(C_{i,t}(j) + I_{i,t}(j)\big)\,di$, where $C_{i,t}(j)$ and $I_{i,t}(j)$ are the consumption and investment demands for domestic goods j from country i respectively.

$$Y_{H,t}(j) = C_{H,t}(j) + I_{H,t}(j) + X_{H,t}(j) \tag{3.50}$$

$$X_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\varepsilon} X_{H,t} \tag{3.51}$$

The demand function for retail goods j of consumption, investment, and export are specified as (3.15), (3.17), and (3.51). The export demand function has a similar form to the consumption and investment demand functions. Given the definitions of domestic final goods and the domestic final goods price index, the demand functions for consumption, investments, and exports should be the same. This setting is different from that in the work of Adolfson et al. (2007) where the export demand is expressed in a similar form but changes with different prices. Put (3.15), (3.17), (3.51), and (3.50) into (3.49), (3.52) can be derived.

$$Y_{W,t} = \big(C_{H,t} + I_{H,t}) + X_{H,t}\big) \int_0^1 \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\varepsilon} dj \tag{3.52}$$

Therefore, the demand for the domestic goods in fact equals the output of intermediate goods. The next step is to build the relationship between the supply and demand for domestic goods, following the approach of Gali and Monacelli (2005). Based on the definition of domestic final goods (3.5), the equilibrium condition (3.53) for domestic goods can be derived.

$$Y_{H,t} \equiv \left(\int_0^1 Y_{H,t}^{\frac{\varepsilon-1}{\varepsilon}}(j)\,dj\right)^{\frac{\varepsilon}{\varepsilon-1}} = C_{H,t} + I_{H,t} + X_{H,t} \tag{3.53}$$

Equilibrium condition (3.53) implies that the market clearing condition in the retail good market is equivalent to the equilibrium condition in the domestic final goods market. The next step is to examine the relationship between the equilibrium conditions for the domestic final goods market and the final goods market. The relationship between domestic final goods and final goods is given by equation (3.12) for consumption. The investment demand functions have the same form as (3.12), as suggested by equation (3.17).

Foreign country i imports goods $Y_{H,t}$ produced in country H and then combines them with imported goods from other countries and the final goods produced within country i for consumption and investment. In particular, the demand functions for domestic final goods from country i are (3.54) and (3.55). P_t^i is the world price level in foreign country i's currency, and $X_{i,t}^F$ is total import in country i. By integrating $X_{i,t}$ over different countries, the total export demand $X_{H,t}$ can be expressed in equation (3.56).

$$X_{i,t} = \left(\frac{P_{H,t}}{\mathcal{E}_{i,t} P_{i,t}^i} \right)^{-\gamma} X_{i,t}^F \tag{3.54}$$

$$X_{i,t}^F = \alpha \left(\frac{P_{i,t}^i}{P_t^i} \right)^{-\eta} (C_t^i + I_t^i) \tag{3.55}$$

$$X_{H,t} = \int_0^1 X_{i,t}\, di = \int_0^1 \left(\frac{P_{H,t}}{\mathcal{E}_{i,t} P_{i,t}^i} \right)^{-\gamma} X_{i,t}^F\, di \tag{3.56}$$

Define $Z_t \equiv C_t + I_t$ as the aggregate domestic demand for the final goods, and $Z_t^i \equiv C_t^i + I_t^i$ as the aggregate domestic demand in country i. Substitute the demand function for the domestic final goods from consumption, investment, and exports into the $Y_{H,t}$. The equilibrium condition for domestic final goods can be written as (3.57), where S_t^i is the effective relative price in country i. This equilibrium condition can be log linearised as (3.58)[22], where $\omega \equiv \gamma + \eta(1-\alpha)$. In this study, the $\hat{z}_t^*$ is assumed to follow an exogenous stochastic

[22]See Appendix 3.A.2 for details.

process.

$$Y_{H,t} = Z_t \left((1-\alpha) + \alpha \int_0^1 \left(S_t^i S_{i,t} \right)^{\gamma-\eta} Q_{i,t}{}^{\eta} \frac{Z_t^i}{Z_t} \, di \right) \left(\frac{P_{H,t}}{P_t} \right)^{-\eta} \tag{3.57}$$

$$\hat{y}_t = (1-\alpha)\hat{z}_t + \alpha \hat{z}_t^* + \alpha\omega s_t \tag{3.58}$$

In this study, the central bank is assumed to be following a Taylor rule to conduct monetary policy, as in (3.59). The parameter $\rho^{\mathfrak{cb}}$ determines the continuity of the monetary policy. Parameters ϕ_y and ϕ_π measure the policy reactions to output gap and inflation rates respectively.

$$r_t = \rho^{\mathfrak{cb}} r_{t-1} + \phi_y \hat{y}_t + \phi_\pi \pi_t \tag{3.59}$$

3.5 Impulse Response Analysis

In this section, the impulse responses of key variables to the foreign demand shock and the foreign interest rate shock are examined. The impulse response analysis focuses on foreign shocks because the model in this chapter aims mainly to examine the effects of capital controls on the economy. Key propagation mechanisms of the model can be clarified through the impulse response analysis. There are three main foreign variables in the model: the foreign demand, foreign inflation, and foreign interest rates. They are assumed to follow an independent AR(1) time series. The coefficients of the AR(1) are assumed to be 0.75 for simplicity, which suggests a half-life period of about 7 months. This simple structure for the foreign economy is useful for focusing on the influence of a specific foreign shock without considering the dependencies of the foreign variables.

Model parameters are calibrated in Table 3.6. The values of $\beta^{\mathfrak{h}}$ and $\beta^{\mathfrak{e}}$ are calibrated at 0.99 and 0.98 respectively, following Iacoviello (2005), Rubio and Carrasco-Gallego (2014) and others. These two discount factors

Table 3.6: Parameters Calibration

Parameters	Values	Description
$\beta^{\mathfrak{h}}$	0.99	Household discount factor
$\beta^{\mathfrak{e}}$	0.97	Entrepreneur discount factor
σ	1.00	Inverse elasticity of intertemporal substitution
φ	1.00	Inverse labour supply elasticity
ε	6.00	ES between goods within a country
γ	1.00	ES between goods from different foreign countries
η	1.00	ES between domestic and foreign goods
α	0.20	Portion of foreign goods in final consumption goods
δ	0.03	Capital depreciation rate
ξ	0.10	Capital share in production function
θ	0.75	Calvo(1983) parameter
$\rho^{\mathfrak{cb}}$	0.20	Coefficient of AR(1) in Taylor rule
ϕ_π	1.50	Coefficient of inflation in Taylor rule
ϕ_y	0.50	Coefficient of output gap in Taylor rule
κ^D	0.30	Capital control parameter
κ^{EB}	0.50	Loan to value ratio
κ^I	0.30	Coefficient for capital installation costs

ES is short for Elasticity of Substitution.

imply steady-state real interest rates for households and entrepreneurs of 4 per cent and 8 per cent respectively. The parameters for the open economy settings follow the work of Gali and Monacelli (2005). In particular, the elasticity of substitution between goods from different foreign countries γ and the elasticity of substitution between domestic and foreign goods η are both calibrated at 1. The inverse elasticity of intertemporal substitution σ is calibrated at 1. This means unit substitutability for goods from different countries and across time. The inverse labour supply elasticity φ is set to 1. The prior mean of the Calvo (1983) parameter θ is calibrated at 0.75, which means that the average period of price lasting is 4 quarters.

The weight of foreign goods in final consumption goods is calibrated at 0.2. Gali and Monacelli (2005) use the ratio of import to GDP to calibrate this weight. In China,it is around 0.2. The ratio of capital depreciation is calibrated to 0.03 which implies an annual depreciation rate of 12 per cent. The substitution parameter between different types of domestic goods is calibrated at 6. This implies that the steady state markup, $\varepsilon/(\varepsilon-1)$, is 1.2. The loan to value ratio is calibrated at 0.50. In China, the minimum down payment ratio is 0.3. Considering that not all fixed assets are used for collateral, the average loan to value ratio should be much lower than 0.7. In the Taylor rule, the prior means of parameters for output and inflation are calibrated at 0.2 and 1.5 respectively. The share of capital is calibrated at 0.1, which is lower than that in developed economies. For example the work of Bailliu, Meh, and Zhang (2015), this rate is set to 0.3 for Canadian data.

3.5.1 Impulse Responses to Foreign Demand Shock

Figure 3.2 gives the impulse responses of key variables to foreign demand shock. The size of the shock is a one percent deviation from its steady state value. In each panel of Figure 3.2 the green line is the impulse response curve with capital controls($\kappa^D = 0.30$), while the blue one is the impulse response curve without capital controls($\kappa^D = 0$). Given a positive shock of foreign demand, aggregate demand and domestic output increase. Domestic goods inflation increases as well because of the demand-driven shock. The fluctuations in domestic goods inflation are very small because foreign demand forms only a small portion of the aggregate demand. Moreover, the increase in aggregate demand is offset by the increase in aggregate supply. Therefore, the size of domestic goods inflation is very small. The consumption of households and entrepreneurs both increase under this positive demand shock because of increases in income and appreciation in exchange rate. Both capital and labour inputs increase resulting in a reduction of the real price of intermediate goods, which is negatively related to the marginal cost of labour.

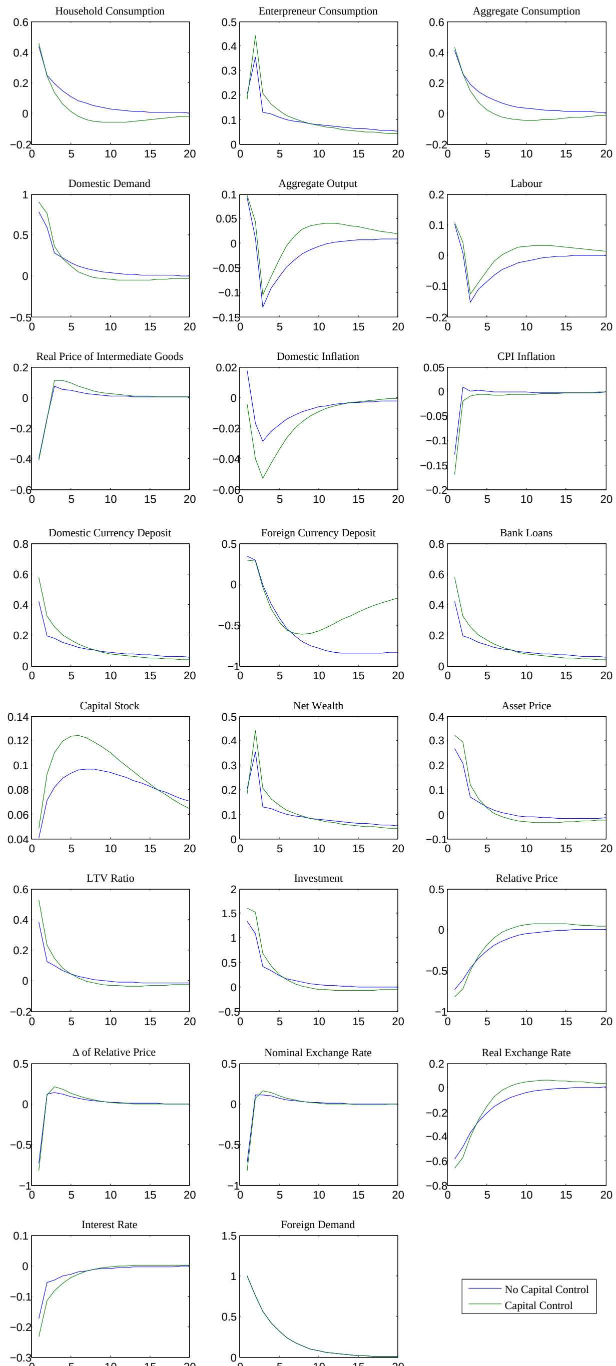


Figure 3.2: Impulse Responses to Foreign Demand Shock

The final goods price experiences a deflation although the domestic goods price increases, because of small fluctuations in domestic inflation and a large appreciation of the nominal exchange rate. In equation (3.41), the difference between CPI inflation and domestic inflation is the product of foreign goods portion α and Δs_t. Δs_t measures the relative inflation between domestic and foreign countries in terms of domestic currency. In response to a positive foreign demand shock, domestic goods become relative expensive and the relative price s_t drops below its steady state level 0. As the economy moves back to the steady state level, the relative price s_t approaches to 0. This means that Δs_t is negative, i.e. the domestic inflation is higher than foreign inflation, in terms of domestic currency. Why is relative inflation Δs_t so negative as to result in a CPI deflation? The relative price s_t is determined by the Backus-Smith condition and thus moves almost proportionally to the foreign demand shock. Changes in the foreign demand shock determine Δs_t as well. Thus, changes to the relative price s_t will dominate the changes in domestic inflation $p_{H,t}$, which results in a CPI deflation.

The variables s_t and $p_{H,t}$ also determine nominal inflation. Equation (3.42) defines the nominal exchange rate by replacing $p_{F,t}$ using the sum of s_t and $p_{H,t}$. The foreign exchange rate p_t^* equals zero by assumption[23]. As explained above, the decrease in s_t dominates the increase in $p_{H,t}$. Thus, the nominal exchange rate e_t decreases, reflecting an appreciation of domestic currency and a drop of $p_{F,t}$ for domestic consumers. The final goods price reduces because it is a weighted average of domestic inflation and foreign inflation in the domestic currency. As domestic inflation $\pi_{H,t}$ is small, foreign goods inflation in terms of domestic currency $p_{F,t}$ dominates, leading to a deflation of CPI. Expansionary monetary policy is conducted by the central bank as a reaction to a small output gap and CPI deflation.

Under a positive foreign demand shock, the production of entrepreneurs

[23]In this specific case, $e_t = p_{F,t} = s_t + p_{H,t}$

increases, resulting in a booming capital market. In particular, investment increases sharply because of the expansion. This leads to increases in asset prices and the net wealth of entrepreneurs as well. The loan to value ratio, together with bank loans, increases because of the low interest rate environment and increased asset prices. The household switches from foreign currency deposits to domestic currency deposits because of the appreciation of the domestic currency.

By comparing the impulse responses with and without capital controls, we can see that capital controls can mitigate the effects of foreign demand shocks, especially for capital market variables. In Figure 3.2, it seems that the deviations of foreign deposits in response to a foreign demand shock under capital controls reduce more quickly compared with the case under no capital controls. However, this should not be interpreted literally. In fact, deposit portfolios will be adjusted immediately in the case of no capital controls. The slow changes in foreign deposits only reflect the intertemporal tradeoff under steadily increasing domestic interest rates. Capital controls impose high adjustment costs on immediate portfolio adjustment, and thus the switch from foreign to domestic deposits needs to take time. However, the prolonged switching process increases the credit supply by the banks. Capital price, loan to value ratios, investments, net wealth, and bank loans all get larger, which indicates that capital controls can increase the volatility of the domestic capital market by speeding up asset circulation among assets in different currencies.

3.5.2 Impulse Responses to Foreign Interest Rate Shock

Figure 3.3 gives the impulse responses of key variables to a foreign interest rate shock. The blue and green lines are for no capital controls ($\kappa^D = 0$) and capital controls ($\kappa^D = 0.30$) respectively. Under the case of no capital controls, only foreign deposits react to the shock, and all other domestic variables stay at the steady-state level. The domestic economy does not respond to the foreign interest rate shock because real foreign variables such as foreign output and demand stay at the steady-state level. Since the foreign inflation rate and relative price s_t between foreign and domestic goods do not change, this implies a constant nominal exchange rate as well. Therefore, the domestic economy responds to this nominal shock only by adjusting foreign currency deposits. Aggregate consumption does not change because foreign deposits can be adjusted without incurring any additional costs.

The domestic interest rate does not change because it follows a Taylor rule depending on the output gap and CPI inflation. The interest rate differentials between domestic and foreign interest rate will lead to immediate adjustment of the deposit portfolio, which cannot be recognised in Figure 3.3. The slow adjustment of foreign deposits observed in Figure 3.3 reflect the intertemporal tradeoff because of the decreasing foreign interest rate. Therefore, the positive foreign interest rate shock results in an immediate change of portfolio to foreign deposits, while all other domestic variables stay at their steady state levels.

However, if capital controls are imposed, consumption will change because adjustment of the foreign currency deposits will incur additional costs which persist over time. In particular, the increase of foreign currency deposits implies an income effect entering into the international risk-sharing relationship between domestic and foreign consumers. Thus, household consumption will increase. This increase in consumption is supported by lower domestic deposits, reducing the ultimate credit supply in the banking system, which leads to wide reductions in investments, asset prices, capital, loan to value ratios, and bank loans. This recession in the credit market reduces the production of the entrepreneur from the supply side. Thus, there is a reduction in output, positive domestic goods and final goods inflation. The final goods inflation is due to the depreciation of the domestic currency, and

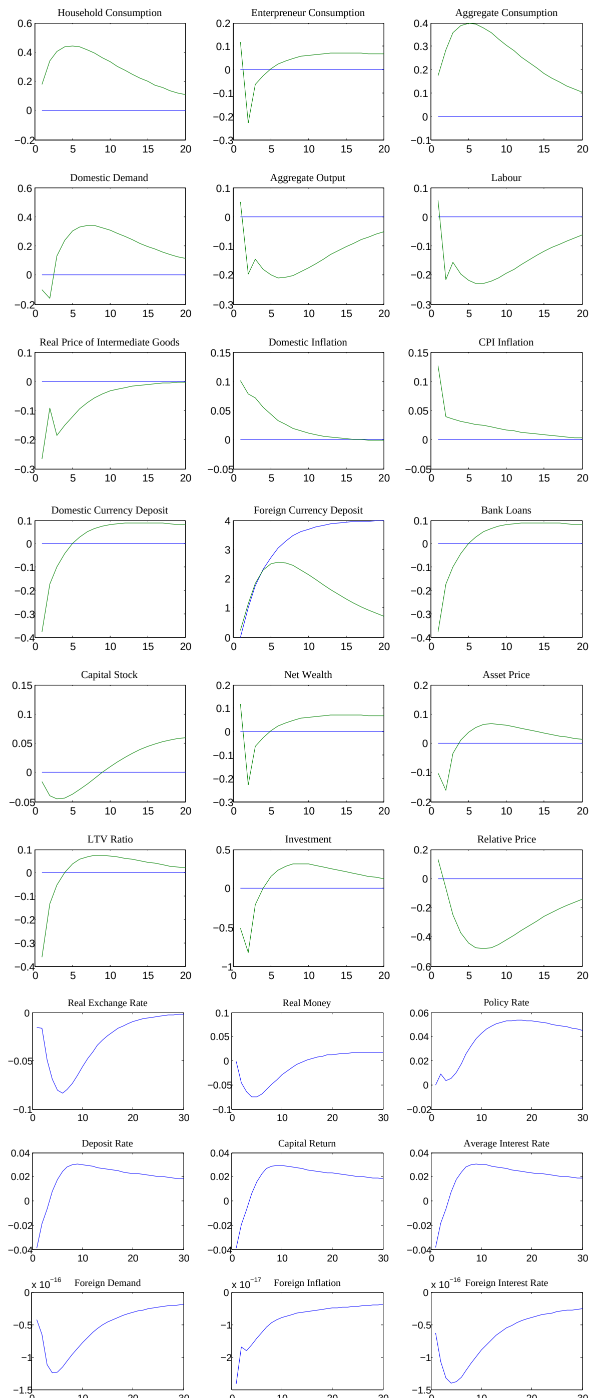


Figure 3.3: Impulse Responses to Foreign Interest Rate Shock

leads to an increased interest rate under the Taylor rule.

In general, capital controls establish a link between domestic interest rates and foreign interest rates such that an increase in foreign interest rates lead to a reduction in domestic credit supply. Capital controls transform the one-shot change of deposit portfolios to a gradual process, and introduce additional volatilities into the economy compared with the case of no capital controls when confronted with a foreign interest rate shock. However, the price for stable domestic variables without capital controls is a dramatic change in deposit portfolios, which is usually related to financial stabilities in emerging economies.

3.6 Effects of Different Levels of Capital Controls

Different degrees of capital controls can have different influences on domestic variables. The patterns of the impulse responses for key variables are related to the calibrated value of the capital control parameter. To examine the performance of the model variables under different calibrated capital control parameters, $SSD(\hat{\tau}_t)$ as defined in (3.60) will be used as the criterion for measuring the accumulated squared percentage deviation from its steady-state level, where $\hat{\tau}_t$ represents the percentage deviation of domestic output, inflation, nominal exchange rate, and bank loans[24]. Parameter β^{cb} is the time discount factor for the central bank.

$$SSD(\hat{\tau}_t) \equiv \sum_{1}^{20} \beta^{\mathsf{cb}} \hat{\tau}_t^2 \tag{3.60}$$

Figure 3.4 gives the responses of $SSD(\hat{\tau}_t)$ under a foreign demand shock.

[24]Only the first 20 $\hat{\tau}_t^2$ will be summarised for simplicity.

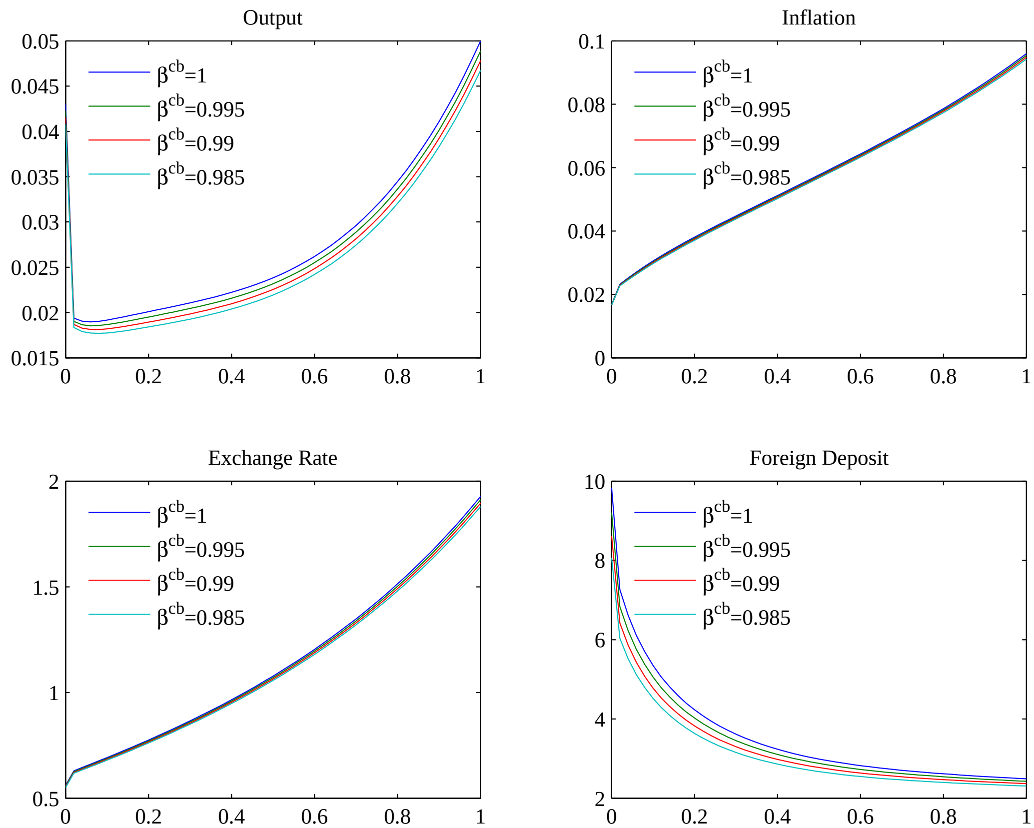


Figure 3.4: $SSD(\hat{\tau}_t)$ under a Foreign Demand Shock

The left axis is the value for $SSD(\hat{\tau}_t)$, and the bottom axis is the value for capital control parameter κ_D.

For different values of the capital control parameter κ_D, the value of $SSD(\hat{y}_t)$ first decreases along with κ_D, then increases. This implies that the volatility of domestic output reduces for mild capital controls.

With no capital controls, consumers will borrow from abroad to support their consumption under a foreign demand shock. Domestic deposits will also increase because of higher loan demand from entrepreneurs. However, capital controls will impose additional costs on foreign deposits and thus restrict of

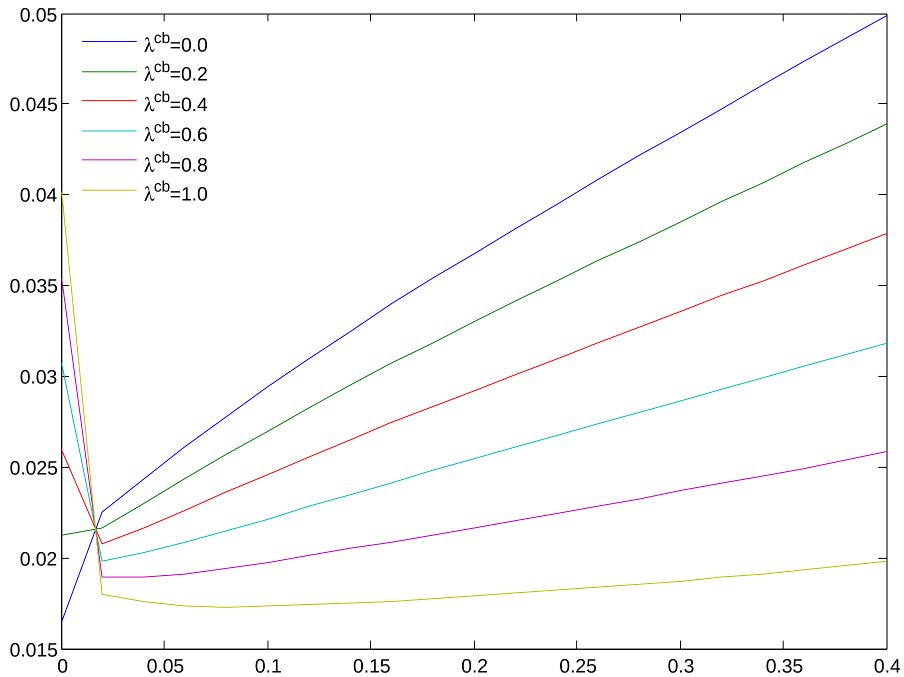


Figure 3.5: Losses under Different Weights on Inflation and Output Gap

households' ability to borrow from abroad because sustained deviations from steady state will be costly for them, as suggested by the decreasing $SSD(\hat{d}_t^F)$ in Figure 3.4.

The reallocation from foreign to domestic deposits will increase the credit supply in the domestic credit market. If the capital control level is too high, the exaggerated effects in the credit market will dominate and thus increase output volatility. Thus, mild capital controls but not strict capital controls can act to isolate foreign demand shocks in the domestic real economy.

However, capital controls are less useful in decreasing the volatility of inflation. The $SSD(\hat{\pi}_t)$ persistently increases with the capital control parameter κ_D. This is not surprising, because inflation acts as a buffer to absorb the

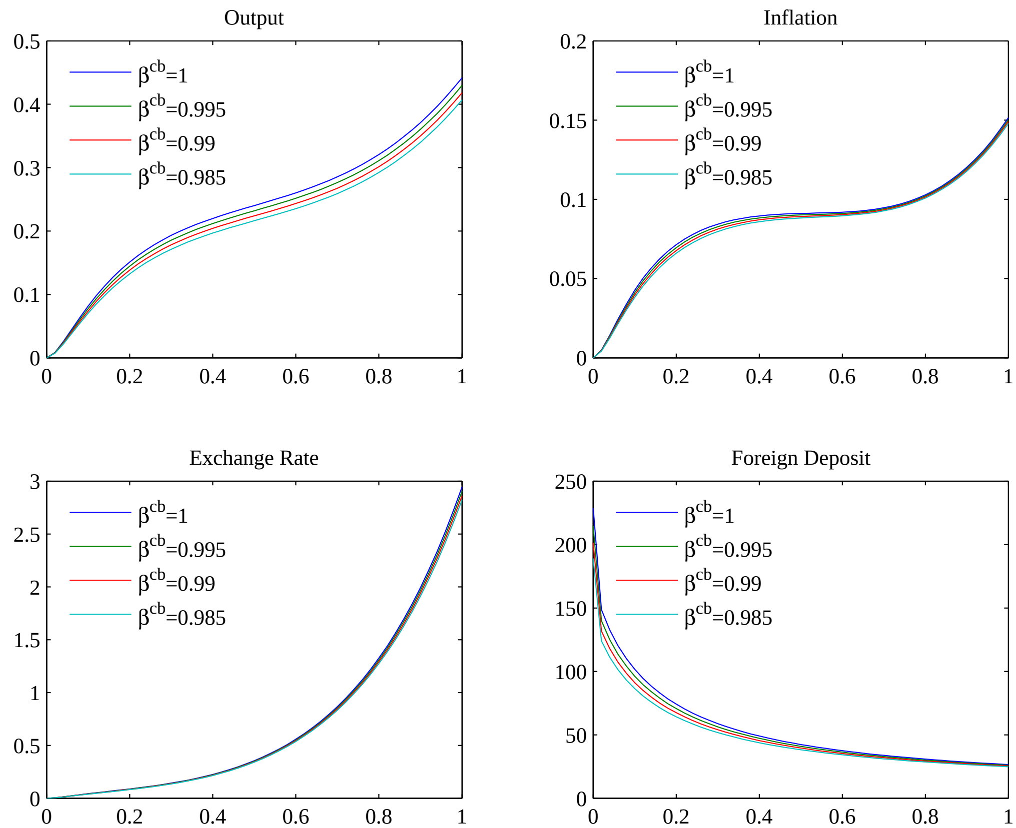


Figure 3.6: $SSD(\hat{\tau}_t)$ under a Foreign Interest Rate Shock

foreign demand shock. The exchange rate has a similar pattern to inflation. Under the assumption of independent foreign shocks, increases in inflation will be accompanied by similar fluctuations of the nominal exchange rate to absorb foreign demand shocks.

As $SSD(\hat{y}_t)$ and $SSD(\hat{\pi}_t)$ are U-shaped and increasing with κ_D respectively, a weighted sum of $SSD(\hat{y}_t)$ and $SSD(\hat{\pi}_t)$ may have a minimum value with respect to κ_D. Assume a loss function for the central bank as in (3.61). The values of $Loss_t$ under different weights λ^{cb} are plotted in Figure 3.5.

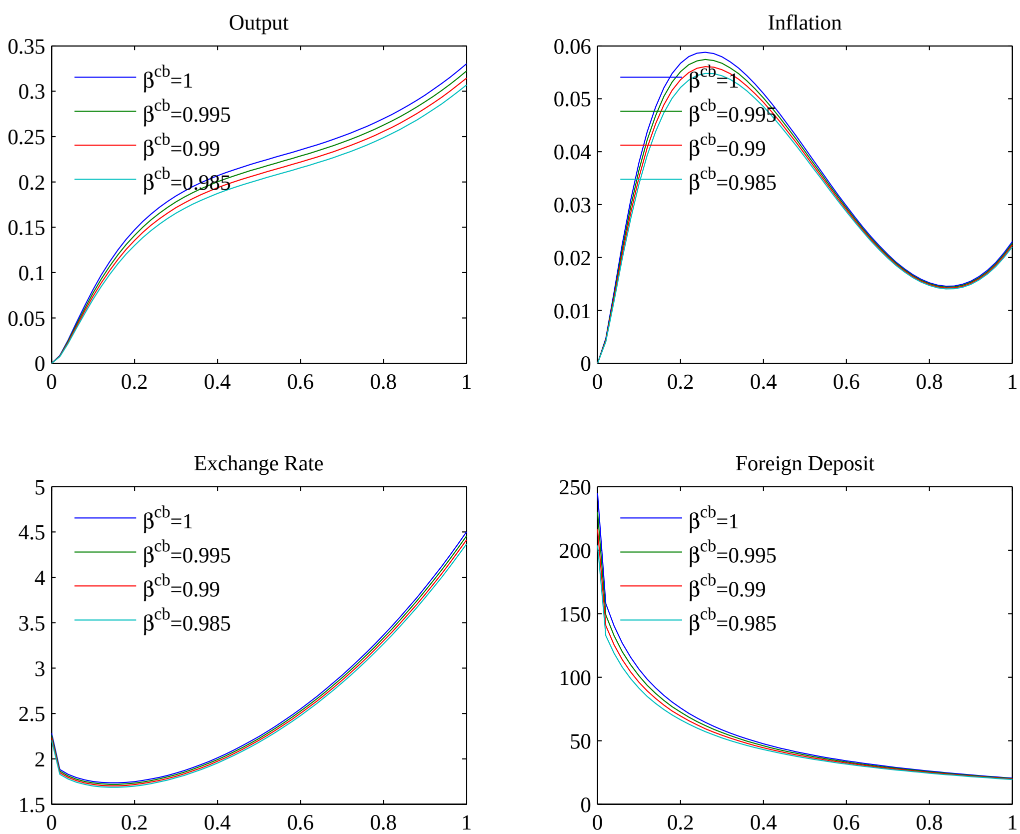


Figure 3.7: $SSD(\hat{\tau}_t)$ under a Foreign Inflation Shock

When λ^{cb} has a value above 0.4, the loss function $Loss_t$ has a minimum value over different λ^{cb}.

$$Loss_t = \lambda^{\mathsf{cb}} SSD(\hat{y}_t) + (1 - \lambda^{\mathsf{cb}}) SSD(\hat{\pi}_t) \tag{3.61}$$

Figure 3.6 gives the sum of squared percentage deviations under a foreign interest rate shock. The sums of the squared output, inflation and exchange rate deviations increase with the level of capital controls. The decrease in foreign deposit deviations are due to the additional costs from capital controls. This finding is consistent with the results of the impulse response analysis which the domestic variables will respond passively to the foreign interest rate shock under capital controls while staying constant if there are no controls at all.

Figure 3.7 gives the sum of the squared percentage deviations under a foreign inflation shock. The sums of squared output and exchange rate deviations increase with the level of capital controls. The top right panel in Figure 3.7 is the sum of squared inflation. $SSD(\pi_t)$ under foreign inflation shock exhibits an inverse S shape. When the capital control parameter κ^D is around 0.80, the value of $SSD(\pi_t)$ is near to that of the no capital control case.

The capital controls on foreign currency deposits in the household budget can reduce output deviations under a foreign demand shock. This type of control can only increase the volatility of the economy under a foreign interest rate and inflation shock. Nevertheless, if there are no capital controls, the deposit portfolio will change dramatically and immediately after the shock, which may incur financial instabilities in emerging economies.

3.7 Conclusion

3.7.1 Main Findings

In an economy with no capital controls, the central bank will be forced to maintain a zero gap between foreign and domestic interest rates under a fixed exchange rate regime because of capital surges and flights. International capital flows thus only play a threatening role in closing the interest rate gap. Capital controls can break the binding relation between interest rate gaps and changes in exchange rates by slowing down the arbitrage transactions.

This study tests and estimates a VECM to examine whether there is a long-run relationship between capital inflows, interest rates differentials, and nominal exchange rates, and whether deviations from the long-run relationship can influence the changes in these variables, based on monthly data from China over the sample period October 2006 to June 2015. It is found that there is a long-run relationship existing between capital inflows and interest rates differentials. Deviations from this long relationship impose an error correction mechanism on the changes in capital inflows, but not on exchange rates and capital inflows. This implies that China has indeed achieved monetary policy autonomy, with a partially opened capital account and an exchange rates regime in general pegged to the US dollar.

The normative analysis using a DSGE model examines the theoretical consequences of capital controls on other variables. A capital control mechanism is introduced by imposing an additional cost on the budget constraint of households such that increases or decreases of foreign currency deposits will incur some transaction costs. The central bank can step into this capital control mechanism by changing the capital control parameter such that it can be extremely costly for households to change their levels of foreign deposits. Under this mechanism, the central bank can influence the speed of capital flows. It is found that capital controls transform dramatic and immediate changes in deposit portfolios into a prolonged and gradually adjusting process. Besides this, capital controls can reduce output fluctuations under a foreign demand shock, but can only increase the volatility of the economy under a foreign interest rate or inflation shock.

If there are no capital controls, consumers will borrow from abroad to support their consumption under a foreign demand shock. Capital controls impose additional costs on holding foreign deposits. Therefore, they can constrain households' incentive to borrow from foreign countries for consumption. Additional costs also lead to reallocation from foreign to domestic deposits. This results in increases in supply in the domestic credit market, and thus lead to increases in asset prices, net wealth of entrepreneurs, investment, and output. If the capital control level is too high, the exaggerated effects in the credit market will dominate and thus increase output volatility. Thus, mild capital controls but strict capital controls cannot act to isolate foreign demand shocks in the domestic real economy.

Moreover, there is an optimal capital control level, if the weight of output volatility in the central banks loss function is high enough. This indicates the proposition of Xiaochuan Zhou may be appropriate if the central bank places sufficient weight on output gaps.

Impulse response analyses suggest that this capital control mechanism can mitigate the output volatility of the economy when facing a foreign demand shock, but may induce additional capital market volatility. A more open capital account suggests that the economies will be more robust because real shocks can be absorbed by the nominal shocks more quickly. Therefore, it can be predicted that, with less restrictions on foreign institutional investors, there will be more fluctuations in financial market variables, such as exchange rates and asset prices. However, the financial sectors can work better to mitigate the real shocks. Capital controls can incur additional volatility in the economy when confronting a foreign interest rate shock, because the controls transform the immediate changes to deposit portfolios to a gradual adjustment process. A foreign interest rate shock cannot influence real variables of the domestic economy if there are no controls, while capital controls create a transmission mechanism that links the domestic economy and foreign nominal shocks.

3.7.2 Future Work

In the empirical section, FDI inflows are used to examine possible arbitrage pressures on interest rate parity, because of the special position of FDI inflows in China's financial and capital account, and the availability of data. However, comprehensive tests can be conducted by using more types of capital flow data in different frequencies.

In the theoretical section, the capital control mechanism is examined by imposing additional costs on the budget constraints of households as portfolio capital inflows and outflows are highly restricted in China. Nevertheless, the theoretical section does not embed FDI inflows in the DSGE model directly and explicitly. Extensions in this direction will enhance the theoretical findings in this study.

3.A Appendix

3.A.1 PP Test and Cointegration Relations

Table 3.7: Phillips-Perron Test for Unit Roots

	Level		1st Difference	
Series	Prob.	Bandwidth	Prob.	Bandwidth
$\log(\mathcal{E}_t/\mathcal{E}_{t-1})$	0.0000	3	0.0001	36
IRD*	0.1858	13	0.0000	16
FDI/GDP	0.0000	4	0.0001	26

Automatic bandwidth is selected using Newey-West procedure. $\mathcal{E}_t$ is nominal RMB/USD exchange rate at month t. Prob. refers to MacKinnon (1996) one-sided p-values. Individual intercept and trend are included in the test equation.

Table 3.8: Estimated Cointegration Relations for Equation (3.1)

Cointegrating Equation	1	2
	(0.0231)	(-0.6187)
Constant	-0.0066	-0.0259
	[3.4968]	[-23.8720]
	-0.0060	0.0564
IRD(-1) *	(-0.0026)	(-0.0103)
	[-2.2947]	[5.4672]
$\Delta\log(\mathcal{E}_t/\mathcal{E}_{t-1})(-1)$	1.0000	0.0000
ΔFDI/GDP(-1)	0.0000	1.0000

Standard errors in ( ), and t-statistics in [ ]. *IRD is short for interest rate differentials between Shibor and effective Federal Funds rate.

3.A.2 Log Linearisation

Log linearize (3.57), we can get (3.63) .

$$y_t = z_t - \eta(p_{H,t} - p_t) + \alpha(\gamma - \eta)s_t + \alpha\eta q_t + \alpha(z_t^* - z_t) \tag{3.62}$$

Note that $p_{H,t} - p_t = -\alpha s_t$, and $q_t = (1-\alpha)s_t$. Define $\omega \equiv \gamma + \eta(1-\alpha)$, we can get (3.63).

$$y_t = (1-\alpha)z_t + \alpha z_t^* + \alpha\omega s_t \tag{3.63}$$

Chapter 4

An Open New Keynesian Model with a Banking Sector

4.1 Introduction

The financial crisis of 2008 revealed that monetary policy is insufficient to maintain a stable financial system. Macroprudential tools were thus proposed as supplements to enhance financial stability under shocks. Nevertheless, the usefulness of macroprudential policy and its relationship to monetary policy are still under open discussion. This chapter builds an open economy model with a banking sector and estimates it using Chinese data, in order to analyse the effects of monetary and macroprudential policies from the Chinese view point.

Compared with the existing literature, this study makes contributions. First, the banks in the model have an elaborated balance sheet structure, through which they can increase their leverage ratio quickly. Banks work as financial intermediaries linking households and entrepreneurs, whose deposits and loans are usually long term, while liabilities from the central bank and foreigners can work as short term funding sources for banks. Borio and Shim (2007) find that financial imbalances will increase with the expansion of funding through the foreign market. This reliance on short-term funding sources enables banks to expand their balance sheets quickly through a higher leverage ratio.

Second, the model economy operates in an open economy environment. The financial crisis in 2008 revealed that an increase of the foreign risk premium had a significant adverse effect on the domestic financial system and economy. Expanding the New Keynesian model with a banking sector to an open economy environment is useful to examine the possible spillover effects of a foreign risk premium shock. The imperfect substitutions between domestic and foreign asset implies that nominal returns on domestic deposits and foreign deposits can be different under the same currency. This provides a mechanism to analyse the relationship between purchasing power parity and interest rate parity in a New Keynesian model.

Third, this study compares the effectiveness of monetary policy and macroprudential policy. Four different policy sets, including different combinations of a standard Taylor rule, a loan to value ratio extended Taylor rule, and a macroprudential tool, are assessed based on a central bank loss function. It is found that the extended Taylor rule has no dominant role among the four combinations of policies. The extended Taylor rule with macroprudential policy has lower losses compared with other policy sets. However, the macroprudential tool can generate a marginal reduction in losses that are in the objective function of the central bank.

Fourth, the model is calibrated and estimated using Bayesian methods based on quarterly data from China, covering a sample period from 1996Q1 to 2015Q4. There is a relatively small body of empirical DSGE literature using Chinese data, compared with the models estimating for data of industrial economies. Estimation results suggests that inflation in China is highly persistent. Substitutability of different funding sources is high, and thus banks are sensitive to different interest rates.

4.2 Literature Review

The main motivation of this study is to build a model that can be used to examine the risk-taking behaviour of banks and the relevant macroprudential and monetary policy that can be used to discipline this behaviour of the banks. There are several strands of literature related to this paper: monetary policy transmission channels; systemic risk and macroprudential regulation; and policy analysis in DSGE models.

4.2.1 Monetary Policy Transmission Channels

The first strand is the monetary policy transmission channel literature. In New Keynesian models for analyzing monetary policy, the interest rate channel is one of the most important channels. Following the work of Bernanke, Gertler, and Gilchrist (1999), one additional transmission channel of monetary policy through the banking sector i.e. the credit channel, is widely examined in the literature both theoretically and empirically. The recent work of Borio and Zhu (2012) specifies another monetary policy transmission channel through the banking sector, refer to as the risk-taking channel. The main difference between the credit channel and the risk-taking channel is that the latter emphasizes the proactive behaviour of the banks. Bernanke, Gertler, and Gilchrist (1999), Iacoviello (2005), Gerali et al. (2010), and Gambacorta and Signoretti (2014), just to name a few, all take the banking system as a passive sector in the economy model. That is, they assume the banks cannot expand their balance sheets at their will. They adjust interest rates to close the gap between ultimate fund supply and demand. In this sense, their risk-taking behaviour cannot be examined in these models because banks are entirely intermediate institutions connecting demand and supply in the credit market. Banks cannot choose to expand their balance sheet proactively even if they want to. However, banks do behave actively rather than passively in the real world. This chapter aims to build a model to examine the active behaviour of banks.

The risk-taking behaviour of banks has several sets of effects on the financial system and real economy because of (Borio and Zhu, 2012). The first set of effects is on risk attitudes and risk evaluation. A low interest environment can reduce a borrower's default rate, which in turn encourages risk-taking behaviour by banks. This impact is similar to the balance sheet channel of monetary policy or the financial accelerator effect. However, the risk-taking channel emphasizes the risks rather than the returns of borrowers. Thus, it is in fact an enhancement of the financial accelerator effect. The second set of effects is on the relationship between market rates and banks' required rates of returns. This effect is sometime referred to as the search for yield effect, which emphasizes the deviation of market interest rates from the banks' required returns (Borio and Zhu, 2012). This search for yield effect is related to the concept of maturity mismatch. For example, returns on loans and deposits cannot change as quickly as policy rates because their terms are usually longer than the terms of policy rates and relatively difficult to adjust due to the nature of contracts. Thus, the banks cannot adjust their asset returns as quickly as their average financing interest rates if they relying mostly on short-term financing sources. The third set of effects of risk-taking is through the communication and reaction function of the central bank. In particular, banks may expect the central bank to cut off large downside risks through expansionary monetary policy. Such commitments by the central bank may encourage banks to engage in more riskiness. This is the case in China for the banking system, particularly for the big four state-owned banks.

4.2.2 Macroprudential Policy and Financial Stability

The second strand of this review is the literature about macroprudential policy and systemic risk. Before the financial crisis in 2008, there was a broad consensus on monetary policy among academics and policy makers. Mishkin (2011) summarises nine basic monetary principles, such as "*price stability has important benefits*". In general, the monetary authority should mainly react to inflation, or improve the employment status in the economy if inflation is well controlled (Galati and Moessner, 2013). After the financial crisis in 2008, macroprudential policy became widely discussed as an additional choice alongside monetary policy. The term, macroprudential policy, dates back to unpublished documents in the late 1970s. It appeared in publications in the 1980s and became well known because of a famous speech by Crockett (2000). However, there is still no consensus on the targets, measurements, and tools of macroprudential policy (Galati and Moessner, 2013).

In general, the aim of macroprudential policy is to maintain financial stability. However, the term financial stability has no concise and widely accepted definition yet. Financial stability can be vaguely defined as providing stable financial services, as suggested by BoE (2009). Nevertheless, macroprudential policy should not react to common booms and instability signals as they may not be directly related to the credit expansion of the banks. Perotti and Suarez (2009) regard the main aim of macroprudential policy as reducing the negative externality of systemic risk. The definitions of financial stability can be divided into two groups. The first focuses on the stability of the financial system when confronting exogenous shocks. The second is about the stability of the financial system when confronting endogenous factors. In this study, both exogenous and endogenous factors will be examined. Endogenous instability is modelled as the risk-taking behaviour of banks when increasing their leverage ratio and loan to value ratio. Exogenous instability is assessed by examining the economy's impulse responses to shocks.

Although there are different opinions on macroprudential policy targets, Crockett (2000) suggests a useful starting point is to distinguish between the micro prudential and macroprudential policies. In general, the ultimate target of macroprudential policy should be to mitigate the costs resulting from financial instability or systemic risk, which are two closely related concepts. Systemic risk and financial stability can be regarded as the object and aim of macroprudential policy respectively. The literature on systemic risk blossomed in the post-financial crisis era and influenced the regulatory and supervisory attitudes of the banking system. Although there are still no dominant methods for measuring systemic risk, the importance and features of systemic risk are widely examined.

Galati and Moessner (2013) suggest that systemic risk can be described through both cross-sectional and longitudinal dimensions. The cross sectional risk mainly refers to contagion among financial institutions, while the longitudinal risk mainly refers to the procyclicality of the financial risks (Caruana, 2010). The distinctions between cross-sectional and longitudinal system risk are important for policy tool design. Trichet (2009) discusses the importance of systemic risk in regard to the contagion effect, the hump effect, and the amplification effect. The dichotomy used by Galati and Moessner (2013) is conceptual while the categorization of Trichet (2009) provides more structural insights into systemic risk.

Contagion can refer to the correlation of individual risks [1]. In the classical asset pricing model, idiosyncratic risks are assumed to be independent. However, what appears as idiosyncratic may have systemic importance under a contagion mechanism, which turns individual and self-contained risks into systemic risk (Trichet, 2009). The transactions between counterparties may impose negative effects on other financial market participants because financial markets segments and participants are interconnected through various

[1] See explanations about the Domino model in the work of Brunnermeier et al. (2009).

types of transactions. This contagion implies that microprudential regulation is not sufficient for assuring systemic stability.

The hump effect refers to the slow buildup and quick unraveling process of financial imbalances. This mechanism is closely related to informational asymmetries and learning mechanisms. A sequence of positive shocks may be regarded as a sign of a long-run expansion while in fact it is not. When market participants finally realize the fact, the imbalance suddenly erupts and it gets evens it out abruptly. The process of unravelling can damage the economy because the financial sector is functionally important for the economic system. In the unravelling process, some banks may go bankrupt because of the drying-up of market liquidity. As explained by Brunnermeier et al. (2009), liquidity can be divided into funding liquidity and market liquidity, which concerns the funding and selling aspects of the banks respectively. In the unravelling process, banks may prefer to shrink their balance sheets by selling assets because of the drying-up of the short term funding sources. However, market liquidity does dry up and margins for fire-selling shoot up. The banks therefore cannot sell their assets at a fair price. At this stage, many of the banks will go bankrupt and this may damage the real economy.

The final feature of systemic risk is the amplification effect. This mechanism concerns mainly the relationship between the financial system and real economic activity. Usually, the individual risks of banks are unable to shake the real economy. However, systemic risk can. One of the famous amplification mechanisms is the financial accelerator effect as explained by Bernanke, Gertler, and Gilchrist (1999). Given asymmetric information in the economy, net worth will act as a buffer absorbing the risks. Net wealth increases in the boom periods and decreases in recession periods, which indicates that wealth worth will amplify the fluctuation of the economy.

For macroprudential policy tools, there are many suggestions in the literature. Hannoun (2010) summarises prudential policy tools. Microprudential tools including the capital ratio and leverage ratio. Macroprudential tools include counter-cyclical capital requirements. It has been suggested that the macroprudential target can also be achieved in developing countries by taming capital flows with controls on outstanding foreign assets (Tucker, 2009). Regarding the cross-sectional and longitudinal aspects of the macroprudential policy target, the tools can be grouped as well. One of the widely suggested longitudinal tool is the counter-cyclical capital adequacy requirement. This tool can be used to reduce the adverse effects of securitisation on systemic stability (Shin, 2010). Another longitudinal tool is the loan to value ratio. Borio, Furfine, and Lowe (2001) suggests that loan loss provision will be higher in recessions because of the influence of account rules, tax codes, and risk measurements. These factors will result in lower loan to value ratios in bad times. The time varying requirement or maximum value restriction on loan to value ratios will mitigate the adverse effect of the procyclical leverage ratio.

In this study, the loan to value ratio will be used as a macroprudential tool to reduce the possible procyclical effects of financial shocks on business cycles in a New Keynesian model. Macroprudential tools may be used to confine systemic risk before it becomes uncontrollable. Arrangements and schemes can be applied to limit the growth and build up of systemic risk. However, even if systemic risk is small, amplification and contagion can exist. Thus, two policy ideas are important based on the features of systemic risk.

The first one is that the macroprudential policy should be designed to mitigate the tendency of the banking sector to build up systemic risk. However, the basic New Keynesian model cannot be employed to examine this type of policy because it assumes the bank sector is usually a passive actor in the economy. That is, imbalances can only originate from the real sector rather from the financial sector. Thus, it is not possible to examine the evolution of financial imbalances via the basic New Keynesian model.

The second idea is to reduce the contagion and the amplification effect. Contagion implies complex inter-connections within the financial sector (Brunnermeier et al., 2009). Liquidity risk connections rather than credit risk connections should be a primary feature of the model because one of the most damaging mechanisms in the 2008 financial crisis was the drying-up of market liquidity (Brunnermeier et al., 2009). When this happens, banks cannot roll over their liabilities or sell their assets at a fair price. The amplification effect is an inherited feature of the financial system under asymmetric information. Given the current stage of the information collection and distribution system, it may be relatively difficult to reduce information asymmetries quickly. A more possible and realistic attitude to handling the amplification mechanism is therefore to accept and control them. For example, in the post-financial crisis era, central banks can step in to provide loans to firms and cut the amplification mechanism from the financial sector to the real economy.

4.2.3 Policy Analysis in DSGE Models

The third strand of literature is about the policy analysis in DSGE models. The Taylor principle was proposed by Taylor (1993) and was then widely used to characterise monetary policies by central banks. There are various types of Taylor rule, with the key being to ensure the determinacy of the linear rational expectation system in dynamic stochastic general equilibrium (DSGE) models. Usually, the linear rational expectation system is derived from first-order conditions using approximation methods, usually log linearisation. The Taylor rule becomes a necessary and sufficient condition for determinacy in such models.

However, when more structures about information and expectations are introduced into the system, the conventional Taylor rule may no longer be sufficient to ensure determinacy. Consider some cases in which the simple Taylor rule must be extended to handle the new situation. The first extension is to handle a regime-switching parameter. As in the work of Davig and Leeper (2005), a Markov switching mechanism is introduced into the model and a generalised Taylor principle is proposed to ensure the stability of the expanded rational expectation system. Another extension is to consider the interest spread in the market. If we consider systemic risk in the financial sector, some type of extended Taylor rule can be employed to handle imbalances in the financial sector. The interest spread or margin can shoot up as the market panics, which leads to liquidity problems for the banks. Taylor et al. (2008) proposes that the conventional rule can be modified to incorporate an interest rate spread. Curdia and Woodford (2010) find that this type of modification can improve the economic responses to shocks from the bank credit supply side.

In order to examine the effects of different proposed policies, DSGE models are now widely used to analyse the relationship between systemic risk and the macroeconomy (Sbordone et al., 2010). However, there are several disadvantages to the basic versions of DSGE models which include no meaningful financial frictions (Bean, 2009), no accumulation and bursting of financial booms (De Bandt, Hartmann, and Peydr, 2009), and an implicit assumption of no bankruptcies (Goodhart, Osorio, and Tsomocos, 2009). In order to provide a more elaborate analysis of monetary and macroprudential policy, it is necessary to overcome these shortcomings.

To deal with these, two types of modifications are developed. The first is a consideration of credit constraints on non-financial borrowers, such as in the work of Curdia and Woodford (2009), Christiano, Trabandt, and Walentin (2011), Gerali et al. (2010), etc. Collateral constraints were used by Iacoviello (2005) which is another widely cited work with this modification. The main idea of this type of model is to build a financial accelerator mechanism similar to that of Bernanke, Gertler, and Gilchrist (1999). In the work of Kannan, Rabanal, and Scott (2012), a model with a financial accelerator is built to examine the performance of the interest rate tool and the macroprudential tool. They found that when monetary policy responds to the financial accelerator if can enhance financial stability. Moreover, macroprudential tools can be used to tame credit cycles. Galati and Moessner (2013) criticise this type of model for focusing only on the frictions of nonfinancial borrowers and argue that it therefore cannot be used to understand the financial crisis of 2008.

The second type of modification considers frictions within the financial sector. These models are widely used to examine the role of bank capital in the policy transmission channel. One of the main finding of these models is the critical importance of different interest rates in the economy. Goodfriend and McCallum (2007) introduce a banking sector into the model to make a clear distinction between mortgage interest rates, Treasury bill rates, net returns to capital, and pure intertemporal rates. In the model of Gertler and Karadi (2011), financial intermediaries face endogenous balance sheet constraints. In the work of Gerali et al. (2010), a competitive competition banking system is embedded to distinguish different interest rates in the model. The real economy part of Gerali et al. (2010) follows the work of Iacoviello (2005) where the collateral constraint of borrowers is always binding. In the work of Bianchi and Mendoza (2011) and Jeanne and Korinek (2012), a collateral constraint that is not always binding is considered. The overborrowing problem is introduced in their models by assuming an externality of borrowers. This provides a hint about now introducing macroprudential tools can reduce externalities in the banking sector. Several other papers consider the externality problem as well, such as Perotti and Suarez (2009). Christensen, Meh, and Moran (2011) assume asymmetric information between banks and borrowers. The externality of bank decisions imply that the countercyclical regulation of the balance sheet will stabilise the financial system and economy. Countercyclical leverage regulation will mitigate the externality, especially when shocks are from the financial sector.

Using these extended DSGE models, the effects of an extended Taylor rule and macroprudential policy are widely discussed. Researchers usually find the extended Taylor rule and macroprudential policy useful, especially when shocks are from the financial sector. Some authors propose an extended Taylor rule as a reaction to procyclical asset prices or other financial factors. As mentioned above, Curdia and Woodford (2010) suggest that the interest rate spread can be added into the standard Taylor rule to deal with procyclical financial factors. However, Faia and Monacelli (2007) find that the marginal welfare gains produced by embedding asset prices in the standard Taylor rule will disappear if the reaction of policy interest rates to inflation becomes substantially large.

Based on the work of Gerali et al. (2010), Angelini, Neri, and Panetta (2011) estimate a New Keynesian model using Europe data. Macroprudential policy is implemented using a countercyclical leverage ratio. It is found that the effectiveness of macroprudential policy is minor if shocks are from the supply side, and sizable if shocks are from the financial sector. It is also found that the combination of monetary policy and macroprudential policy is beneficial. Quint and Rabanal (2014) estimate a New Keynesian model using European data as well and find macroprudential policy can reduce business fluctuations. Rubio and Carrasco-Gallego (2014) establish a model using a collateral constraint. They select the loan to value ratio as the macroprudential policy tool. It is found that a mix of monetary policy and macroprudential policy can increase the overall welfare of the economy. The welfare analysis of Rubio and Carrasco-Gallego (2014) follows the work of Mendicino and Pescatori (2007) using a weighted average welfare of households and entrepreneurs. Nevertheless, this overall increase in welfare is in fact an aggregated result of the welfare tradeoff between the ultimate borrowers and lenders.

Benes and Kumhof (2011) compare the capital adequacy ratio tool with traditional monetary policy. They find that the capital adequacy ratio will reduce the adverse effects of a creditability shock on entrepreneurs and increase the welfare of the economy. Brzoza-Brzezina, Kolasa, and Makarski (2015) establish a two-country model to examine the imbalance between central countries and peripheral countries in Europe, following the collateral constraint setting of Iacoviello (2005). The loan to value ratio is used as the macroprudential policy. It is found that macroprudential policy can reduce the credit and output fluctuations of peripheral countries.

Lambertini, Mendicino, and Punzi (2013) find that the loan to value ratio reacting to credit expansion can stabilise the economy. Funke and Paetz (2012) find the loan to value ratio rule works better than the traditional Taylor rule in a New Keynesian model. Darracq-Paries, Sorensen, and Rodriguez-Palenzuela (2011) find that countercyclical capital requirements can smooth the business cycle but may lead to high fluctuations in balance sheets. Brzoza-Brzezina, Kolasa, and Makarski (2014) examine the welfare implications of foreign loans. It is found that foreign loans have a positive influence on monetary policy transmission. In the work of Brzoza-Brzezina, Kolasa, and Makarski (2014), the total loans of households are defined in terms of a constant elasticity function. Gilchrist and Zakrajšek (2011) extend the work of Bernanke, Gertler, and Gilchrist (1999) and find an extended Taylor rule reacting to the interest spread will reduce the adverse impact of financial shocks. Bailliu, Meh, and Zhang (2015) establish a model based on Gilchrist and Zakrajšek (2011) and estimate it using Canadian data. Four different combinations of policies are examined including the standard Taylor rule, an extended Taylor rule, a mix of a standard Taylor rule and macroprudential policy, and a mix of an extended Taylor rule and macroprudential policy. It is found that both the extended Taylor rule and the macroprudential tool policy increase the welfare of the economy.

4.3 An Open Economy Model with a Banking Sector

The model in this Chapter will contribute to the DSGE literature by clarifying the choice between the extended Taylor rule and the macroprudential rule. Three features are introduced in order to handle the considerations discussed in the previous subsection.

First, the banks can adjust their balance sheet structure to actively adapt to different interest rates and risk environments. Second, liquidity effects can be examined in the model to address the interactions between credit and liquidity risk. Third, foreign funds can be one of the main funding sources so that the effects of foreign risk premium shocks can be examined. The main difference between the model in this chapter and other models is that the banks can expand their balance sheets through relying more on wholesale market financing.

The model elaborates on the banking sector typical in Iacoviello (2005), Gerali et al. (2010), and Gambacorta and Signoretti (2014). In the work of Bernanke, Gertler, and Gilchrist (1999), an interest rate spread is introduced through a costly state verification assumption. This spread is negatively related to the net worth of firms, which is implicitly pledged as collateral. This wedge between the deposit and loan interest is the key through which the financial accelerator mechanism works. However, the banks in their model are not permitted to actively take more risks because households' deposits are the only liability of the banking sector. The deposit and the loan markets are not treated separately, and thus banks actually passively adjust loan interest rates to maintain the balance sheet constraint, i.e. deposits must equal loans in size. Iacoviello (2005) establishes a model in which the banking sector follows the collateral constraints specified by Kiyotaki and Moore (1997).

Entrepreneurs' borrowing is constrained by the the value of their housing as collateral, which is determined by housing prices, interest rates, and a loan-to-value parameter. This model cannot be used to examine banks' risk-taking behaviour because the collateral constraint is always binding, and household deposits are the only source of funding. Gerali et al. (2010) extend the work of Iacoviello (2005) by considering a banking sector with retail and wholesale funding departments. Gambacorta and Signoretti (2014) use a simplified version of the Gerali et al. (2010) model to examine a leaning-against-the-wind monetary policy. Both of these models divide a bank into two departments - the wholesale department and the retail department. The wholesale department in general determines the capital structure given the current level of bank capital. The retail department determines the interest rates for deposits and loans in the retail market using a markup pricing method. In the wholesale market, optimal leverage is externally assumed and banks bear additional deadweight loss if they deviate from this optimal leverage. As there are costs incurred in building up capital, the banks cannot adjust their bank capital immediately.

In the model of this chapter, the balance sheet of the banking sector is introduced structurally in the sense that the asset and liability parts are modelled separately. This is usually the case in reality because banks usually manage their assets and liabilities in different departments. The funding problem will be considered independently from the asset side. In particular, banks consider their loan problem without directly bothering to address where these funds will come from. The funding sources do not strictly restrict the loans extended. In the liability department, the bank will take the loan demand as given, while seeking to find various sources to satisfy this demand, keeping the financial costs as low as possible. This type of bank structure can be supported by a typical bank sector balance sheet, as shown in Table 4.1. The asset side of the bank sheet includes the loans and reserves, while the liability and equity side includes the financial sources from cash, debts, and bank capital[2]. The funds collected from deposits and central bank lending are not used entirely for granting loans. In fact, only a fraction of the money can be used to extend loans[3].

Table 4.1: Sources & Uses of Funds Depository Financial Institutions

Asset	Liability and Equity
Reserves, Cash, and other Asset (38%)	Retail Deposit (88%)
Loans (62%)	Financial Bonds (2%)
	Equity (10%)

Ratios in this table are the average monthly data of first four months in 2016. The financial bonds are the sum of domestic bonds and liabilities to international financial institutions. The ratio of foreign bonds to total bonds is 5.8 per cent. Data Source: Sources & Uses of Credit Funds of Financial Institutions, available at: `http://www.pbc.gov.cn/diaochatongjisi/116219/116319/3013637/3013643/index.html`

Using the bank balance sheet structure in Table 4.1, the risks on the asset and liability sides can be considered separately. One of the main concerns is the liquidity problem, which results from the mismatch of long term assets and short term liabilities. This mismatching requires banks to reserve some cash to cope with cash withdrawal demands. In this chapter, this cash withdrawal demand is captured using the money demand of households.

On the funding source side, the terms of the sources are not the same. The terms of deposits are typically longer than for wholesale funding. Equity has an "infinite" term and is used as a credit and liquidity buffer to supplement the demand for retail and wholesale funding liquidity. In particular, liquidity demand is modelled through a hair cut or a margin required by the ultimate fund suppliers. For example, only a portion of the retail deposit is used for extending loans. The loanable portion of the wholesale fund is usu-

[2]In China, the retail deposit, wholesale funding, and equity comprise 88 per cent, 2 per cent and 10 per cent of the entire financial source respectively.

[3]As shown in Table 4.1, about 62 per cent of the total funding is used for loans.

ally smaller because of the higher liquidity demand in the wholesale funding market. That is, the wholesale funding portion needs more equity to act as a liquidity buffer. On the asset side of the balance sheet, there are loans granted and cash reserves. The reserves are not necessarily cash. However, in this study, for simplicity, it is assumed that all the reserves are in cash. The loans are granted to entrepreneurs.

Other sectors in the economy include households, entrepreneurs, retailers, capital goods producers, and the central bank. Households provide labour to the entrepreneur and earn wages to consume. Following the specification in Iacoviello (2005), households are assumed to be more patient than entrepreneurs as they choose to save in the steady state. Entrepreneurs consume too. The difference is that entrepreneurs are more impatient and own firms. They employ the labour supplied by the households to produce. The funding sources of the entrepreneur include internal sources, i.e. capital, and external sources, i.e. bank loans. The size of the bank loans is constrained by the value of the capital. The retailers are important because they are critical to the sticky pricing mechanism. Retailers are monopolistic competitive in that they can charge a markup over marginal cost. The stylised Calvo (1983) sticky price is used to generate the New Keynesian Phillips Curve. The central bank uses policy rules to achieve its policy goals. One of the aims of this model is to compare the impacts of different types of rules on the banking sector and the real economy.

4.3.1 Goods and Prices

Both the households and entrepreneurs need consumption to achieve utility. This assumption follows the work of Dixit and Stiglitz (1977) in which diversity of goods is favoured by consumers. In this study, the setting of different goods and their prices follows the work of Gali and Monacelli (2005). The final consumption goods C_t is a bundle of domestic goods $C_{H,t}$ and foreign goods $C_{F,t}$, which are defined as (4.1), (4.2), and (4.3) respectively. In (4.2), $C_{H,t}(j)$ is the retail goods j produced domestically. In (4.3), $C_{i,t}$ and $C_{i,t}(j)$ is the goods index and retail goods j produced within country i. Different goods are not perfectly substitutable in the sense that they enter into final consumption goods C_t nonlinearly.

In these equations, parameters including η, ε, and γ represent the elasticity of substitution among different types of goods. For example, when $\eta \to 0$, the index C_t approaches the Leontief function such that there is no substitution between $C_{H,t}$ and $C_{F,t}$ at all. When $\eta \to \infty$, the index C_t approaches to a linear function such that $C_{H,t}$ and $C_{F,t}$ are perfect substitutes. This substitution parameter is important because it determines the slope of the demand function for the intermediate goods, and thus the market power of the retailers. Other substitution parameters can be interpreted similarly. The parameter α represents the degree of home bias in preferences and can be regarded as a natural index of openness.

$$C_t \equiv \left((1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \tag{4.1}$$

$$C_{H,t} \equiv \left(\int_0^1 C_{H,t}^{\frac{\varepsilon-1}{\varepsilon}}(j)\, dj \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{4.2}$$

$$C_{F,t} \equiv \left(\int_0^1 C_{i,t}^{\frac{\gamma-1}{\gamma}}\, di \right)^{\frac{\gamma}{\gamma-1}} \tag{4.3}$$

$$C_{i,t} \equiv \left(\int_0^1 C_{i,t}^{\frac{\varepsilon-1}{\varepsilon}}(j)\, dj \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{4.4}$$

The price for goods $C_{H,t}(j)$ is $P_{H,t}(j)$. When markets clear, supply equals demand for retail goods j at time t, i.e. $Y_{H,t}(j) = C_(H, t(j)$. It can be verified that C_t is a homogenous function of degree one and can be regarded as an index of domestic and foreign goods. This suggests that the construction of final goods satisfies the condition of two-stage budgeting. That is, the problem of choosing the optimal level for each retail goods j from domestic and foreign countries can be divided into two stages. At the first stage, the optimal level for the final goods C_t is solved. At the second stage, the optimal levels for the domestic goods $C_{H,t}$ and foreign goods $C_{F,t}$ are solved.

The two-stage budgeting results are exactly the same as the results of solving the optimisation problem directly for $C_{H,t}$ and $C_{F,t}$, according to Green (1964)[4]. Moreover, based on the definition of C_t, a price index P_t can be constructed as a byproduct of the second stage optimisation problem. P_t can be defined as (4.1) and it is only a function of $P_{H,t}$ and $P_{F,t}$. In fact, the final goods index C_t and price index P_t are two dual variables which can be recovered from each other. We will solve the second-stage optimisation problem, by which the optimal level of the intermediate goods $C_{H,t}$ and $C_{F,t}$, and price index P_t can be found. In particular, the second stage problem is specified as (4.5), subject to budget constraint (4.6), where $\mathbb{E}_t$ is the total expenditure from the first stage optimisation.

$$\max_{C_{H,t},C_{F,t}} C_t \tag{4.5}$$

$$P_{H,t}C_{H,t}+P_{F,t}C_{F,t} = \mathbb{E}_t \tag{4.6}$$

Using the Lagrange method, the demands for $C_{H,t}$ and $C_{F,t}$ can be derived as in (4.7) and (4.8) respectively. Similarly, the demands for $C_{i,t}$, $C_{H,t}(j)$, and $C_{i,t}(j)$, can be derived similarly using the two-step budgeting method,

[4]This trick is used in the banking sector problem to separate the asset and liability problem as well. Details for the banking sector will be illustrated in subsection 4.3.3.

as in equations (4.9), (4.10), and (4.11).

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \tag{4.7}$$

$$C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{\eta} C_t \tag{4.8}$$

$$C_{i,t} = \left(\frac{P_{i,t}}{P_{F,t}}\right)^{-\gamma} C_{F,t} \tag{4.9}$$

$$C_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\varepsilon} C_{H,t} \tag{4.10}$$

$$C_{i,t}(j) = \left(\frac{P_{i,t}(j)}{P_{i,t}}\right)^{-\varepsilon} C_{i,t} \tag{4.11}$$

The two-stage budgeting method ensures that the demand functions derived above are the same as those from the direct optimisation methods. Moreover, the relevant price indexes for final consumption goods, domestic goods, foreign goods, and final goods from country i can be defined as (4.12), (4.13), (3.10), and (4.15). It can be verified that $P_{H,t}C_{H,t} + P_{F,t}C_{F,t} = P_t C_t$. This means that the newly defined indexes can be used as an aggregation in calculation and will not influence the optimisation results.

$$P_t = \left((1-\alpha)\, P_{H,t}^{1-\eta} + \alpha P_{H,t}^{1-\eta}\right)^{\frac{1}{1-\eta}} \tag{4.12}$$

$$P_{H,t} = \left(\int_0^1 P_{H,t}^{1-\varepsilon}\,(j)\, dj\right)^{\frac{1}{1-\varepsilon}} \tag{4.13}$$

$$P_{F,t} = \left(\int_0^1 P_{i,t}^{1-\gamma} di\right)^{\frac{1}{1-\gamma}} \tag{4.14}$$

$$P_{i,t} = \left(\int_0^1 P_{i,t}^{1-\varepsilon}\,(j)\, dj\right)^{\frac{1}{1-\varepsilon}} \tag{4.15}$$

4.3.2 Households and Entrepreneurs

Suppose there is a continuum $(0, 1)$ of consumers in the economy of these consumers, $(0, \tau^{\mathfrak{e}})$are entrepreneurs and the rest $(\tau^{\mathfrak{e}}, 1)$ are households. Define $\tau^{\mathfrak{h}} \equiv 1 - \tau^{\mathfrak{e}}$ as the norm of the household[5]. It is assumed that each of these entrepreneurs on the $(0, \tau^{\mathfrak{e}})$ owns a firm and produces intermediate domestic goods. Intermediate domestic goods are homogenous by assumption. As each entrepreneur owns one specific firm, the terms firm and entrepreneur are used interchangeably hereafter. Intermediate goods cannot be consumed directly and must be combined into final domestic goods and then into final goods for consumption.

Households consume final goods and provide labour to entrepreneurs for wage income. In this study, money is introduced into the model through a cash in advance constraint rather than money in utility. Money in the model can improve social welfare by facilitating transactions rather than by directly increasing the utility of the household in an ad hoc manner. The utility function for the household is specified as (4.16), subject to the budget constraint (4.17) and a cash in advance constraint (4.18).

$$\max_{C_t^{\mathfrak{h}}, L_t^{\mathfrak{h}}, D_t, M_t} E_0 \sum_{t=0}^{\infty} {\beta^{\mathfrak{h}}}^t \left(\ln C_t^{\mathfrak{h}} - \frac{{L_t^{\mathfrak{h}}}^{1+\phi}}{1+\phi} \right) \tag{4.16}$$

In (4.16) and (4.17), $\beta^{\mathfrak{h}}$ is the time discount parameter for households. $C_t^{\mathfrak{h}}$ represents the demand for the final goods from the household. L_t is labour supply and W_t is real wage. Labour leads to disutility in (4.16) but will increase the income by earning more wages. D_{t-1} is real deposits chosen by households at time $t-1$. It pays a predetermined nominal interest rate r_{t-1}^D at time t. $m_t \equiv M_t/P_t$ is real money held by the household, where M_t is

[5]In this chapter, symbols $\mathfrak{e}$ and $\mathfrak{h}$ indicate parameters or variables for households and entrepreneurs respectively

nominal money held by households. Households need cash for consumption, as in (4.18). $\pi_t \equiv P_t/P_{t-1} - 1$ is the growth of the price index. Government controls are prevailing in Chinese economy. In the previous chapter, the controls on foreign assets are embedded. Similar settings can be introduced in this chapter. These controls will establish a link between the interest parity relation and foreign capital flows. Future work can be conducted in this direction to examine the policy implications.

$$C_t^{\mathfrak{h}} + D_t + m_t \leq \frac{1+r_{t-1}^D}{1+\pi_t} D_{t-1} + W_t L_t + \frac{m_{t-1}}{1+\pi_t} \tag{4.17}$$

$$C_t^{\mathfrak{h}} \leq \frac{m_{t-1}}{1+\pi_t} \tag{4.18}$$

The first-order conditions for the household optimisation problem are (4.19), (4.20), and (4.21). Equation (4.19) is a demand function for real money. It suggests that higher consumption will lead to higher money demand.

$$m_{t-1} = C_t^{\mathfrak{h}}(1+\pi_t) \tag{4.19}$$

$$\frac{1}{C_t^{\mathfrak{h}}} = \beta^{\mathfrak{h}} E\left[\frac{1+r_{t-1}^D}{1+\pi_{t+1}} \frac{1}{C_{t+1}^{\mathfrak{h}}}\right] \tag{4.20}$$

$$L_t^{\phi} = \frac{W_t}{(1+r_{t-1}^D)C_t^{\mathfrak{h}}} \tag{4.21}$$

Equation (4.20) is the Euler equation for households which determines the intertemporal consumption. The left-hand side of equation (4.20) is the utility from consumption by spending one unit of wealth in period t. The term $1/C_t^{\mathfrak{h}}$ is the marginal utility from one unit of consumption. One unit of consumption in period t needs one unit of real money saved in period $t-1$. If this one unit of wealth is consumed in period $t+1$ rather than in period t, $1 + r_{t-1}^D$ unit cash can be reserved as cash in period t. Therefore, $(1+r_{t-1}^D)/(1+\pi_{t+1})$ unit real income can be used for consumption in period $t+1$. The discounted utility from consumption in period $t+1$ should equal the utility acquired from consumption directly in period t. The Euler condition (4.20) is quite standard for when a cash-in-advance constraint is incurred.

Equation (4.21) is the labour supply function of households. On the right-hand side is the marginal disutility of providing one unit of labour. W_t in equation (4.21) is the real wage income from one unit of labour. The left hand side of equation (4.21) is thus the utility from consumption using real wage income. The equality suggests that the disutility from labour supply should be compensated by the consumption utility using real wage income. The deposit demand of the household is determined by the budgeting constraint (4.17).

As explained above, there are two types of consumers in the economy: households and entrepreneurs. The time discount factor for entrepreneurs is $\beta^{\mathfrak{e}}$ and we assume $\beta^{\mathfrak{e}} < \beta^{\mathfrak{h}}$. That is, entrepreneurs are less patient than households. Under this assumption, entrepreneurs act as ultimate fund demanders and households as ultimate fund suppliers. Each entrepreneur owns one firm and produces intermediate goods. Entrepreneurs employ labour from households and buy the capital from capital market for production [6]. In this chapter, no risks in production are assumed. Suppose, for modelling simplicity, that entrepreneurs have no transaction costs involved in consumption . Entrepreneurs solve the optimisation problem (4.22).

$$. \max_{C_t^{\mathfrak{e}}, L_t, B_t, K_t^{\mathfrak{e}}} E_0 \sum_{t=0}^{\infty} \beta^{\mathfrak{e}t} \ln C_t^{\mathfrak{e}} \tag{4.22}$$

Entrepreneurs face a real budget constraint and a collateral constraint, as in (4.23) and (4.24) respectively. In constraint (4.23), $C_t^{\mathfrak{e}}$ is the consumption of entrepreneurs. r_{t-1}^B and B_{t-1} are the loan interest rate and loan demand at time $t-1$. In period $t-1$, entrepreneurs determine capital demand

[6] The SOEs and state-owned financial institutions are not treated as special entities in the model.

$K^{\mathfrak{e}}_{t-1}$ and labour demand L_t for production. After production, a δ portion of the capital is depreciated. The rest of the capital $(1-\delta)K^{\mathfrak{e}}_{t-1}$ can be used to produce in the next period. Entrepreneurs determine the level of capital $K^{\mathfrak{e}}_t(j)$ and buy $K^{\mathfrak{e}}_t - (1-\delta)K^{\mathfrak{e}}_{t-1}$ units of the new capital in period t. Both the residual capital after depreciation and the new capital can be traded in the capital market at the real price of Q^K_{t+1} in period t.

$$\frac{Y_t}{X_t} + B_t = C^{\mathfrak{e}}_t + \frac{1+r^B_{t-1}}{1+\pi_t}B_{t-1} + W_tL_t + Q^K_t\left(K^{\mathfrak{e}}_t - (1-\delta)K^{\mathfrak{e}}_{t-1}\right) \tag{4.23}$$

$$B_t \leq E_t\left[\frac{\kappa^{EB}(1-\delta)Q^K_{t+1}K^{\mathfrak{e}}_t}{1+r^B_t}\right] \tag{4.24}$$

Equation (4.24) is the borrowing constraint faced by entrepreneurs. As loans in period t are paid back in $t+1$, the binding borrowing constraint is a portion of the capital value after depreciation at time t. Following Iacoviello (2005), the borrowing constraint is assumed to be always binding. Once the capital size $K^{\mathfrak{e}}_t$ is determined, the relevant loan size $B_t(j)$ is determined as well.

$$Y_t \equiv A_t {K^{\mathfrak{e}}_{t-1}}^{\xi} {L^{\mathfrak{e}}_t}^{1-\xi} \tag{4.25}$$

$$A_t = \rho^A_v A_{t-1} + v^A_t \tag{4.26}$$

The production function Y_t is defined as (4.25). A_t is the technology used by entrepreneurs, and follows an AR(1) process as in (4.26), where $v^A_t \sim N(0, \epsilon^A)$ is a technology shock. $Y_t(j)$ is a Cobb-Douglas function of predetermined capital $K^{\mathfrak{e}}_{t-1}$, and labour $L^{\mathfrak{e}}_t$ employed in this period, given $A^{\mathfrak{e}}_t$. It is assumed that there is no uncertainty in production. First-order conditions of the entrepreneurs' optimisation problem with respect to $C^{\mathfrak{e}}_t$,$K^{\mathfrak{e}}_t$, B_t, and

L_t are as (4.27), (4.28), (4.29), and (4.30) respectively.

$$C_t^{\mathfrak{e}} = (1 - \beta^{\mathfrak{e}})NW_t \tag{4.27}$$

$$K_t^{\mathfrak{e}} = \frac{\beta^{\mathfrak{e}}}{Q_t^K - \chi_t} NW_t \tag{4.28}$$

$$B_t = \chi_t K_t^{\mathfrak{e}} \tag{4.29}$$

$$L_t = (1 - \xi)\frac{Y_t}{X_t W_t} \tag{4.30}$$

In equations (4.27) and (4.28), NW_t is the net wealth held by entrepreneurs after production in period t, defined as in (4.31). As shown in (4.31), NW_t has three parts in the bracket. The first part in the bracket is the marginal return to the capital from production, defined as $R_{t-1}^K \equiv \partial Y_t/(X_t \partial K_{t-1}^{\mathfrak{e}}) = \xi Y_t/(X_t K_{t-1}^{\mathfrak{e}})$. The second is the residual value of one unit capital after production in period t. The sum of the first two items reflect of the total wealth after production in period t. These wealth items may be financed through borrowing from banks. The loan size is expressed in the third part in the bracket. χ_{t-1} is the collateral value for one unit of capital, defined as (4.32). As the borrowing constraint is always binding, the loan size B_t thus can be expressed as in (4.29). From this expression, χ_t can be interpreted as the loan-to-value ratio. The net wealth NW_t is thus defined as the difference between total wealth and loan payoffs to banks in period t.

$$NW_t \equiv \left(R_{t-1}^K + Q_t^K(1-\delta) - \chi_{t-1}\frac{1 + r_{t-1}^B}{1 + \pi_t} \right) K_{t-1}^{\mathfrak{e}} \tag{4.31}$$

$$\chi_t \equiv \frac{\kappa^{EB}(1-\delta)Q_{t+1}^K}{1 + r_t^B} \tag{4.32}$$

Based on the definition of net wealth NW_t, the budget constraint (4.23) can be expressed as (4.33). Thus, consumption and capital demand are constrained by the sum of net wealth and new loans from banks in period t. Moreover, the Euler equation can be expressed in terms of NW_t, as in (4.34). It can be verified that equation (4.27) satisfies the budget constraint (4.33) and Euler equation (4.34). Thus, equation (4.27)is indeed the first-order condition for consumption of entrepreneurs. Based on (4.27), the consumption of entrepreneurs is a linear function of net wealth NW_t. That is, entrepreneurs consume a certain portfolio of the net wealth each period. The rest of the net wealth, together with the loans from the banks, is used to buy the capital for production in the next period, as in (4.28).

$$C_t^{\mathfrak{e}} + Q_t^K K_t^{\mathfrak{e}} = NW_t + \chi_t K_t^{\mathfrak{e}} \tag{4.33}$$

$$\frac{Q_t^K - \chi_t}{C_t^{\mathfrak{e}}} = \beta^{\mathfrak{e}} \frac{1}{C_{t+1}^{\mathfrak{e}}} \frac{NW_{t+1}}{K_t^{\mathfrak{e}}} \tag{4.34}$$

The linear expression of consumption $C_t^{\mathfrak{e}}$ as a portion of net wealth NW_t reflects the idea of intertemporal smooth consumption. In period t, given the price levels for capital and final goods, NW_t is determined by production. Each unit of consumption or investment must be financed through net wealth and borrowing. For each additional unit $K_t^{\mathfrak{e}}$ in period t, consumption will reduce by $Q_t^K - \chi_t$ accordingly, and net wealth will increase by $NW_{t+1}/K_t^{\mathfrak{e}}$ in period $t+1$. As NW_{t+1} is a linear function of $K_t^{\mathfrak{e}}$, this suggest that consumption should be proportional to current net wealth, as reflected in (4.34). Equation (4.30) is the labour demand of entrepreneurs. As the labour employed influences the utility of entrepreneurs only indirectly through the production function, the first-order necessary condition only reflects the tradeoff between marginal output and labour cost.

4.3.3 Banking Sector

The banking problem is divided into two separated problems determining loan supply and funding source respectively. This is based on the two-stage budgeting result of Green (1964). In order to separate these two problems, loan supply should not influence the relative portions of various funding sources. The loan supply problem side determines the loan interest rate given the loan demand from entrepreneurs. Taking the loan supply as given, the funding source problem determines the levels of different funding resources to satisfy demand for loans. There are three different sources of funding: deposits from households, liabilities from the central bank and foreign investors, and bank equity. This setup improves on the work of Gerali et al. (2010) by enabling the banks to expand the balance sheet quickly in the short run, by relying on short-term funding from the central bank and foreign investors.

In the work of Gerali et al. (2010), commercial banks are divided into two parts: the retail department and the wholesale department. For the wholesale department, the market is competitive. Thus, this department faces a competitive constraint leading to zero profit in this market. Banks determine the size of wholesale deposits and loans to maximise profits, taking both the deposit and loan interest rates as given. If there are no uncertainties from the loans, the competitive condition will ensure that the loan interest rate equals the deposit interest rate. Gerali et al. (2010) assume an optimal leverage ratio from which leverage deviations will result in additional costs for the banks. In this way, a wedge is introduced between the wholesale loan and deposit interest rates for any deviations from the optimal leverage ratio. Because of the assumption of costly accumulation of capital, capital cannot change immediately in the short run. Thus, the size of loans and deposits will be determined by the capital size. However, in the long run, the banks can accumulate capital to achieve the desired level of loans and deposits.

As to the retail department, the market is monopolistically competitive. The retail department is able to determine the interest rate because of the downward sloping demand curves for retail loans. The problems of deposits and loans are solved separately. In the deposit market, banks choose the interest rate to maximise the department's profit, taking the wholesale deposit size and the downward sloping deposit demand curve as given. This leads to a markup of the retail deposit interest rate over the wholesale deposit interest rate. The specifications in the retail loan market are similar and lead to a markup of the retail loan interest rate over the wholesale loan interest rate.

The banking sector inGerali et al. (2010) establishes an interest rate system with various spreads. The relative magnitude among the four types of interest rate can be expressed as *retail deposit interest rate* $<$ *wholesale deposit interest rate* $<$ *wholesale loan interest rate* $<$ *retail deposit interest rate*. The retail deposit profit and loan profit are thus the spread between wholesale loan interest rates and retail loan interest rates. The spread between wholesale deposit and loan interest rates consists of the wholesale market profit. The final profit for banks is thus the spread between the interest rates of retail deposits and retail loans. In the retail loan department, a markup of the wholesale loan interest rate is imposed when granting loans to the entrepreneur. In this whole process of fund flows, banks earn all the spreads between the retail loan and deposit interest rate.

However, Gerali et al. (2010) cannot model the banks' risk-taking behaviour. Keeley (1990) suggests two approaches through which the banks can take more risks. The first one is to change the risk of the portfolio. Several works link portfolio risks to bank risks, such as Boyd and De Nicolo (2005), and Martinez-Miera and Repullo (2010). The second approach is to change the leverage ratio of banks. As banks' capital usually stays at a level above the minimum required by the Basel Accords, it seems that the leverage ratio is not the primary concern for banks' daily risk management. According to the work of Brunnermeier et al. (2009), liquidity risks rather than credit risks should be the primary concern for supervision and regulation.

Thus, two different leverages can be attributed to bank risks. The first one is through the equity leverage ratios of asset to equity. The second is the liquidity leverage ratio, i.e., the short term debt funding to the retail deposit funding. For given losses from loans, the equity acts as a buffer for these losses. However, if banks have a high liquidity leverage, loan losses will result in a quick reduction in short-term funding sources. Therefore, banks will not have enough funds to support their long-term loans. Thus, the exposed credit risks will lead to a sharp shrinkage of both the asset and liability sides. The fire sales of assets will push down asset prices and worsen the banks financial position.

In this subsection, the banking sector of the Gerali et al. (2010) model will be extended to allow bank risk-taking behaviour through high leverages, and shows how relevant monetary and macroprudential policies can mitigate the consequences of bank risk-taking behaviour.

Compared with Gerali et al. (2010), the wholesale market in this study is one of the funding sources for banks, rather than just as a pass-through mechanism. The full list of funding sources includes the retail deposit market, wholesale debt markets, and bank capital, as shown in Table 4.1. In the retail market, banks acquire funds from households by collecting deposits. In the wholesale market, banks acquire funds by issuing bonds. The interest rate in the wholesale market is determined by the central bank through a policy rule as in (4.58). Suppose the ultimate fund suppliers in the wholesale market are the central bank and foreign investors. In this market, $\tau^{\mathfrak{cb}} \in [0, 1]$ of the wholesale funds are from the central bank, and the rest $\tau^{\mathfrak{fi}} \equiv 1 - \tau^{\mathfrak{cb}}$ are from foreign investors. These funds are mainly used to support the loans granted to the entrepreneur. It is assumed that not all funds collected can be used for loans. In particular, there is a reserve ratio for fund usage. For example, a reserve ratio of 0.2 means that only \$80 out of \$100 financed can be used for loans and the other \$20 must be kept as cash reserves. It is assumed that cash reserves have zero returns. This cash reserve ratio is to satisfy the liquidity demand of households.

Asset Side Problem of the Banks

The optimisation problem for the asset side of the bank is (4.35). In (4.35), $B_t(n)$ is retail loans n provided by banks. D_t^{LF} is the loanable funds from the funding department. Banks face a loanable constraint $B_t(n) \leq D_t^{LF}$. As the banks maximise profits, it can be assumed that this inequality is always binding. $r_t^B(n)$ and r_t^{LF} are the interest rates for retail loans n and average funding costs for loanable funds. $\Lambda_{0,t}^{\mathfrak{h}} \equiv \lambda_t^{\mathfrak{h}}/\lambda_0^{\mathfrak{h}}$ is the Lagrange multiplier of households. Using the binding loanable funds constraint, this optimisation problem can be written as (4.35).

$$\max_{r_t^B(n)} \sum_{t=0}^{\infty} \Lambda_{0,t}^{\mathfrak{h}} \Big(\left(1 + r_t^B(n)\right) B_t(n) - \left(1 + r_t^{LF}\right) D_t^{LF} \Big) \tag{4.35}$$

It is assumed that retail loans are not perfectly substitutable with each other such that entrepreneurs demand a basket of retail loans B_t, defined in (4.36). The parameter $\varepsilon^{\mathfrak{b}} > 1$ represents the elasticity of substitution among different retail loans. Suppose there are N types of retail loan. This is different from the setup in Gerali et al. (2010) and follows the seminal work of Dixit and Stiglitz (1977) by assuming an integral number rather than a continuum of types in the monopolistic competition market. Given this loan package B_t in (4.36), demand for retail loans n can be derived as (4.37) using the two-stage budgeting method. (4.38) is the interest rate index from the two-stage budgeting method. In a symmetric equilibrium, $r_t^B = r_t^B(n)$ because the retail interest rate $r_t^B(n)$ is the same for $n = 1,\ 2,\ 3,\ \dots\ ,\ N$.

$$B_t \equiv \left(\sum_{n=1}^{N} B_t^{\frac{\varepsilon^{\mathfrak{b}}-1}{\varepsilon^{\mathfrak{b}}}}(n) \right)^{\frac{\varepsilon^{\mathfrak{b}}}{\varepsilon^{\mathfrak{b}}-1}} \tag{4.36}$$

$$B_t(n) = \left(\frac{1 + r_t^B(n)}{1 + r_t^B} \right)^{-\varepsilon^{\mathfrak{b}}} B_t \tag{4.37}$$

$$r_t^B = \left(\sum_{n=1}^{N} \left(1 + r_t^B(n)\right)^{1-\varepsilon^{\mathfrak{b}}} \right)^{\frac{1}{1-\varepsilon^{\mathfrak{b}}}} - 1 \tag{4.38}$$

Given the demand function (4.37), the first order condition for the optimisation problem (4.35) with respect to retail loan n is (4.39). (4.39) specifies a markup relation between the retail loan interest rate $r_t^B(n)$ and loanable funding cost r_t^{LF}. Thus, the size of borrowing is in fact determined entirely by the loan demand from entrepreneurs, especially the collateral constraint faced by entrepreneurs.

$$r_t^B(n) = \frac{\varepsilon^{\mathfrak{b}}}{\varepsilon^{\mathfrak{b}} - 1} \left(1 + r_t^{LF}\right) - 1 \tag{4.39}$$

Credit Side of the Bank Balance Sheet

There are three different funding resources including deposits D_t, financial bonds $B_t^{\mathfrak{b}}$, and capital $K_t^{\mathfrak{b}}$. Suppose a $\rho^{IB} \in (0, 1)$ portion of $B_t^{\mathfrak{b}}$ is bought by the central bank and the rest is bought by foreign investors. The required capital return is $r_t^K = R_t^K - 1$, defined in the problem of entrepreneurs. D_t^{LF} is the loanable funds and $D_t + B_t^{\mathfrak{b}} + K_t^{\mathfrak{b}} - D_t^{LF}$ is cash reserves for the liquidity demands of households. In particular, the loanable fund is defined in (4.40). In (4.40), $0 \leq \psi \leq 1$ and is the parameter to capture the imperfect substitution effect among the three funding sources. Parameters ρ^D and ρ^i are used to represent the ratios of deposit and debt funding respectively. Intrinsic links between assets and liabilities are largely simplified for modelling purposes. One possible links is the term match for asset and liabilities. This can be measured by the difference between the ratio of cash assets to total liability and parameter ρ^b. Suppose there is only one type of funding source D_t in the market. Then $D_t^{LF} = (\rho^D)^{1/\psi} D_t$. This implies that only a portion $0 < (\rho^D)^{1/\psi} \leq 1$ of the deposit D_t can be used as the loanable fund D_t^{LF}.

$$D_t^{LF} \equiv \left[\rho^D D_t^{\psi} + \rho^{\mathfrak{b}} B_t^{\mathfrak{b}\psi} + (1 - \rho^D - \rho^i) K_t^{\mathfrak{b}\psi}\right]^{\frac{1}{\psi}} \tag{4.40}$$

There are three reasons to define loanable funds D_t^{LF} as (4.40). The first is to endow banks with the capacity to expand the balance sheet. As mentioned above, in Gerali et al. (2010) and Gambacorta and Signoretti (2014), banks cannot expand their balance sheets because credit supply and demand are determined by the real sectors in the economy. However, in this model, the balance sheet of the banks can be expanded by issuing more debts in the wholesale market. This is referred to as active bank management, compared with passive bank management. The definition of loanable fund D_t^{LF} means a substitutional relationship between wholesale funding and retail deposits.

The second reason is to establish a liquidity demand for the banks' asset management[7]. The wholesale funding is more flexible for banks to acquire funds. The cost of this flexibility is the higher liquidity requirement for the wholesale funding. For deposit funding, the liquidity requirement is relatively smaller. In particular, in normal times, the wholesale market requires less cash reserves and is thus favoured by commercial banks. However, in a crisis, the wholesale market funding supply may dry up so quickly that the banks will suffer a huge cost to adjust the asset side of the balance sheet.

It can be verified that the partial effect of D_t on D_t^{LF} is $\rho^D(D_t/D_t^F)^{\psi-1}$

[7]In the deposit market of China, only about 70 per cent of the entire deposits can be used for loanable funds. In the Australian banking sector, the ratio of net deposit to loans is 118.7 per cent for the major banks. The main difference here is wholesale funding. More debts are issued by Australian banks to fund the loan demands.

from (4.39). Thus, the partial effect is linearly related to parameter ρ^D. This partial effect provides another interpretation of the parameter ρ^D. That is, $1-\rho^D$ represents the liquidity requirement from households. If ρ^D increases, a higher portion of deposits can be used for generating loanable funds. In this way, the liquidity requirement from households can be linked to the deposit financing of the banks. Moreover, if D_t/D_t^{LF} gets very close to zero, the partial effect will grow very fast such that the return to a tiny increase in D_t will surpass the cost. The partial effect of $B_t^{\mathfrak{b}}$ on D_t^{LF} is similar to that of D_t on D_t^{LF} and thus will not be analysed further here.

Besides the liquidity requirements of deposits, for each unit deposit and wholesale liability financed by banks, a portion of capital is required for regulation reasons. The Basel III Accords require a minimum ratio of 6 per cent for Tier 1 capital. Therefore, for every unit of funds financed, a portion of the capital should be complemented. Similarly, the partial effect of capital $K_t^{\mathfrak{b}}$ on loanable funds D_t is $\rho^K(K_t^{\mathfrak{b}}/D_t)^{\psi-1}$, where $\rho^K \equiv 1-\rho^D-\rho^{\mathfrak{b}}$. Obviously, this partial effect is also a linear function of ρ^D and $\rho^{\mathfrak{b}}$. As analysed above, ρ^D and $\rho^{\mathfrak{b}}$ can be regarded as liquidity parameters which means that an increase of ρ^D and $\rho^{\mathfrak{b}}$ means lower liquidity requirements from households and wholesale market and thus lower capital demand. In a recession or crisis, the liquidity requirement increases and will thus lead to higher capital requirements for banks, which might further dampen the economy.

Suppose the loanable fund demand from the asset side problem is B_t, i.e. $D_t^{LF} = B_t$, then the liability side of the bank problem can be specified as (4.41) to find the minimum financing cost given the level of the loanable funds B_t, and interest rates r_t^D, $r_t^{\mathfrak{cb}}$, and r_t^K.

$$\min_{D_t, B_t^{\mathfrak{b}}, K_t^{\mathfrak{b}}} (1+r_t^D)D_t + (1+r_t^{\mathfrak{cb}})B_t^{\mathfrak{b}} + (1+r_t^k)K_t^{\mathfrak{b}} \tag{4.41}$$

The modelling problem here is how to determine the deposit interest rate in the model. There are several possible ways to handle the retail deposit rate. The first choice is to treat them entirely exogenously. This is neat but lacks an economic explanation. Usually, the deposit rate will be influenced by other economic variables. The second choice is to introduce a similar monopolistic competition mechanism into the retail loan market. This is a good idea because banks have market power and thus a sticky interest rate or loan size can be introduced. However, this will complicate the solution of the problem because of the functional form of the loanable funds. The third choice is to assume a competitive deposit market. Using this approach, the bank will treat the retail deposit interest rate as given. The deposit interest rate will finally be determined by the competitive condition. This implies that there will be a small wedge between the deposit interest rate and the policy interest rate because of the existence of cash reserves of the banks. In this study, this last approach is adopted. The first-order conditions for problem (4.41) are as follows.

$$K_t^{\mathfrak{b}} = \left(\frac{1}{\rho^K}\frac{1+r_t^K}{1+r_t}\right)^{\frac{1}{\psi-1}} B_t \tag{4.42}$$

$$B_t^{\mathfrak{b}} = \left(\frac{1}{\rho^{\mathfrak{b}}}\frac{1+r_t^{\mathfrak{cb}}}{1+r_t}\right)^{\frac{1}{\psi-1}} B_t \tag{4.43}$$

$$D_t = \left(\frac{1}{\rho^D}\frac{1+r_t^D}{1+r_t}\right)^{\frac{1}{\psi-1}} B_t \tag{4.44}$$

$$r_t^{LF} \equiv \left[\rho^{\mathfrak{b}}\left(\frac{1+r_t^{\mathfrak{cb}}}{\rho^{\mathfrak{b}}}\right)^{\frac{\psi}{\psi-1}} + \rho^D\left(\frac{1+r_t^D}{\rho^D}\right)^{\frac{\psi}{\psi-1}} + \rho^K\left(\frac{1+r_t^K}{\rho^K}\right)^{\frac{\psi}{\psi-1}}\right]^{\frac{\psi-1}{\psi}} - 1 \tag{4.45}$$

r_t^{LF} is the overall interest rate. It is a function of the interest rate only and independent of the size of the funding sources. The ratio of the deposit, wholesale market liability, and the capital to bank loans B_t to entrepreneurs is determined by the ratio of the relevant interest rates to the overall interest rate r_t^{LF} . Equation (4.46) gives the derivatives of $B_t^{\mathfrak{b}}/B_t$ with respect to $\rho^{\mathfrak{b}}$. This partial effect is positive if $\psi < 1$. Moreover, this ratio is linear to $B_t^{\mathfrak{b}}/B_t$. Thus, when $B_t^{\mathfrak{b}}/B_t$ increases, the partial effect will increase.

$$\frac{\partial B_t^{\mathfrak{b}}/B_t}{\partial \rho^{\mathfrak{b}}} = \frac{1}{\rho^{\mathfrak{b}}(1-\psi)} \frac{B_t^{\mathfrak{b}}}{B_t} > 0 \tag{4.46}$$

The equilibrium condition for liquidity demand is (4.47). This condition enables the model to link household liquidity demands and the balance sheet structure of banks.

$$m_t = D_t + B_t^{\mathfrak{b}} + K_t^B - B_t \tag{4.47}$$

4.3.4 Capital Producers and Retailers

There are capital producers in the market who provide capital to entrepreneurs and banks. They buy final goods and then transform them into capital goods. The problem of the capital goods producer is as (4.48), where $\Lambda_{0,t}^{\mathfrak{e}} \equiv \beta^{\mathfrak{e}} \lambda_t^{\mathfrak{e}} / \lambda_0^{\mathfrak{e}}$, and $\lambda_t^{\mathfrak{e}}$ is the Lagrange multiplier of entrepreneurs. I_t is the input of final goods to produce capital goods. Suppose capital prices suffer a shock ς_t specified as $\varsigma_t = \rho_v^Q \varsigma_t + v_t^Q$, where $v_t^Q \sim N(0, \epsilon^Q)$.

The production function of the capital goods is (4.49), where $\exp(v_t^I)$ is the technology used in capital goods production. $v_t^I \sim N(0, \epsilon^I)$ is an investment technology shock. A positive shock implies higher efficiency in capital goods production. Capital producers choose I_t to maximise the discounted sum of the real profits. Capital goods produced are traded in the capital market, where the equilibrium condition is $Y_t^{\mathfrak{k}} = K_t^{\mathfrak{e}} + K_t^{\mathfrak{h}}$.

$$\max_{I_t} E_0 \sum_{t=0}^{\infty} \lambda^{\mathfrak{e}}{}_{0,t} \Big(\exp(\varsigma_t) Q_t^K Y_t^K - I_t \Big) \tag{4.48}$$

$$Y_t^{\mathfrak{k}} = \exp(v_t^I) \left[1 - \frac{\kappa^I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t \tag{4.49}$$

Entrepreneurs produce intermediate goods and then sell them to retailers at the wholesale price $P_{H,t}^W$. Retailers transform intermediate goods into the retail good j, and sell it at the price of $P_{H,t}(j)$. As the final goods price is P_t, the real price of intermediate goods for entrepreneur j is thus $X_t = P_{H,t}^W(j)/P_t$. The relative price between wholesale price and domestic goods price is $X_{H,t} = P_{H,t}^W(j)/P_{H,t}$. Therefore, $X_t/X_{H,t} = P_{H,t}/P_t$. Retail goods are not perfectly substitutable for each other, which leads to a downward-sloping demand function for intermediate goods. Therefore, the retailers have market power that enables them to choose the price levels for retail goods. The question in this section is to find the optimal retail price $P_{H,t}^*(j)$ for the retail good j. In particular, the problem of the retailers is specified as (4.50). In (4.50), $\lambda_{t,k}^{\mathfrak{h}} \equiv \beta^{\mathfrak{h}^k} \lambda_{t+k}^{\mathfrak{h}} / \lambda_t^{\mathfrak{h}}$ is the discount factor for households. The parameter θ is the Calvo (1983) sticky price parameter. In each period, each retailer has a probability $1 - \theta$ to adjust the price for the retail goods j. Therefore, the maximisation problem (4.50) is to choose an optimal retail price $P_{H,t}^*(j)$ for goods j given that this price may last for many periods following. The θ^k is the probability that the price $P_{H,t}^*(j)$ can last for k period continuously.

$$\max_{P_{H,t}^*(j)} \sum_{k=0}^{\infty} \theta^k E_t \Big(\lambda^{\mathfrak{h}}{}_{t,k} Y_{H,t+k}(j) \big(P_{H,t}^*(j) - P_{H,t+k}^W \big) \Big) \tag{4.50}$$

Equation (4.51) is the demand function for the retail good j faced by retailers, analogous to (4.10). This demand function is the necessary condition for the second-stage budgeting problem faced by consumers. The only difference is that the consumption $C_{H,t}(j)$ and $C_{H,t}$ is replaced by output $Y_{H,t}(j)$ and $Y_{H,t}$.

$$Y_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\varepsilon} Y_{H,t} \tag{4.51}$$

In a symmetric equilibrium, the retail price $P_{H,t}(j)$ of goods j equals the domestic final goods price $P_{H,t}$. This implies equality between intermediate goods $Y_{H,t}(j)$ and final domestic goods output $Y_{H,t}$. The first order necessary condition for the retailers' problem is (4.52).

$$\sum_{k=0}^{\infty} \theta^k E_t \left[C_{t+k}^{\mathfrak{h}} Y_{H,t+k}(j) \frac{1}{P_{t+k}} \left(P_{H,t}^*(j) - \frac{\varepsilon}{\varepsilon - 1} P_{H,t+k}^W \right) \right] = 0 \tag{4.52}$$

Based on the final price index form (4.12), the relationship between the current domestic price level $P_{H,t}$, previous period price level $P_{H,t-1}$, and optimal price $P_{H,t}^*$ selected by retailers can be written as (4.53).

$$\Pi_{H,t}^{1-\varepsilon} = \theta + (1-\theta) \left(\frac{P_{H,t}^*}{P_{H,t-1}} \right)^{1-\varepsilon} \tag{4.53}$$

Equations (4.52) and (4.53) together can be used to establish the relationship between the domestic final goods price index $P_{H,t}$ and the markup $X_{H,t}$ chosen by the retailers. A New Keynesian Phillips Curve (4.54) can be derived, where $x_{H,t}$ is the percentage deviation from the steady state value of $X_{H,t}$, and $\kappa^X (1-\theta)(1-\theta\beta^{\mathfrak{h}})/\theta$. This New Keynesian Phillips Curve provides the possibility for the central bank to influence the real economy.

$$\pi_{H,t} = \beta^{\mathfrak{e}} E_t[\pi_{H,t+1}] - \kappa^X x_{H,t} \tag{4.54}$$

The sticky price parameter θ is essential because if it equals zero, the goods price $P_{H,t}$ will adjust so quickly that it equals P_t^*. In this case, the demand function (4.51) implies that the real variables $Y_{H,t}(j)$ and $Y_{H,t}$ will not change at all. Thus, the impact of the monetary policy relies heavily on the asynchronous change of the$P^*_{H,t}$ and $P_{H,t}$ which results from the sticky price parameter θ.

4.3.5 Equilibrium

Define the bilateral relative price between the domestic country and country i as $S_{i,t} \equiv P_{i,t}/P_{H,t}$. The effective relative price is defined as (4.55). The log linear form of (4.55) is $s_t = p_{F,t} - p_{H,t}$[8]. This implies that $\pi_t = \pi_{H,t} + \alpha \Delta s_t$, combining with the definition of gross CPI inflation $\Pi_t \equiv P_t/P_{t-1}$, and the definition of gross domestic inflation $\Pi_{H,t} \equiv P_{H,t}/P_{H,t-1}$. Assume the law of one price holds for retail goods j at all times, i.e. $P_{i,t}(j) = \mathcal{E}_{i,t} P^i_{i,t}(j)$, where $P^i_{i,t}(j)$ is the import price of retail good j in terms of country i currency. Thus, the relationship between the domestic price and foreign price can be established using the nominal exchange rate $\mathcal{E}_{i,t}$ defined as the bilateral nominal exchange rate.

$$S_t = \frac{P_{F,t}}{P_{H,t}} = \left(\int_0^1 S_{i,t}{}^{1-\gamma} di \right)^{\frac{1}{1-\gamma}} \tag{4.55}$$

Using the definition of $P_{i,t}$ in (4.15), it can be found that $P_{i,t} = \mathcal{E}_{i,t} P^i_{i,t}$. Substitute $P_{i,t}$ into $P_{F,t}$, and log-linearize $P_{F,t}$ around the steady state. Then we get $p_{F,t} = e_t + p^*_t$, where $p^*_t \equiv \int_0^1 P^i_{i,t}\, di$. Substitute $p_{F,t}$ into s_t, and we can get (4.56). The bilateral real exchange rate with country i is $Q_{i,t} = \mathcal{E}_{i,t} P^i_t / P_t$.

$$e_t = s_t + p_{H,t} - p^*_t \tag{4.56}$$

There are several goods including homogeneous intermediate goods, retail goods, domestic final goods, imported foreign goods, and final goods. For each of the retail goods j, its output equals the input of homogenous inter-

[8] Lower case letters represent the logs of capital letters, eg. $s_t = \log S_t$, $\pi_t = \log \Pi_t$, etc.

mediate goods by assumption. Thus, retail goods demand can be summed up directly to get intermediate goods demand. Let $Y_{W,t}$ represent the output of intermediate goods. Thus, the equilibrium condition of intermediate goods is $Y_{W,t} = \int_0^1 Y_{H,t}(j)\, dj$. There are different demands for the retail good j, including consumption, investment, and export. It can be verified that $Y_{H,t} = C_{H,t} + I_{H,t} + X_{H,t}$. This implies that the market clearing condition in the retail good market is equivalent to the equilibrium condition in the domestic final goods market.

In order to close the model, the relationship between domestic final goods and final goods is needed. Define $Z_t \equiv C_t + I_t + G_t$ as the aggregate domestic demand for final goods, and $Z_t^i \equiv C_t^i + I_t^i$ as the aggregate domestic demand from country i. Suppose G_t is government spending, following an AR(1) process. In particular, $G_t = \rho_v^Z G_{t-1} + v_t^Z$ and $v_t^Z \sim N(0, \epsilon^Z)$ is aggregate demand shock from government spending. Moreover, domestic output can be expressed as (4.57), where S_t^i is the effective relative price for country i.

$$Y_{H,t} = Z_t \left((1-\alpha) + \alpha \int_0^1 \left(S_t^i S_{i,t} \right)^{\gamma-\eta} Q_{i,t}{}^{\eta} \frac{Z_t^i}{Z_t}\, di \right) \left(\frac{P_{H,t}}{P_t} \right)^{-\eta} \tag{4.57}$$

$$r_t^{\mathfrak{cb}} = \rho^{\mathfrak{cb}} r_{t-1}^{\mathfrak{cb}} + \phi_y \hat{y}_t + \phi_\pi \pi_t + v_t^R \tag{4.58}$$

Suppose the central bank determines the wholesale market interest rate $r_t^{\mathfrak{cb}}$ by following a Taylor rule as in (4.58). The parameter $\rho^{\mathfrak{cb}}$ measures the persistence of monetary policy. Parameters ϕ_y and ϕ_π measure the policy reactions to the output gap and inflation respectively. $v_t^R \sim N(0, \epsilon^R)$ is a domestic interest rate shock. The central bank may use different policy tools but the interest rate is the most important one. These policies in general move in the same direction. The discount rates and deposit reserve ratio can be embedded in the model through relevant parameters in the banking sector's but this model needs further extensions to examine moral suasion and direction intervention.

Moreover, suppose the foreign economies suffer demand shocks, inflation shocks, and interest rate shocks as in (4.59), (4.60), and (4.61). These shocks work on the log forms of foreign demand z_t^*, π_t^*, and r_t^* respectively [9].

$$\varsigma_t^{FZ} = \rho_v^{FZ}\varsigma_{t-1}^{FZ} + v_t^{FZ} \tag{4.59}$$

$$\varsigma_t^{FR} = \rho_v^{FR}\varsigma_{t-1}^{FR} + v_t^{FR} \tag{4.60}$$

$$\varsigma_t^{F\pi} = \rho_v^{F\pi}\varsigma_{t-1}^{F\pi} + v_t^{F\pi} \tag{4.61}$$

4.4 Estimation

4.4.1 Bayesian Estimation Method

In this section, the model specified above is estimated using the Bayesian method. Bayesian analysis starts from a joint probability distribution $p(\boldsymbol{\theta}, \boldsymbol{y})$ of the parameter $\boldsymbol{\theta}$ and the observed data $\boldsymbol{y}$, where $p(\cdot)$ is a density function[10]. In the DSGE framework, the joint distribution is implicitly determined by the solution to the rational expectation model. The joint probability distribution $p(\boldsymbol{\theta}, \boldsymbol{y})$ can be written as $p(\boldsymbol{\theta}, \boldsymbol{y}) = p(\boldsymbol{\theta})p(\boldsymbol{y}|\boldsymbol{\theta})$, where $p(\boldsymbol{\theta})$ and $p(\boldsymbol{y}|\boldsymbol{\theta})$ are the prior distribution of $\boldsymbol{\theta}$ and the sampling distribution of $\boldsymbol{y}$ given $\boldsymbol{\theta}$ respectively. It can be regarded as a function of $\boldsymbol{\theta}$ given $\boldsymbol{y}$. In this case, it becomes a likelihood function.

Using the Bayes rule, the distribution of $\boldsymbol{\theta}$ given the observations $\boldsymbol{y}$, i.e. the posterior distribution $p(\boldsymbol{\theta}|\boldsymbol{y})$, can be written as (4.62). The last term of (4.62) is the unnormalised posterior distribution. The denominator $p(\boldsymbol{y})$ can be omitted because it is independent of the parameter value $\boldsymbol{\theta}$. The

[9] The log linearised foreign economy is specified in log forms as follows, $\hat{z}_t^* = E(\hat{z}_{t+1}^*) - \sigma^{*-1}\left(\hat{r}_t^* - E(\pi_{t+1}^*)\right) + \varsigma_t^{FZ}$, $\pi_t^* = \beta^* E(\pi_{t+1}^*) + \theta^{*-1}(1-\theta^*)(1-\theta^*\beta^*)\hat{z}_t^* + \varsigma_t^{F\pi}$, and $\hat{r}_t^* = \rho_v^*\hat{r}_{t-1}^* + \phi_y^*\hat{z}_t^* + \phi_\pi^*\pi_t^* + \varsigma_t^{FR}$, where σ^*, β^*, θ^*, ρ_v^*, ϕ_y^*, and ϕ_π^* are parameters for the foreign economy.

[10] Bold symbols represent a vector or matrix.

unnormalised posterior distribution reveals that the technical core of the Bayesian analysis is to model $p(\boldsymbol{\theta}, \boldsymbol{y})$, and to compute $p(\boldsymbol{\theta}|\boldsymbol{y})$ based on priors $p(\boldsymbol{\theta})$ and the likelihood function $p(\boldsymbol{y}|\boldsymbol{\theta})$ (Gelman et al., 2014). In this sense, priors and the likelihood function are two building blocks of the Bayesian analysis.

$$p(\boldsymbol{\theta}|\boldsymbol{y}) = \frac{p(\boldsymbol{\theta}, \boldsymbol{y})}{p(\boldsymbol{y})} = \frac{p(\boldsymbol{\theta})p(\boldsymbol{y}|\boldsymbol{\theta})}{\int p(\boldsymbol{\theta})p(\boldsymbol{y}|\boldsymbol{\theta})\, d\boldsymbol{\theta}} \propto p(\boldsymbol{\theta})p(\boldsymbol{y}|\boldsymbol{\theta}) \tag{4.62}$$

In the Bayesian analysis of DSGE, the likelihood function is estimated using the Kalman filter. As mentioned above, the likelihood function is regarded as a function of parameters $\boldsymbol{\theta}$ given the data observations $\boldsymbol{y}$. In an independent and identically distributed sampling case, each realisation of the observed data $\boldsymbol{y}_k$ is independent of all other observations, where k represents the k^{th} sampling. Thus, the likelihood function $p(\boldsymbol{y}_t^*|\boldsymbol{\theta})$ can be written as the product of likelihoods for each observations, i.e. $p(\boldsymbol{y}_t^*|\boldsymbol{\theta}) = \prod_{k=1}^{t} p(\boldsymbol{y}_k|\boldsymbol{\theta})$, where $\boldsymbol{y}_t^* = (\boldsymbol{y}_1,\ \boldsymbol{y}_2,\ \dots\ ,\ \boldsymbol{y}_t)$ represents observations from period 1 to period t.

However, in macroeconomic analysis, realisations of the data may be time dependent. It is not possible to multiply each likelihood function $p(\boldsymbol{y}_k|\boldsymbol{\theta})$ directly to get the final likelihood $p(\boldsymbol{y}_t^*|\boldsymbol{\theta})$. The Kalman filter is a recursive algorithm to provide an easy way to find out the likelihood $p(\boldsymbol{\theta}|\boldsymbol{y})$. The key idea of this recursive approach is to orthogonalise the series-dependent $\boldsymbol{y}_k$ into a new series-independent $\boldsymbol{e}_k$ whose spanned linear space is equivalent to that of $\boldsymbol{y}_k$, for $k =\ 1,\ 2,\ 3,\ \dots\ .$

$$\boldsymbol{s}_t = \boldsymbol{F}\boldsymbol{s}_{t-1} + \boldsymbol{V}\boldsymbol{\epsilon}_t \tag{4.63}$$

$$\boldsymbol{y}_t = \boldsymbol{H}\boldsymbol{s}_t + \boldsymbol{\eta}_t \tag{4.64}$$

The key of the Kalman filter is to find the innovation series $\boldsymbol{e}_t$ in each recursive step. Consider a canonical state space model where the Kalman filter can be applied. Equations (4.63) and (4.64) are the state equation and the observation equation respectively. In equation (4.63) and (4.64), $\boldsymbol{s}_t$ are the state variables containing log-linearised variables in the model such as the domestic output gap $\hat{y}_t$, log deviations of households' consumption $\hat{c}_t^{\mathfrak{e}}$, etc. $\boldsymbol{y}_t$ are observations used for estimation. $\boldsymbol{\epsilon}_t$ and $\boldsymbol{\eta}_t$ are state and observation errors following multivariate normal distributions by assumption. The state variable errors $\boldsymbol{\epsilon}_t$ can be regarded as shocks to state variables. $\boldsymbol{F}$, $\boldsymbol{V}$, and $\boldsymbol{H}$ are the coefficient matrix adapted to relevant variables.

The innovation series $\boldsymbol{e}_t$ is constructed from residuals when projecting $\boldsymbol{y}_t$ onto the linear space expanded by $\boldsymbol{y}_t^*$. In particular, the innovation $\boldsymbol{e}_t$ is defined as the prediction error, i.e. $\boldsymbol{e}_t = \boldsymbol{y}_t - \text{Proj}(\boldsymbol{y}_t|\boldsymbol{y}_{t-1}^*) = \boldsymbol{y}_t - \boldsymbol{HF}\text{Proj}(\boldsymbol{s}_{t-1}|\boldsymbol{y}_{t-1}^*)$, where $\text{Proj}(\cdot|\boldsymbol{y}_t^*)$ is the projection operator on the space expanded by $\boldsymbol{y}_t^*$. Obviously, $\boldsymbol{e}_t$ is orthogonal to the linear space expanded by $\boldsymbol{y}_{t-1}^*$. Note that the linear spaces spanned by observed data series $\boldsymbol{y}_{t-1}^*$ and innovation series $\boldsymbol{e}_{t-1}^*$ are equivalent[11]. Thus, the likelihood function $p(\boldsymbol{y}_t^*|\boldsymbol{\theta})$ can be equivalently written as $p(\boldsymbol{y}_t^*|\boldsymbol{\theta}) = p(\boldsymbol{e}_t^*|\boldsymbol{\theta}) = \sum_{k=1}^{t} p(\boldsymbol{e}_k|\boldsymbol{\theta})$. Using this representation of $p(\boldsymbol{y}_t^*\boldsymbol{\theta})$, a recursive form for likelihood function can derived as $p(\boldsymbol{y}_t^*|\boldsymbol{\theta}) = p(\boldsymbol{e}_t|\boldsymbol{\theta})p(\boldsymbol{y}_{t-1}^*|\boldsymbol{\theta})$, where the density function $p(\boldsymbol{e}_t|\boldsymbol{\theta})$ is straightforward, by considering the conditional distribution of $\boldsymbol{e}_t$ on $\boldsymbol{s}_t^*$, i.e. $p(\boldsymbol{e}_t|\boldsymbol{s}_t^*, \boldsymbol{\theta})$[12] and using the property of multivariate normal distribution .

The second building block of Bayesian analysis is the prior distribution of parameters. If priors are not used in estimation, the Bayesian analysis will retreat to a pure likelihood estimation based only on the sample observations. Priors can be used as weights in parameter estimation to avoid estimation results purely relying on the maximum likelihood estimation. Another commonly encountered issue in likelihood estimation is the weak identification problem, which primarily results from the relatively flat area in the likelihood

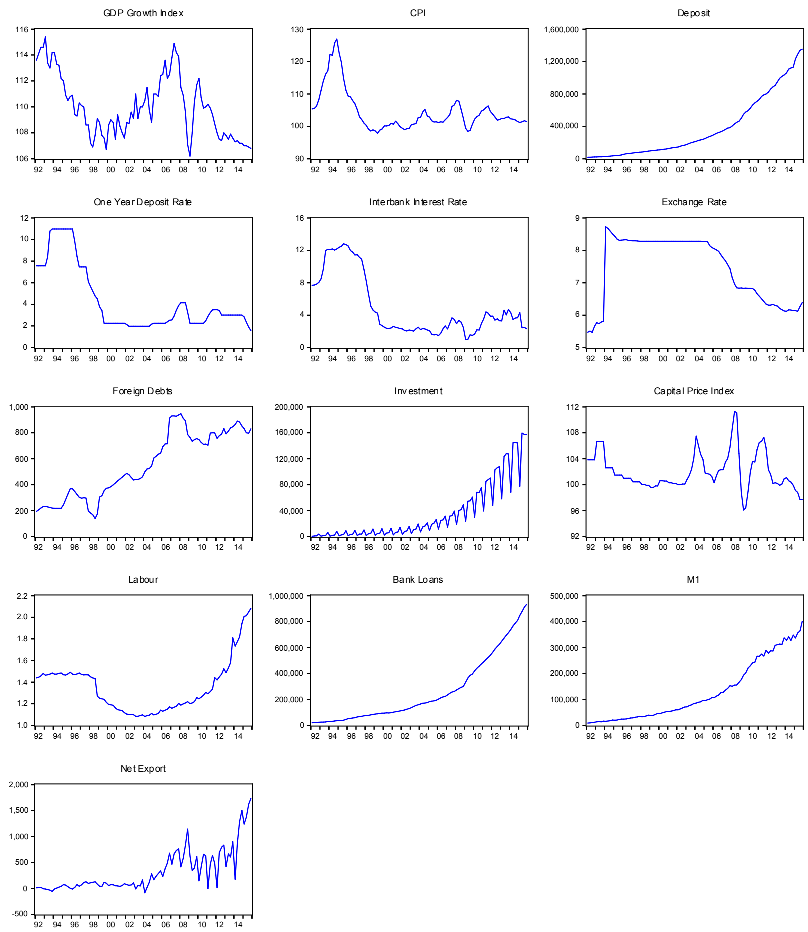
[11] $\boldsymbol{e}_{t-1}^* = (\boldsymbol{e}_1,\ \boldsymbol{e}_2,\ \ldots\ ,\ \boldsymbol{e}_{t-1})$

[12] $\boldsymbol{s}_t^* = (\boldsymbol{s}_1,\ \boldsymbol{s}_2,\ \ldots\ ,\ \boldsymbol{s}_{t-1})$

function with respect to some parameters. Priors usually have a good curvature property, which can be used to mitigate the weak identification problem in likelihood ratio estimation. Priors are important to Bayesian analysis because they contain information about the model parameters that are not in the data observations (Del Negro and Schorfheide, 2008).

Priors reflect subjective beliefs about the parameter values and can be useful to identify parameters. If the variance of a prior approaches zero, the posterior will approach to a constant. In this case, the Bayesian estimation reverts to the calibration method. In this sense, Griffoli (2007) suggests that Bayesian estimation is "*somewhere between calibration and maximum likelihood estimation*".

The remaining problem is to analyse the property of posterior distributions whose kernel is the product of priors and the likelihood function. The posterior has a similar form to the prior if it is a conjugate prior for the likelihood function. In this case, it is relatively straightforward to examine the posterior distribution analytically. However, in the Bayesian analysis of the DSGE model, priors are usually not conjugate to the likelihood. Thus, the Metropolis-Hastings algorithm is used as a sampling method to examine the posterior distribution numerically. The Metropolis-Hastings algorithm is in general an accept-reject method widely used in the Markov Chain Monte Carlo (MCMC) simulation. Each Markov Chain has a transition kernel and a correspondent invariant density. The stable realisations of the Markov Chain can be regarded as sampled from the invariant density. The accept-reject method is used to modify a proposed transition kernel to a new one whose invariant density is the posterior (Chib and Greenberg, 1995).



Data are complied from National Bureau of Statistics of China, Federal Reserve Bank of St. Louis, RESSET data base, and People's Bank of China.

Figure 4.1: Variables for Estimation

4.4.2 Data and Variables

As shown in Figure 4.1, 13 variables are used for estimation including the real GDP growth rate, consumer price index (CPI), deposits, one year deposit interest rate, interbank interest rate, nominal exchange rate of RMB/USD, liabilities from international institutions, fixed asset investment, fixed asset price index, employed population in urban area, bank loans, M1, and net exports. There are several sources of the data including the National Bureau of Statistics of China (NBSC)[13], RESSET Database[14], Ministry of Human Resources and Social Security of the People's Republic of China (MHRSS of China)[15], State Administration of Foreign Exchange of China (SAFE of China)[16], and Peoples Bank of China (PBC)[17]. The final frequency used in the estimation is quarterly, from 1996Q1 to 2015Q4.

There are missing observations for some variables, especially the liabilities from international institutions. To deal with the missing data problem, the linear interpolation method is used. Missing data may not significantly influence the estimation results if the portion of the missing data is small and randomly distributed. Moreover, the state space model allows for observation errors. Thus, we believe the missing data will not influence the estimation result significantly.

The real GDP growth rate and CPI is from the NBSC. The one year deposit interest rate and M1 data are from the PBC. The monthly M1 is arithmetically averaged within the quarter to get the quarterly data. The nominal RMB/USD exchange rate is from the SAFE of China. The original data are at a monthly frequency, and the quarterly data are the arithmetical average of the monthly data. The fixed asset price index is from the RESSET Database. Data from 1996 to 1997 is at an annual frequency. Data from 1998 to 2002 is at a semi-annual frequency. The quarterly data are calculated using linear interpolation.

Deposit data, bank loans, employed population in urban area, and the liabilities from international financial institutions are from the RESSET Database, with the original source of the PBC. For the foreign liabilities,

[13] http://www.stats.gov.cn
[14] http://www.resset.com
[15] http://www.stats.gov.cn
[16] http://www.safe.gov.cn/
[17] http://www.pbc.gov.cn

the data of 1996 is at an annual frequency. Data from Quarter 1, 1997 to Quarter 4 1999 is at a quarterly frequency. Data from January 2000 to December 2015 is at a monthly frequency with a missing data period from April 2000 to December 2001. The annual data are transformed to the quarterly data using linear interpolation. The monthly data are arithmetically averaged within the quarter to get the quarterly data. The missing data are filled using the linear interpolation method. The original employment data are from the NBSC. Data in 2015Q4 has not been released yet which is filled by the moving average of the recent two quarters.

Interbank interest rate is measured by the seven-day interbank offered rate. The data from 1996 to 2015 is from the RESSER Database. Arithmetical averaging is used to adjust the daily and monthly frequency data to the quarterly frequency data. The one-year deposit benchmark interest rate is set by the central bank of China and changes irregularly over the sample period. The one-year deposit benchmark interest rate can be maintained for periods lasting from several weeks to two years. Because the central bank changed the one-year deposit benchmark interest rates irregularly, the quarterly data of the one-year deposit benchmark interest rate is calculated by averaging the daily benchmark rates within the quarter. The real GDP growth rate is used to measure the output of the economy. The GDP deflator rate is not available publicly from NBSC, but the real GDP growth rate is widely cited, both in the academic literature and in public policies. The CPI rate is used to measure inflation. The CPI rate is published by the NBSC in monthly frequency.

M1 is used to approximate money demand in the model. The policy interest rate is measured using the China interbank offered seven-day interest rate, though there is no widely accepted benchmark policy rate in China yet. The China interbank offered seven-day interest rate is publicly available from January 1996.

Table 4.2: Calibrated Parameters

Parameters	Values	Description
$\beta^{\mathfrak{h}}$	0.99	Household discount factor
$\beta^{\mathfrak{e}}$	0.97	Entrepreneur discount factor
$\beta^{\mathfrak{f}}$	0.98	Foreign discount factor
$\tau^{\mathfrak{e}}$	0.08	Share of entrepreneurs in the economy
γ	1.00	Substitution between goods from foreign countries
η	1.00	Substitution between domestic and foreign goods
ρ^D	0.88	Share of deposits in bank funding sources
$\rho^{\mathfrak{b}}$	0.02	Share of financial bonds in bank funding sources
ρ^K	0.10	Share of capital in bank funding sources

Some variables exhibit strong seasonal effects, such as fixed asset investment, employment in urban areas, and M1. The X-12 seasonal adjustment tool in Eviews is used to adjust the seasonal effects [18]. For all variables, the Hodrick-Prescott filter is used to separate the trend and cycles components. The lambda parameter of the Hodrick-Prescott is set to 1200. The ratios of cycles to trends for these variables are used to measure the percentage deviations of the relevant variables from the steady state level.

4.4.3 Calibrated Parameters

Some parameters are calibrated in Table 4.2 because the data used in the estimation may not have enough information for identification. The discount factors for households and entrepreneurs are calibrated at 0.99 and 0.97 respectively. These two discount factors imply that steady-state real interest rates for household and entrepreneurs are 4 per cent and 12 per cent respectively. This is very close to the average of the historical annual deposits and loan interest rates. The discount factor for foreign consumers is calibrated

[18]The Chinese new-year effect does not come regularly across different years. This neglected effect can possibly be captured by larger measurement errors in the Bayesian estimation.

at 0.98.

The parameters for open economy settings follow the work of Gali and Monacelli (2005) because the data used in this study provides little information to reveal values for these parameters. In particular, substitution between goods from different foreign goods γ is calibrated at 1. Substitution between foreign and domestic goods η is calibrated at 1. This means unit substitutability for goods from different countries[19]. By the end of 2013, the labour force in China was about 800 million, while the number of entrepreneurs was about 60 million[20]. Thus, the share of entrepreneurs $\tau^{\mathfrak{e}}$ in the economy is calibrated at 0.08. The ratios of deposit, liability and equity in bank funding sources are calibrated at 0.88, 0.02, and 0.10 respectively, according to the data in Table 4.1.

4.4.4 Estimation Results

In Table 4.3, priors and posteriors for parameters are listed. The estimated inverse Frisch elasticity φ in (3.19) is 2.74, which is higher than the calibration value used in Chang, Liu, and Spiegel (2015). The estimated κ^I in (4.49) is 0.11. The estimated ξ in (4.25) is 0.11 with a wide HPD interval. The estimated α in (4.1) is 0.11, indicating that the portion of foreign goods in final goods is only about 11%. This is much lower than the imports to GDP ratio in China.

The estimated Calvo (1983) parameter θ in (4.50) is 0.84. This means that the average period for a given level price can last about 6 quarters. The estimated κ^{EB} in (4.32) is 0.11. This estimated loan to value ratio is much lower than the prior mean. Estimated coefficients for output gap and inflation in a standard Taylor rule (4.58) are about 1.22 and 0.22. In US, estimated coefficients for output gap and inflation are 1.5 and 0.5 respectively (Clarida,

[19]Identification test using Dynare suggests γ and η are pairwise collinear.

[20]`http://www.gov.cn/xinwen/2014-03/31/content_2650031.htm`

Table 4.3: Priors and Posteriors of Parameters

	Prior mean	Post mean	90% HPD interval		Prior distribution	Prior variance
φ	2.00	2.74	0.93	4.45	INVG	1.00
κ^I	0.20	0.11	0.08	0.14	INVG	0.10
ξ	0.10	0.11	0.04	0.20	INVG	0.05
α	0.30	0.16	0.11	0.22	BETA	0.20
θ	0.70	0.84	0.79	0.89	BETA	0.15
κ^{EB}	0.70	0.11	0.04	0.18	BETA	0.15
ϕ^π	1.50	1.22	1.14	1.31	INVG	0.50
ϕ^y	0.50	0.22	0.16	0.29	INVG	0.50
$\rho^{\mathfrak{cb}}$	0.50	0.49	0.37	0.62	BETA	0.20
ψ	0.40	0.98	0.97	0.99	BETA	0.20
ρ^{IB}	0.85	0.96	0.91	1.00	BETA	0.10

Prior and post means are listed in the second and third columns. The fourth and fifth columns give the highest posterior density (HPD) interval at the confidence level of 90 per cent. Prior distributions and variances are in the last two columns. INVG and BETA represent inverse gamma distribution and beta distribution respectively.

Galí, and Gertler, 1999). Thus, the central bank of China react to output gaps and inflation less aggressively. Moreover, the central bank of China reacts to inflation more aggressively compared with the output gaps. In fact, the PBC claims that the target of the central bank is to stabilise the price level, reduce unemployment, enhance economic growth, and balance international trade, with a primary focus on the inflation. The estimated AR(1) coefficient $\rho^{\mathfrak{cb}}$ in the Taylor rule is 0.49, suggesting inertia in the policy rate.

The estimated ψ in (4.40) is 0.98, implying very high substitutability among different funding sources. This also means that banks are very sensitive to interest rate changes. The estimated ρ^{IB} is 0.96, suggesting 96 per cent of the financial bonds are financed from the central bank and about 4 per cent is financed from foreign investors[21]. As shown in Table 4.1, the ratio of foreign bonds to total bonds is 5.8 per cent based on the first four months of 2016.

[21] ρ^{IB} is the portion of financial bonds $B_t^{\mathfrak{b}}$ bought by the central bank.

Table 4.4: Auto Regression Coefficients of Shocks

	Prior mean	Post mean	90% HPD interval		Prior distribution	Prior variance
ρ_v^Z	0.50	0.81	0.71	0.92	BETA	0.20
ρ_v^Q	0.50	0.39	0.29	0.48	BETA	0.20
ρ_v^A	0.50	0.61	0.45	0.76	BETA	0.20
ρ_v^I	0.50	0.40	0.21	0.59	BETA	0.20
ρ_v^{FR}	0.50	0.35	0.13	0.58	BETA	0.20
ρ_v^{FZ}	0.50	0.79	0.68	0.89	BETA	0.20
$\rho_v^{F\pi}$	0.50	0.85	0.78	0.93	BETA	0.20

Prior and post means are listed in the second and third columns. The fourth and fifth columns give the highest posterior density (HPD) interval at the confidence level of 90%. Prior distributions and variances are in the last two columns. BETA represents inverse gamma distribution.

Tables 4.4 and 4.5 give the estimated AR coefficients and standard deviations for shocks. In Table 4.4, AR coefficients for domestic and foreign demand shocks are 0.81 and 0.79 respectively, implying that demand shocks are persistent over time. Foreign inflation shock is persistent as well. Its AR coefficient is 0.85. The estimated AR coefficient for foreign short-term interest rate shock is 0.35, and thus is less persistent than demand shocks. AR coefficients for investment and asset prices are 0.39 and 0.40 respectively. The AR coefficient for technology shocks is 0.61.

In Table 4.5, the estimated standard deviation for investment shocks is 16.49. In China, government-oriented investment is one of the most important driving forces for GDP growth. In (4.49), $\exp\left(v_t^I\right)$ is regarded as the technology used in capital goods production. The volatile $\exp\left(v_t^I\right)$ may be related to the varying efficiency in investment because of too much government intervention. The size for domestic demand shocks ϵ^Z is 2.77, following investment shocks as the second highest estimated value.

The size for foreign demand shocks ϵ^{FZ} is 0.69 and thus smaller than the domestic shock size. The size for foreign interest rate shocks is higher than domestic interest rate shocks. This suggests that foreign interest rates

Table 4.5: Estimated Standard Deviations of Shocks

	Prior mean	Post mean	90% HPD interval		Prior distribution	Prior variance
ϵ^A	2.00	1.06	0.93	1.20	INVG	0.50
ϵ^Z	5.00	2.77	2.35	3.22	INVG	5.00
ϵ^Q	2.00	1.75	1.49	2.01	INVG	1.00
ϵ^I	18.00	16.49	12.58	20.48	INVG	5.00
ϵ^R	2.00	0.56	0.46	0.66	INVG	2.00
ϵ^{FZ}	2.00	0.69	0.57	0.81	INVG	1.00
ϵ^{FR}	2.00	1.25	0.71	1.84	INVG	1.00
$\epsilon^{F\pi}$	2.00	1.14	0.68	1.58	INVG	1.00

Prior and post means are listed in second and third columns. The forth and fifth columns give the highest posterior density (HPD) interval at the confidence level of 90%. Prior distributions and variances are in the last two columns. INVG represents inverse gamma distribution.

may have substantial influences on the domestic economy, compared with domestic interest rates. The estimated technology shocks and foreign inflation shocks are 1.14 and 1.06 respectively.

4.5 Impulse Response Analysis

In this subsection, the impulse responses of key variables to shocks of domestic demand, foreign demand, and foreign interest rate will be examined to show the propagation mechanisms of the model. The impulse response analysis is based on the calibrated and estimated parameters under the baseline Taylor rule (4.58). Comparisons of different impulse patterns of key variables will provide insight for further analysis of different sets of policies.

4.5.1 Domestic Demand Shock

Figure 4.2 shows the impulse responses of key variables to a domestic demand shock. The size of the demand shock is a one per cent deviation from its steady state. This domestic demand shock can be interpreted as an increase in government spending. Consumption and investment both decrease because

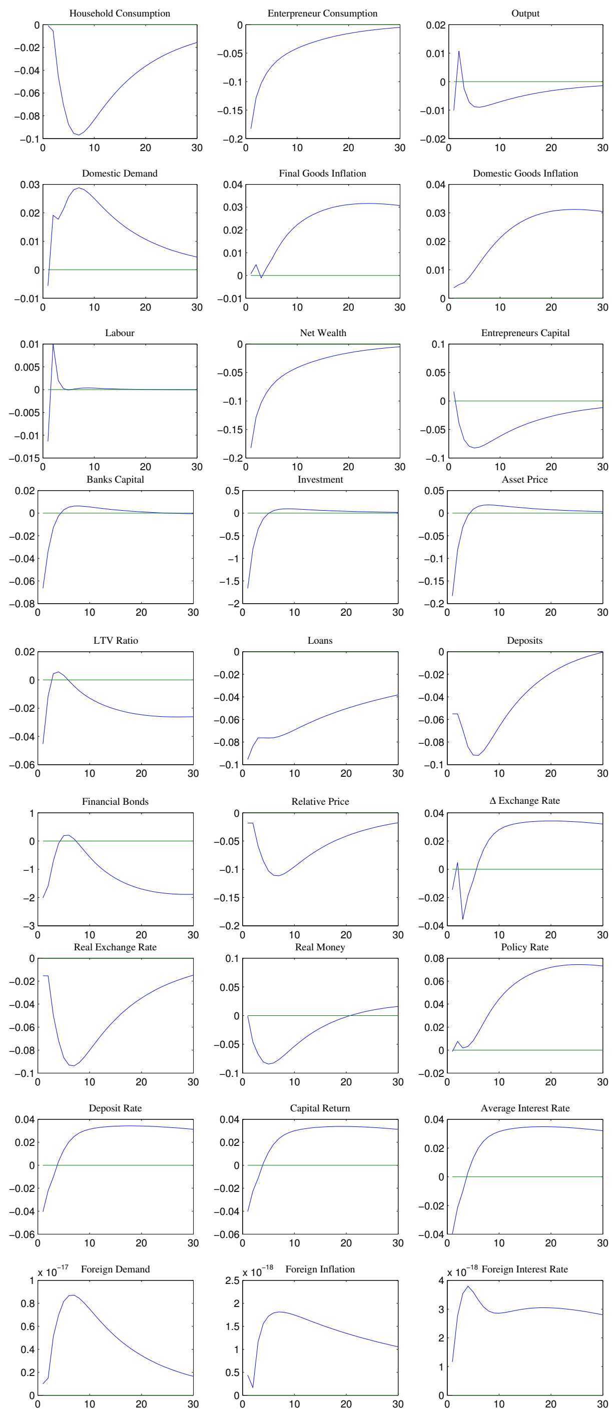


Figure 4.2: Impulse Responses to Domestic Demand Shock

of the crowding-out effect of government spending. Decreases in investment in turn lead to decreases in asset prices, the net wealth of entrepreneurs, the loan-to-value ratio, bank capital, and bank loans.

The significant crowding-out effect is related to the high persistence in inflation and the Taylor rule followed by the central bank. Inflation increases slowly following increases in aggregate demand. The central bank using the Taylor rule thus increases the policy interest rate to curb inflation. The subsequent reduction in bank loans reduces deposit demand and deposit interest rates initially. However, persistently high policy rates imply that banks need to rely on deposit funding. Thus the deposit interest rate reverts to a positive level after the first 3 quarters. The average interest rate for banking funding in general shares a similar pattern to the deposit interest rate.

Financial bonds fluctuate sharply over time. This is consistent with the fact that financial bonds are usually only short term. In the first several periods, the policy rate remains unchanged because of sticky inflation while the deposit interest rate reduces to below zero. Therefore, banks reduce financial bonds demand sharply in the first several quarters. However, as the deposit rate reverts to a positive level, banks find it cheaper to finance from the interbank market. As the policy interest rate stays at a high level, the financial bonds level stays negative. The relative price of foreign goods decreases because domestic goods become more expensive. This is also reflected in the fall of the real exchange rate.

The nominal exchange rate is defined as the ratio of domestic price to foreign price in terms of the same currency, as expressed in (4.56), i.e. the law of one price. In Gali and Monacelli (2005), the interest parity relationship is equivalent to international risk-sharing conditions given the domestic and foreign Euler conditions, where there is perfect substitution between domestic and foreign deposits. In their case, purchasing power parity and interest rate parity are equivalent.

In this study, the domestic and foreign deposits are not perfectly substitutable anymore. This means that the nominal exchange rate will be influenced both by the short- and long-term interest rates. In particular, the difference between the domestic deposit rate r_t^D and the foreign interest rate r_t^* determines the overall pattern of changes in nominal exchange rates in long term, and the difference between the domestic policy rate $r_t^{\mathfrak{cb}}$ and the foreign interest rate r_t^* determines the overall pattern of changes in nominal exchange rates in the short term.

The estimated ratio of funds from foreign investors is only 0.04 in the wholesale funding market[22]. This suggests that the nominal exchange rate will be determined mainly by the long-run force, i.e. purchasing power parity, while still being influenced partially by the short-run force, i.e. interest rate parity. In Figure 4.2, changes in the nominal exchange rate in general follow the pattern of the deposit interest rate. The initial fluctuations of changes in the nominal exchange rate in the first three quarters are due to similar fluctuations of the policy interest rate.

4.5.2 Foreign Demand Shock

In this section, the impulse responses of key variables to a foreign demand shock are presented in Figure 4.3. The foreign demand shock leads to increases in output, inflation, and the interest rate in the foreign economy. Increases in foreign demand result in decreases in relative price, implying cheaper foreign goods in terms of domestic goods. Therefore, domestic consumers become wealthier, leading to an increase in aggregate demand. The sharp increase in relative price results in a drop in aggregate output in the first quarter.

[22] The estimated ρ^{IB} is 0.96, suggesting only 4 per cent of bank funds are financed from foreign investors, as shown in Table 4.3

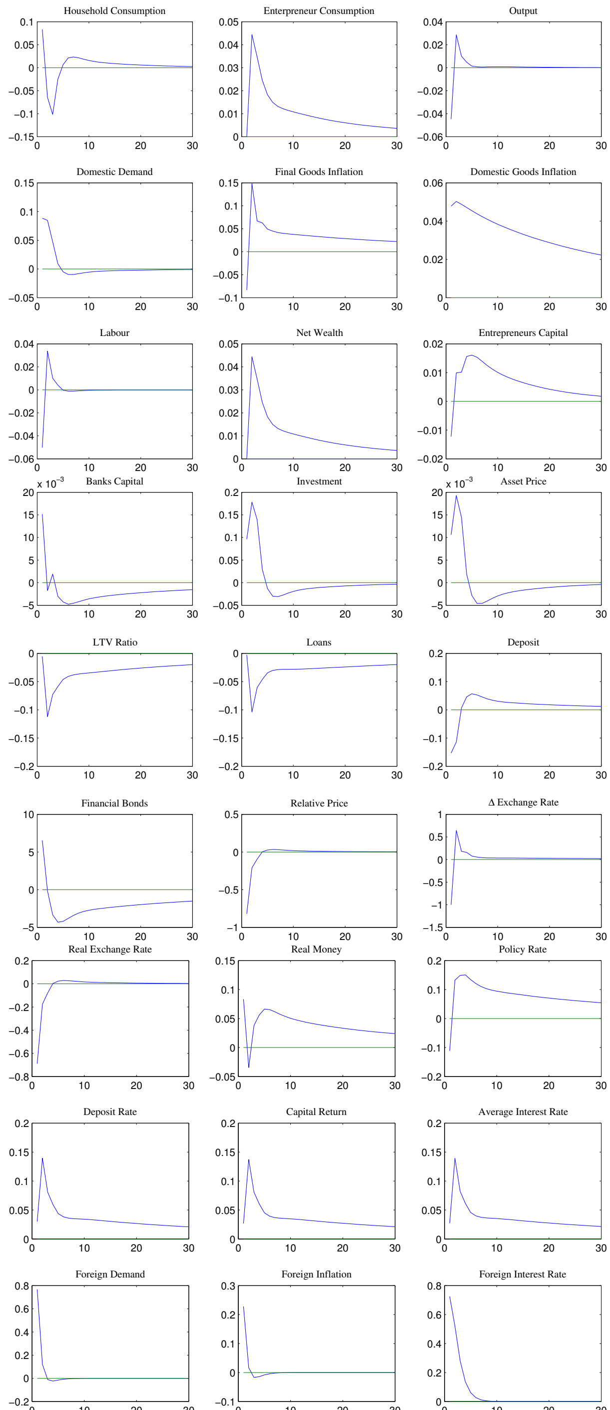


Figure 4.3: Impulse Responses to Foreign Demand Shock

The nominal exchange rate is determined jointly by relative price and domestic and foreign inflation, as in (4.56), through the purchasing power parity in the long term. Foreign goods become cheaper for domestic consumers because of decreases in relative price. This initially results in the nominal appreciation of domestic currency in the first quarter[23]. Domestic inflation exhibits strong persistence over time while foreign inflation inertia is not very strong. After the relative price returns to the steady-state level, the difference between domestic and foreign inflation dominates (4.56), leading to a depreciation of the nominal exchange rate in the third quarter and after.

The appreciation of the nominal exchange rate can also be interpreted from the perspective of interest parity relation. In general, the foreign interest rate is higher than the domestic interest rate. Therefore, the nominal exchange rate should depreciated because of less demand for domestic currency. Thus, the nominal exchange rate exhibits a similar hump shape to the deposit interest rate.

The financial market in general experiences a boom under foreign demand shock. In general, the domestic country becomes wealthier because of appreciation of the currency. Higher investment results in higher asset prices, net wealth, banks and entrepreneur capital, and a higher households consumption leads to less deposit supply and higher deposit interest rate. Bank loans provided by the banks decrease rather than increase. The increasing demand for bank loans is mitigated by decreasing bank loan supply because of the reduction in household deposits.

As to different funding sources, banks rely more on household deposits and bank capital because the central bank maintains a high policy interest rate over time under the Taylor rule. Initially, the policy interest rate is lower

[23]The nominal exchange rate can be expressed as $e_t = p_{F,t} - p_t^*$ in log form, where $p_{F,t}$ and p_t^* are the prices of foreign goods in terms of domestic and foreign currencies respectively.

than the average financing costs. Therefore, banks increase the financial bonds funding quickly after a demand shock. However, the deposit rate and capital return returns to the steady state quickly, while the policy rate is still at a high level. Banks thus adjust their funding portfolio by relying more on deposits and less on financial bonds.

4.5.3 Foreign Interest Rate Shock

In this section, the impulse responses of key variables to a foreign interest rate shock are presented in Figure 4.4. Under this shock, the interest rate increases while inflation and output decrease in foreign countries. This positive foreign interest rate implies higher interest rates facing households and other market players. This is in general similar to a negative demand shock resulting in lower output and deflation.

The reduction in foreign output adversely influences demand for domestic goods, as in (4.57). The international risk sharing condition implies that the domestic aggregate consumption reduces while the relative price acts as a buffer mechanism. The relative price increases, implying that domestic goods are cheaper. Therefore, there is an increase in domestic output, which acts as a risk-sharing mechanism between the domestic economy and the rest of the world. Confronted with world recession, the domestic demand decreases, but aggregate output increases in the first quarter, as shown by aggregate demand and output respectively in Figure 4.4.

Because of reduced foreign demand under a foreign interest rate shock, domestic goods prices decrease. Initially, there is a sharp increase in relative price, but increases in domestic and foreign goods inflation are small. This leads to a depreciation of domestic currency after the interest rate shock, as suggested by (4.56). The depreciation in general implies that domestic consumers are less wealthy, resulting in less consumption. Investment, asset

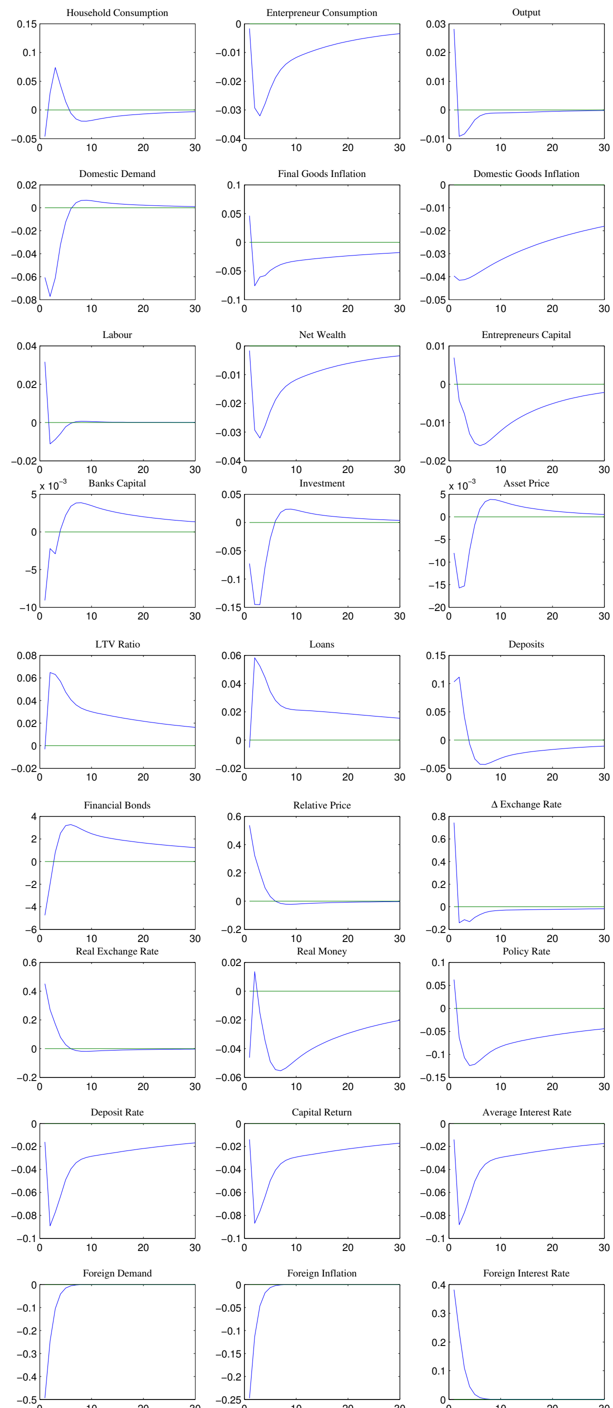


Figure 4.4: Impulse Responses to Foreign Interest Rate Premium Shock

prices, and the capital all reduce as well.

Financial bonds reduce sharply in response to a foreign interest rate shock. Because of this shock, it is very costly for banks to finance through issuing bonds. Therefore, banks choose to rely more on deposits which is relatively cheaper. It is found that there is an increase in deposits from households. As deposit rates and capital returns revert to the steady-state level, policy interest rates become lower than the average funding costs of banks. Thus, financial bonds stay above the steady state after the first several periods.

4.6 Policy Analysis

In this section, the impulse responses to a foreign interest rate shock of a central bank loss function will be analysed for different policy combinations. There are three different policy tools which can be used by the central bank, including the standard Taylor rule, the credit extended Taylor rule, and the macroprudential tool. The extended Taylor rule and macroprudential tool are specified as (4.65) and (4.66), where $\phi_\chi \in [0,1]$ and $\kappa_\chi \in [0,1]$ are parameters controlled by the central bank. By adjusting the value of κ_χ, the central bank can control the desired steady-state loan to value ratio. The prudential policy and monetary policy were named two pillars of macroeconomic regulation and control in China. Indicators including loan-to-value ratios are actively monitored, based on which prudential policies are conducted by the central bank.

$$r_t^{\mathsf{cb}} = \rho^{\mathsf{cb}} r_{t-1}^{\mathsf{cb}} + \phi_y \hat{y}_t + \phi_\pi \pi_t + \phi_\chi \chi_t \tag{4.65}$$

$$\chi_t \equiv \exp(\kappa_\chi) \frac{\kappa^{EB}(1-\delta) Q_{t+1}^K}{1 + r_t^B} \tag{4.66}$$

Different combinations of these four basic policy tools are described in Table 4.6, where ✓ indicates that a policy is included and × indicates that it is not included. For example, the policy set A has only the standard Taylor rule as the policy tool. In this section, the impulse response analysis will be conducted first to show the performance of the model under the basic Taylor rule. After that, different sets of policies will be compared based on the arbitrary loss function.

Table 4.6: Four Policy Mix

Policy Mix	A	B	C	D
Standard Taylor Rule	✓	×	✓	×
Extended Taylor Rule	×	✓	×	✓
Macroprudential Tool	×	×	✓	✓

The ad hoc bank loss function is specified as (4.67), where $\hat{y}_t^2$ and π are domestic output gap and final goods inflation respectively. Parameter $\lambda^{\mathfrak{cb}}$ represents the weight of the output gap in this loss function. In relation to the ad hoc loss function set up, Benigno and Woodford (2012) suggest that there are in general two welfare analysis approaches in the DSGE model: a Ramsey policy analysis and a linear quadratic approximation for the utility function. The latter approach is adopted by Mendicino and Pescatori (2007), Rubio and Carrasco-Gallego (2014) and others. A linear quadratic approximation can be applied if some conditions are satisfied. The ad hoc loss function is used here as a criterion because it is consistent with the policy aim stated by the PBC. Moreover, the loss function is similar to the linear quadratic approximation results developed by Benigno and Woodford (2012). Based on these two considerations, the ad hoc loss function used to the evaluate different sets of policies is (4.67).

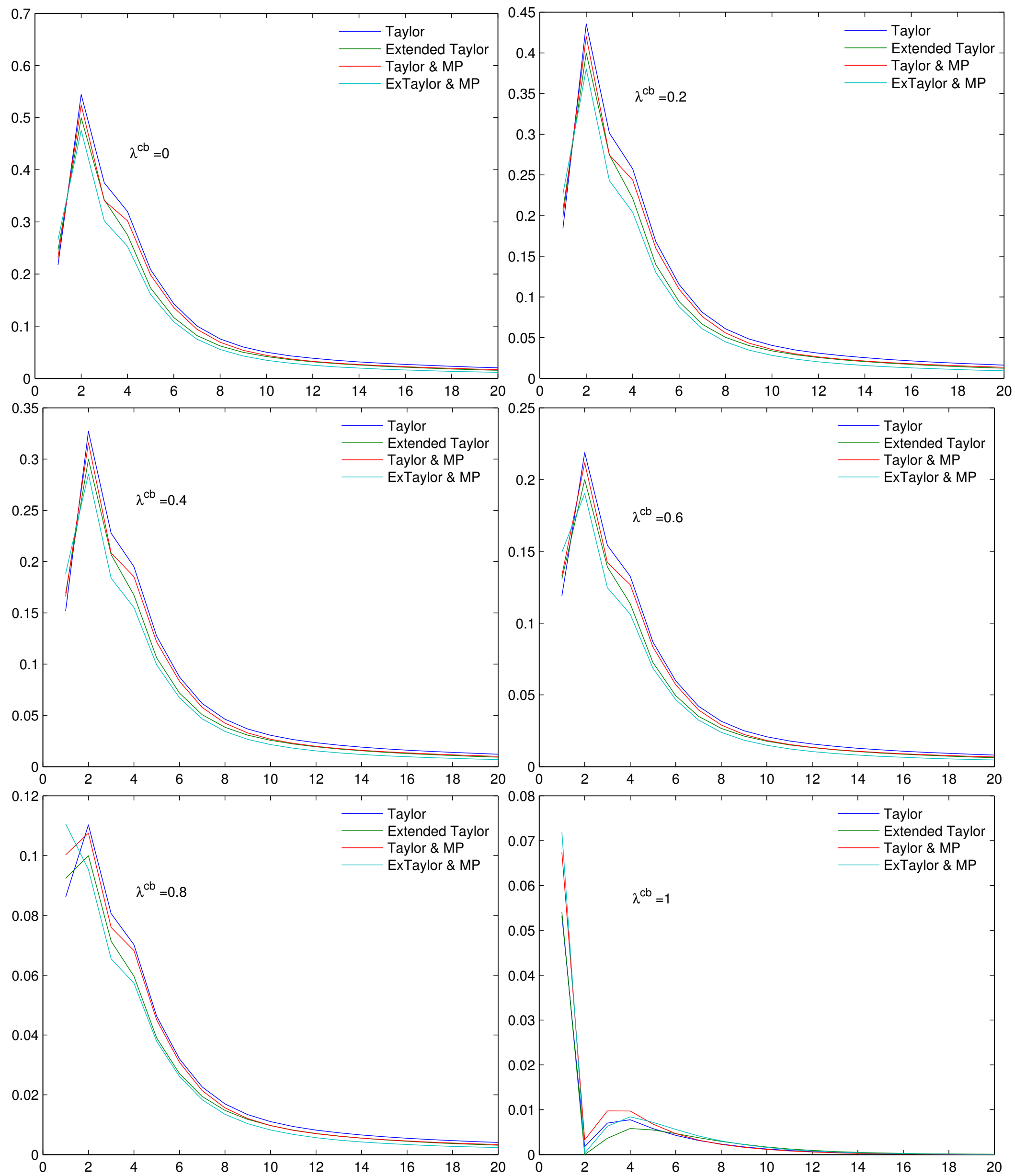
$$loss_t = \lambda^{\mathfrak{cb}}\hat{y}_t^2 + (1-\lambda^{\mathfrak{cb}})\hat{\pi}_t^2 \tag{4.67}$$

Another issue related to policy comparison is the determination of policy parameters. Obviously, optimal parameters can easily be found given a loss function. However, this usually delivers very large Taylor rule coefficients which are obviously not consistent with estimation results and policy practices in China. Thus, relative comparisons are conducted based on this loss function, rather than searching to find optimal parameters. The performance of different policy mixes will be compared under different weights of λ^{cb} in loss function.

Figure 4.5 presents the impulse response of the central bank loss function to a foreign interest rate shock. The losses in each figure are magnified 100 times. Different values of λ^{cb} are labelled in Figure 4.5. One of the main limitations of this approach is that we did not use optimal parameters to compare the performance of alternative monetary policies. Usually, the optimal parameters can be found by a numerical search over a range given welfare maximisation function. Future work can be conducted in this direction.

When λ^{cb} equals zero, i.e., the central bank cares only about the final goods inflation in the economy. It can be observed that the four different policy sets have very similar effects in the first two quarters. From the fourth quarter to the fourteenth quarter, the inflation deviations under the extended Taylor rule with macroprudential policy have smaller squared inflation rates. When λ^{cb} equals 0.2, 0.4, 0.6, and 0.8, the general patterns of the loss function for different sets of policies are similar to those when λ^{cb} equals to 0. The extended Taylor rule with macroprudential policy has lower losses, compared with other policy sets. When λ^{cb} equals 1, the extended Taylor rule is dominant while the extended Taylor rule with the macroprudential policy has the second smallest losses.

The extended Taylor rule has no dominant role among the four combinations of policies. The macroprudential policy can work as an additional tool for smoothing economic fluctuations. If that λ^{cb} is smaller than 0.8, the extended Taylor rule with macroprudential policy works well to reduce the



This figure gives impulse responses of central bank loss function to foreign interest rate premium shock, given different values of λ^{cb}. MP and ExTaylor represent the macroprudential tool and the extended Taylor rule respectively.

Figure 4.5: Impulse Responses of Central Bank Loss Function

inflation deviations and output gaps. The usefulness of the extended Taylor rule may be related to the high persistence of inflation. The additional item reacting to the loan to value ratio can reduce the persistence in the interest rate under the standard Taylor rule. The central bank should therefore design additional policy tools beyond the interest rate, such as loan to value ratio. Trying an extended Taylor rule seems not to be a good choice for the central bank.

4.7 Conclusion

This chapter builds an open economy New Keynesian model with a banking sector which finances itself from three different funding sources. The model allows banks to rely more on short-term funding when it is relatively difficult to fund by collecting deposits from households. Compared with the existing literature, the model in this chapter allows banks to undertake risk-taking behaviour by relying more on short-term funding sources.

The model in this study has two distinctive features compared with existing models. First, short-term funding sources exhibit high volatility which may lead to endogenous financial instability in a crisis. The financial bonds financed by banks can increase and decrease dramatically because of the differences between policy interest rates and other interest rates. In a crisis, banks may find it difficult to finance from the wholesale market when they want to. Shrinking funding sources in bad times can increase financial stress on the loan supply and thus dampen the real economy.

Second, the nominal exchange rate can be analysed from both purchase power parity and interest rate parity perspective. The nominal exchange rate is determined mainly by purchasing power parity in the long run and partially influenced by interest rate parity in the short run. The imperfect substitutions between domestic and foreign assets implies that nominal returns to domestic deposits and foreign deposits can be different in terms of the same currency. This provides a mechanism to analyse the relationship between purchasing power parity and interest rate parity in a New Keynesian model.

The model is estimated by the Bayesian method using quarterly data of China from 1996Q1 to 2015Q4. Based on the estimated and calibrated parameters, impulse responses are conducted to examine the performance of the model. In order to compare the traditional Taylor rule based monetary policy and macroprudential policy, this study uses an ad hoc central bank loss function based on the squared sum of inflation and the output gap. Different weights on the output gap and inflation are tried and it is conclusively found that the macroprudential policy based on loan-to-value ratio can enhance the ability of the extended Taylor rule to tame the fluctuations of the economy. Moreover, the extended Taylor rule alone has a relatively limited effect on controlling business cycles. Calibrated and estimated parameters can contribute to further empirical works using Chinese data.

Chapter 5

Conclusion

This thesis examines the monetary policy implications of the risk-taking behaviour of banks in an open economy environment. In order to investigate this monetary policy issue, a macroeconomic model with an elaborated banking system is developed.

In Chapter 2, we mainly discuss the influences of the possible weak identification problem on the NKPC estimation using the data of China. The relevant reasons for and influences of the weak identification problem are reviewed. Moreover, weak identification robust statistics are analysed as well. Based on these reviews, the NKPC in China is tested and estimated using the quarterly data. The weak identification problem mainly refers the case that the correlation between instrument variables and endogenous variables is weak. Because the change of inflation in the NKPC is usually difficult to predict, the weak instrument problem is common in estimating the NKPC using GMM. The main consequences of the weak identification problem are that the relevant point is inconsistent and that the confidence interval cannot cover the true value of the parameter at the given confidence level. The

Cragg-Donal F statistic can be used to test the weak identification problem and Stock and Yogo (2005) proposed relevant critical value using the simulation method. By partitioning the endogenous and exogenous variables, the relevant AR, LM and CLR statistics can be constructed and these statistics are robust to the weak identification problem. By inverting these statistics, a relevant confidence interval can be constructed. The size of the confidence interval equals the confidence level, which solves the problem of distorted type I error implied by the confidence level in large sample GMM estimation.

In the empirical part, this study adopted quarterly data from Q1 1994 to Q3 2014 covering 79 observations. The CPI and RPI are used as measurements for inflation, and the GDP gap is used for the driving force variable in NKPC. The three-period lagged inflation and GDP gaps are used as the instrument variables. The Cragg-Donal F statistic estimated suggests that there is a weak identification problem using the large GMM estimation. To solve this problem of weak identification, the CUE is used and relevant CLR inverted confidence intervals are constructed. The full sample empirical results suggest that inflation dynamics in China have both a forward- and a backward-looking component, and while the forward-looking component is the major one and the backward-looking component is not negligible. The subsample results suggest that the backward-looking component in the first ten years of the sample is not significant but the forward-looking part is significant. In the second ten years, the forward- and backward-looking components are quite similar. This implies a tendency toward more inflation inertia. The central bank should consider past inflation paths together with the impact of future real GDP gaps on current inflation.

In Chapter 3, we test and estimate a VECM to examine whether there is a long-run relationship existing between the capital inflows, interest rates differentials and nominal exchange rates, and whether deviations from the long-run relationship can influence changes in these variables, based on monthly data from China over the sample period from October 2006 to June 2015. It is found that there is a long-run relationship existing between capital inflows and interest rates differentials. Deviations from this long relationship can impose an error correction mechanism on the changes in capital inflows, but not on exchange rates and capital inflows. This implies China indeed achieved monetary policy autonomy with a partially opened capital account and exchange rate regime in general pegging on the US dollar.

The normative analysis using DSGE model is used to examine the theoretical consequences of capital controls on other variables. The capital control mechanism is introduced by imposing an additional cost on the budget constraint of households such that increases or decreases in foreign currency deposits will incur some transaction costs. The central bank can step into this capital control mechanism by changing the capital control parameter such that it can be extremely costly for households to change their level of foreign deposits. Under this mechanism, the central bank can influence the speed of the capital flows. It is found that capital controls transform dramatic and immediate changes in deposit portfolios to a prolonged and gradual adjustment process. Besides this, capital controls can reduce output fluctuations under a foreign demand shock, but can only increase the volatility of the economy under foreign interest rate and inflation shocks. Moreover, there is an optimal capital control level, if the weight of output volatility in the central bank's loss function is high enough. This indicates the proposition of Xiaochuan Zhou may be appropriate if the central bank places sufficient weight on the output gaps.

The impulse response analyses suggest that this capital control mechanism can mitigate the output volatility of the economy when facing a foreign demand shock, but may induce additional capital market volatility. Capital controls can only incur additional volatility in the economy when confronting a foreign interest rate shock, because the controls transform the immediate changes to deposit portfolios to a gradual adjustment process. A foreign interest rate shock cannot influence real variables of the domestic economy if there are no controls, while capital controls create a transmission mechanism that links the domestic economy and foreign nominal shocks.

In Chapter 4, we build up an open economy New Keynesian model with a banking sector which finances itself from three different funding sources. The model allows the bank to rely more on short-term funding when it is relatively difficult to finance itself by collecting deposits from households. Compared with the existing literature, the model in this chapter allows risk-taking behaviour of banks by relying more on short-term funding sources. The model is estimated by the Bayesian method using quarterly Chinese data from 1996Q1 to 2015Q4. Based on the estimated and calibrated parameters, impulse responses are conducted to examine the performance of the model. In order to compare the traditional Taylor rule based monetary policy and macroprudential policy, this study uses an ad hoc central bank loss function based on the squared sum of inflation and the output gap. Different weights on the output gap are tried and it is conclusively found that a macroprudential policy based on loan to value ratio can enhance the ability of the extended Taylor rule to tame fluctuations of the economy. Moreover, the loan to value ratio extended Taylor rule alone has relatively limited effects on controlling business cycles.

Bibliography

Adolfson, Malin et al. (2007). "Bayesian estimation of an open economy DSGE model with incomplete pass-through". In: *Journal of International Economics* 72.2, pp. 481–511.

Aguiar, Mark and Gita Gopinath (2007). "The role of interest rates and productivity shocks in emerging market fluctuations". In: *Working Papers Central Bank of Chile* 12, pp. 345–367.

Ahmed, Shaghil and Andrei Zlate (2014). "Capital flows to emerging market economies: a brave new world?" In: *Journal of International Money and Finance* 48, pp. 221–248.

Aizenman, Joshua and Hiro Ito (2012). "Trilemma policy convergence patterns and output volatility". In: *The North American Journal of Economics and Finance* 23.3, pp. 269–285.

Anderson, Theodore W and Herman Rubin (1949). "Estimation of the parameters of a single equation in a complete system of stochastic equations". In: *The Annals of Mathematical Statistics*, pp. 46–63.

Andrés, Javier, Oscar Arce, and Carlos Thomas (2013). "Banking competition, collateral constraints, and optimal monetary policy". In: *Journal of Money, Credit and Banking* 45.s2, pp. 87–125.

Andrews, Donald WK, Marcelo J Moreira, and James H Stock (2006). "Optimal two-sided invariant similar tests for instrumental variables regression". In: *Econometrica*, pp. 715–752.

Angelini, Paolo, Stefano Neri, and Fabio Panetta (2011). "The Interaction between Capital Requirements and Monetary Policy". In: *Journal of Money, Credit and Banking* 6.46, pp. 1073–1112.

Backus, David K and Gregor W Smith (1993). "Consumption and real exchange rates in dynamic economies with non-traded goods". In: *Journal of International Economics* 35.3, pp. 297–316.

Bailliu, Jeannine, C. E. Saire Meh, and Yahong Zhang (2015). "Macroprudential rules and monetary policy when financial frictions matter". In: *Economic Modelling* 50, pp. 148–161.

Bean, Charles (2009). "The Great Moderation, the Great Panic and the Great Contraction Text of the Schumpeter Lecture by Mr Charles Bean". In:

Benes, Jaromir and Mr Michael Kumhof (2011). *Risky bank lending and optimal capital adequacy regulation*. International Monetary Fund.

Benigno, Pierpaolo and J David Lopez-Salido (2006). "Inflation persistence and optimal monetary policy in the euro area". In: *Journal of Money, Credit and Banking* 38.3, pp. 587–614.

Benigno, Pierpaolo and Michael Woodford (2012). "Linear-quadratic approximation of optimal policy problems". In: *Journal of Economic Theory* 147.1, pp. 1–42.

Bernanke, Ben (2005). *The global saving glut and the US current account deficit*. Tech. rep.

— (2007). "Global imbalances: recent developments and prospects". In: *Bundesbank Lecture speech, September*.

— (2013). "Long-term interest rates". In: *remarks at the Annual Monetary/Macroeconomics Conference: The Past and Future of Monetary Policy, sponsored by Federal Reserve Bank of San Francisco, March*. Vol. 1.

Bernanke, Ben S., Mark Gertler, and Simon Gilchrist (1999). "The financial accelerator in a quantitative business cycle framework". In: *Handbook of macroeconomics* 1, pp. 1341–1393.

Bianchi, Javier and Enrique G. Mendoza (2011). "Overborrowing, Financial Crises and Macro-PrudentialPolicy?" In: *IMF Working Papers*, pp. 1–53.

Blanchard, Olivier and Jordi Galí (2007). "Real wage rigidities and the New Keynesian model". In: *Journal of Money, Credit and Banking* 39.s1, pp. 35–65.

BoE (2009). "The Role of Macroprudential Policy". In: *Bank of England Discussion Paper*.

Borio, C., C. Furfine, and P. Lowe (2001). "Procyclicality of the financial system and financial stability: Issues and policy options". In: *Marrying the Macro-and Micro-Prudential Dimensions of Financial Stability*, pp. 1–57.

Borio, Claudio and Haibin Zhu (2012). "Capital regulation, risk-taking and monetary policy: a missing link in the transmission mechanism?" In: *Journal of Financial Stability* 8.4, pp. 236–251.

Borio, Claudio EV and Ilhyock Shim (2007). "What can (macro-) prudential policy do to support monetary policy?" In:

Boyd, John H. and Gianni De Nicolo (2005). "The theory of bank risk taking and competition revisited". In: *The Journal of finance* 60.3, pp. 1329–1343.

Brunnermeier, Markus Konrad et al. (2009). *The fundamental principles of financial regulation*. Vol. 11. Centre for Economic Policy Research London.

Brzoza-Brzezina, Micha L., Marcin Kolasa, and Krzysztof Makarski (2014). "Monetary and macroprudential policy with foreign currency loans". In:

— (2015). "Macroprudential policy and imbalances in the euro area". In: *Journal of International Money and Finance* 51, pp. 137–154.

Brzoza-Brzezina, Michał and Krzysztof Makarski (2011). "Credit crunch in a small open economy". In: *Journal of International Money and Finance* 30.7, pp. 1406–1428.

Calvo, Guillermo A. (1983). “Staggered prices in a utility-maximizing framework”. In: *Journal of monetary Economics* 12.3, pp. 383–398.

Calvo, Guillermo A., Leonardo Leiderman, and Carmen M. Reinhart (1996). “Inflows of Capital to Developing Countries in the 1990s”. In: *The Journal of Economic Perspectives*, pp. 123–139.

Caruana, James (2010). “Macroprudential Policy: Working Towards a New Consensus”. In: *Bank for International Settlements, Basel, Switzerland.*

Chang, Chun, Zheng Liu, and Mark M Spiegel (2015). “Capital controls and optimal Chinese monetary policy”. In: *Journal of Monetary Economics* 74, pp. 1–15.

Cheung, Y.W., D.C. Tam, and M.S. Yiu (2008). “Does the Chinese interest rate follow the US interest rate?” In: *International Journal of Finance & Economics* 13.1, pp. 53–67.

Chib, Siddhartha and Edward Greenberg (1995). “Understanding the metropolis-hastings algorithm”. In: *The american statistician* 49.4, pp. 327–335.

Chowdhury, Ibrahim, Mathias Hoffmann, and Andreas Schabert (2006). “Inflation dynamics and the cost channel of monetary transmission”. In: *European Economic Review* 50.4, pp. 995–1016.

Christensen, Ian, C. E. Saire Meh, and Kevin Moran (2011). “Bank leverage regulation and macroeconomic dynamic”. In: *CIRANO-Scientific Publications 2011s-76.*

Christiano, Lawrence J., Mathias Trabandt, and Karl Walentin (2011). “Introducing financial frictions and unemployment into a small open economy model”. In: *Journal of Economic Dynamics and Control* 35.12, pp. 1999–2041.

Clarida, R., J. Galí, and M. Gertler (1999). “The Science of Monetary Policy”. In: *Journal of Economic Literature* 37, pp. 1661–1707.

Cragg, John G and Stephen G Donald (1993). “Testing identifiability and specification in instrumental variable models”. In: *Econometric Theory* 9.02, pp. 222–240.

Crockett, A. (2000). "Marrying the micro-and macroprudential dimensions of financial stability. BIS-Speeches (21. September 2000)". In:

Curdia, Vasco and Michael Woodford (2009). "Conventional and unconventional monetary policy". In:

— (2010). "Credit spreads and monetary policy". In: *Journal of Money, Credit and Banking* 42.s1, pp. 3–35.

Darracq-Paries, M., C. K. Sorensen, and Diego Rodriguez-Palenzuela (2011). "Macroeconomic propagation under different regulatory regimes: Evidence from an estimated dsge model for the euro area". In: *International Journal of Central Banking* 7.4, pp. 49–113.

Davig, Troy and Eric M Leeper (2005). "Generalizing the Taylor principle". In: *National Bureau of Economic Research*.

De Bandt, O., P. Hartmann, and Jos-Luis Peydr (2009). "Systemic risk: An update". In: *Oxford Handbook of Banking, Oxford University Press*.

Del Negro, Marco and Frank Schorfheide (2008). "Forming priors for DSGE models (and how it affects the assessment of nominal rigidities)". In: *Journal of Monetary Economics* 55.7, pp. 1191–1208.

Dixit, Avinash K. and Joseph E. Stiglitz (1977). "Monopolistic competition and optimum product diversity". In: *The American Economic Review* 67.3, pp. 297–308.

Dufour, Jean-Marie, Lynda Khalaf, and Maral Kichian (2006). "Inflation dynamics and the New Keynesian Phillips Curve: an identification robust econometric analysis". In: *Journal of Economic dynamics and control* 30.9, pp. 1707–1727.

Faia, Ester and Tommaso Monacelli (2007). "Optimal interest rate rules, asset prices, and credit frictions". In: *Journal of Economic Dynamics and control* 31.10, pp. 3228–3254.

Farhi, Emmanuel and Ivan Werning (2012). *Dealing with the trilemma: Optimal capital controls with fixed exchange rates*. Tech. rep. National Bureau of Economic Research.

Farhi, Emmanuel and Ivan Werning (2014). “Dilemma not trilemma? Capital controls and exchange rates with volatile capital flows”. In: *IMF Economic Review* 62.4, pp. 569–605.

Fischer, Stanley (2001). “Exehange Rate Regimes: Is the Bipolar View Correct? Distinguished Lecture on Economics in Government”. In: *Journal of Economic Perspectives Vol115, No12 (Spring), pp13-24*.

Fisher, Irving (1933). “The debt-deflation theory of great depressions”. In: *Econometrica: Journal of the Econometric Society*, pp. 337–357.

Fleming, J Marcus (1962). “Domestic Financial Policies under Fixed and under Floating Exchange Rates”. In: *Staff Papers-International Monetary Fund*, pp. 369–380.

Forbes, Kristin J. and Francis E. Warnock (2012). “Capital flow waves: Surges, stops, flight, and retrenchment”. In: *Journal of International Economics* 88.2, pp. 235–251.

Frankel, J., S.L. Schmukler, and L. Servén (2002). “Global transmission of interest rates: monetary independence and currency regime”. In: *Journal of International Money & Finance* 23.5, pp. 701–733.

Fuhrer, Jeffrey C and Giovanni Olivei (2010). “The role of expectations and output in the inflation process: an empirical assessment”. In: *FRB of Boston Public Policy Brief* 10-2.

Funke, M. and M. Paetz (2012). “A DSGE-Based Assessment of Nonlinear Loanto-Value Policies: Evidence from Hong Kong. BOFIT Discussion Papers 11/2012. Bank of Finland”. In: *Institute for Economies in Transition*.

Galati, Gabriele and Richhild Moessner (2013). “Macroprudential Policy - A Literature Review”. In: *Journal of Economic Surveys* 27.5, pp. 846–878.

Galí, Jordi and Mark Gertler (1999). “Inflation dynamics: A structural econometric analysis”. In: *Journal of monetary Economics* 44.2, pp. 195–222.

Galí, Jordi, Mark Gertler, and J David Lopez-Salido (2001). “European inflation dynamics”. In: *European Economic Review* 45.7, pp. 1237–1270.

Gali, Jordi, Mark Gertler, and J David Lopez-Salido (2005). “Robustness of the estimates of the hybrid New Keynesian Phillips curve”. In: *Journal of Monetary Economics* 52.6, pp. 1107–1118.

Gali, Jordi and Tommaso Monacelli (2005). “Monetary policy and exchange rate volatility in a small open economy”. In: *The Review of Economic Studies* 72.3, pp. 707–734.

Gambacorta, Leonardo and Federico M. Signoretti (2014). “Should monetary policy lean against the wind?: An analysis based on a DSGE model with banking”. In: *Journal of Economic Dynamics and Control* 43, pp. 146–174. DOI: 10.1016/j.jedc.2014.01.016.

Gelman, Andrew et al. (2014). *Bayesian data analysis*. Vol. 2. Taylor & Francis.

Gerali, Andrea et al. (2010). “Credit and Banking in a DSGE Model of the Euro Area”. In: *Journal of Money, Credit and Banking* 42.s1, pp. 107–141.

Gertler, Mark and Peter Karadi (2011). “A model of unconventional monetary policy”. In: *Journal of monetary Economics* 58.1, pp. 17–34.

Gilchrist, Simon and Egon Zakrajšek (2011). “Monetary policy and credit supply shocks”. In: *IMF Economic Review* 59.2, pp. 195–232.

Goodfriend, Marvin and Bennett T. McCallum (2007). “Banking and interest rates in monetary policy analysis: A quantitative exploration”. In: *Journal of Monetary Economics* 54.5, pp. 1480–1507.

Goodhart, C and P Turner (2014). “Pattern of policy tightening is different this time”. In: *Financial Times*.

Goodhart, Charles, Carolina Osorio, and Dimitrios P. Tsomocos (2009). “Analysis of monetary policy and financial stability: A new paradigm”. In:

Green, HAl (1964). “Aggregation in Economics Analysis”. In:

Griffoli, Tommaso Mancini (2007). “Dynare User Guide. An introduction to the solution and estimation of DSGE models”. In: *Manuscript, http://www. cepremap. cnrs. fr/dynare*.

Guo, K., H. Ai, and Z. Zheng (2013). “Tongzhang Guanxing, Hunhe Feilipusi Quxian Yu Zhongguo Tongzhang Dongtai Tezheng”. In: *Studies of International Finance* 2, pp. 74–84.

Hannoun, Herv E. (2010). “Towards a global financial stability framework”. In: pp. 26–27.

Hansen, B.E (2016). *Econometrics*. `http://www.ssc.wisc.edu/2013-10-10`.

Hansen, Christian, Jerry Hausman, and Whitney Newey (2012). “Estimation with many instrumental variables”. In: *Journal of Business & Economic Statistics*.

Hansen, Lars Peter and Kenneth J Singleton (1982). “Generalized instrumental variables estimation of nonlinear rational expectations models”. In: *Econometrica: Journal of the Econometric Society*, pp. 1269–1286.

Hausmann, Ricardo (1999). “Should there be five currencies or one hundred and five?” In: *Foreign Policy*, pp. 65–79.

He, H. (2007). “Zhongguo Waihui Chongxiao Ganyu he Huobi Zhengce Dulixing Yanjiu”. In: *Journal of Finance and Economics* 33.11, pp. 18–30.

Iacoviello, Matteo (2005). “House prices, borrowing constraints, and monetary policy in the business cycle”. In: *American economic review*, pp. 739–764.

Jeanne, O. and A. Korinek (2012). “Managing credit booms and busts: A Pigouvian taxation approach”. In: *The American Economic Review: Papers and Proceedings* 2.1oo, pp. 403–407.

Jin, Y. and B. Zhou (2014). “Xinxing Shichang Guoliang Sanyuan Beilun Kuangjia Xuanze Weihe Zhongjianhua”. In: *Studies of International Finance* 09. : 11, pp. 34–44.

Jin, Z. (2013). “China’s Capital Account Opening-up and Dynamic Equilibrium of Balance of Payments”. In: *International Economic Review* 3, pp. 57–64.

Kannan, Prakash, Pau Rabanal, and Alasdair M. Scott (2012). “Monetary and macroprudential policy rules in a model with house price booms”. In: *The BE Journal of Macroeconomics* 12.1.

Keeley, Michael C. (1990). “Deposit insurance, risk, and market power in banking”. In: *The American Economic Review*, pp. 1183–1200.

Kiyotaki, Nobuhiro and John Moore (1997). “Credit cycles”. In: *Journal of Political Economy* 105.2, pp. 211–248.

Kleibergen, Frank (2002). “Pivotal statistics for testing structural parameters in instrumental variables regression”. In: *Econometrica* 70.5, pp. 1781–1803.

Kleibergen, Frank and Sophocles Mavroeidis (2009). “Weak instrument robust tests in GMM and the New Keynesian Phillips curve”. In: *Journal of Business & Economic Statistics* 27.3, pp. 293–311.

Klein, Michael W (2012). *Capital controls: Gates versus walls.* Tech. rep. National Bureau of Economic Research.

Krause, Michael U, David Lopez-Salido, and Thomas A Lubik (2008). “Inflation dynamics with search frictions: A structural econometric analysis”. In: *Journal of Monetary Economics* 55.5, pp. 892–916.

Krugman, Paul (2010). “Taking on China”. In: *New York Times* 14, pp. 2010–2011.

Laffer, Art (2015). “Currency Manipulation And Its Impact On Free Trade”. In: *Forbes.*

Lambertini, Luisa, Caterina Mendicino, and Maria Teresa Punzi (2013). “Leaning against boom–bust cycles in credit and housing prices”. In: *Journal of Economic Dynamics and Control* 37.8, pp. 1500–1522.

Lindé, Jesper (2005). "Estimating New-Keynesian Phillips curves: A full information maximum likelihood approach". In: *Journal of Monetary Economics* 52.6, pp. 1135–1149.

Ma, Adrian (2002). "GMM estimation of the new Phillips curve". In: *Economics Letters* 76.3, pp. 411–417.

Martinez-Miera, David and Rafael Repullo (2010). "Does competition reduce the risk of bank failure?" In: *Review of Financial Studies* 23.10, pp. 3638–3664.

Mavroeidis, Sophocles (2005). "Identification issues in forward-looking models estimated by GMM, with an application to the Phillips curve". In: *Journal of Money, Credit and Banking*, pp. 421–448.

Mavroeidis, Sophocles, Mikkel Plagborg-Møller, and James H Stock (2014). "Empirical evidence on inflation expectations in the New Keynesian Phillips Curve". In: *Journal of Economic Literature* 52.1, pp. 124–188.

McKinnon, Ronald (2010). "A Reply to Krugman: What Manipulation?" In: *The International Economy*, pp. 37–9.

McKinnon, Ronald and Gunther Schnabl (2003). "China: A Stabilizing or Deflationary Influence in East Asia". In: *The Problem of Conflicted Virtue*.

— (2012). "China and Its Dollar Exchange Rate: A Worldwide Stabilising Influence? 1". In: *The World Economy* 35.6, pp. 667–693.

Mendicino, Caterina and Andrea Pescatori (2007). *Credit Frictions, Housing Prices and Optimal Monetary Policy Rules*. Memo.

Mikusheva, (2013). "Survey on statistical inferences in weakly-identified instrumental variable models". In: *Applied Econometrics* 29.1, pp. 116–131.

Mikusheva, Anna and Brian P Poi (2006). "Tests and confidence sets with correct size when instruments are potentially weak". In: *Stata Journal* 6.3, pp. 335–347.

Mishkin, Frederic S. (2011). "Monetary policy strategy: lessons from the crisis". In: *Workong Paper*.

Mohan, Rakesh and Muneesh Kapur (2009). "Managing the Impossible Trinity: Volatile Capital Flows and Indian Monetary Policy". In: *Social Science Electronic Publishing*.

Moreira, Marcelo J (2003). "A conditional likelihood ratio test for structural models". In: *Econometrica* 71.4, pp. 1027–1048.

— (2009). "Tests with correct size when instruments can be arbitrarily weak". In: *Journal of Econometrics* 152.2, pp. 131–140.

Mundell, Robert A (1963). "Capital mobility and stabilisation policy under fixed and flexible exchange rates". In: *Canadian Journal of Economics and Political Science/Revue canadienne de economiques et science politique* 29.04, pp. 475–485.

Nason, James M. and Gregor W. Smith (2008). "Identifying the New Keynesian Phillips curve". In: *Journal of Applied Econometrics* 23.5, pp. 525–551.

Obstfeld, Maurice (2015). "Trilemmas and trade-offs: living with financial globalisation". In:

Obstfeld, Maurice and Alan M. Taylor (2004). *Global capital markets: integration, crisis, and growth.* Cambridge University Press.

Ostry, Jonathan et al. (2010). "Capital inflows: The role of controls". In: *IMF Stafl Position Note* 10.04.

Perotti, E. and J. Suarez (2009). "Liquidity risk charges as a macro prudential tool. CEPR Policy Insight 40, November; forthcoming in the". In: *International Journal of Central Banking*.

Quint, Dominic and Pau Rabanal (2014). "Monetary and macroprudential policy in an estimated DSGE model of the euro area". In: *International Journal of Central Banking* 10, pp. 169–235.

Ravenna, Federico and Carl E Walsh (2008). "Vacancies, unemployment, and the Phillips curve". In: *European Economic Review* 52.8, pp. 1494–1521.

Rey, Helene (2013). "Dilemma not trilemma: the global cycle and monetary policy independence". In: pp. 1–2.

Rubio, Margarita and Jos E. A. Carrasco-Gallego (2014). "Macroprudential and monetary policies: Implications for financial stability and welfare". In: *Journal of Banking & Finance* 49, pp. 326–336.

Rudd, Jeremy and Karl Whelan (2005). "New tests of the new-Keynesian Phillips curve". In: *Journal of Monetary Economics* 52.6, pp. 1167–1181.

Sbordone, Argia M. et al. (2010). "Policy analysis using DSGE models: an introduction". In: *Economic policy review* 16.2.

Schroder, Marcel (2015). *Mercantilism and Chinas hunger for international reserves*. Tech. rep.

Shambaugh, J.C. (2004). "The Effect of Fixed Exchange Rates on Monetary Policy". In: *The Quarterly Journal of Economics* 119.1, pp. 300–351.

Shin, Hyun Song (2010). "Financial Intermediation and the Post-Crisis Financial System". In: *SSRN Electronic Journal* 68.304, pp. 1–18.

Sjö, Bo (2008). "Testing for unit roots and cointegration". In: *Nationalekonomiska institutionen, Lindköpings Universitet*.

Song, Zheng, Kjetil Storesletten, and Fabrizio Zilibotti (2011). "Growing like china". In: *The American Economic Review* 101.1, pp. 196–233.

Stock, James H and Mark W Watson (2007). "Why has US inflation become harder to forecast?" In: *Journal of Money, Credit and banking* 39.s1, pp. 3–33.

Stock, James H and Jonathan H Wright (2000). "GMM with weak identification". In: *Econometrica* 68.5, pp. 1055–1096.

Stock, James H, Jonathan H Wright, and Motohiro Yogo (2002). "A survey of weak instruments and weak identification in generalized method of moments". In: *Journal of Business & Economic Statistics* 20.4, pp. 518–529.

Stock, James H and Motohiro Yogo (2005). "Testing for weak instruments in linear IV regression". In: *Identification and inference for econometric models: Essays in honor of Thomas Rothenberg*.

Sun, H (2006). “Zhongguo Huobi Zhengce Dulixing he Youxiaoxing Jianyan – Jiyu 1994-2004 Nian Shuju”. In: *Contemporary Finance and Economics* 7, pp. 26–32.

Taylor, John B. (1993). “Discretion Versus Policy Rules in Practice”. In: 39, pp. 195–214.

— (2009). “The Financial Crisis and the Policy Responses: An Empirical Analysis of What Went Wrong”. In: *NBER Working Paper* 14631.

Taylor, John B et al. (2008). “Monetary Policy and the State of the Economy”. In: *testimony before the Committee on Financial Services, US House of Representatives*.

Trichet, Jean-Claude (2009). “Systemic risk”. In: *Clare Distinguished Lecture in Economics and Public Policy, organised by Clare College, University of Cambridge* 10.

Tucker, Paul (2009). “The debate on financial system resilience: macroprudential instruments”. In: *Barclays annual lecture, London* 22.

Wang, S. and Y. Wang (2011). “Ziben Jianjin Kaifang, Waihui Chubei Jilei yu Huobi Zhengce Dulixing – Zhongguo Shuju de Shizheng Yanjiu”. In: *Studies of International Finance* 3, pp. 37–45.

Woodford, Michael (2001). “The Taylor rule and optimal monetary policy”. In: *American Economic Review*, pp. 232–237.

Xie, P. and X. Luo (2002). “Taile Guize jiqi zai Zhongguo Huobi Zhengce Zhong de Jianyan”. In: *Economic Research Journal* 3.3, p. 12.

Yang, J. (2009). “Tongzhang Yuqi, Liudongxing Guosheng yu Zhongguo Tonghuo Pengzhang de Dongtai Xingzhi”. In: *Economic Research Journal* 1, pp. 106–117.

Zhao, Q (2007). “Woguo Waihui Chubei Genyuan ji Zhili Yanjiu”. In: *Studies of International Finance* 08. : 7, pp. 73–79.

Zhou, X. (2012). “Renminbi Ziben Xiangmu Keduihuan De Qianjing he Lujing”. In: *Journal of Financial Research* 1, pp. 1–19.