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The Monetary Policy and Exchange Rate Policy of China

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Abstract

Unlike the other countries, China as a developing country, from the transformation of a planned economy, its monetary policy and exchange rate policy have many characteristics. In this doctoral dissertation, both China's monetary policy and exchange rate policy will be discussed in detail from three aspects: monetary policy rule, the effectiveness of monetary policy and the sterilization of foreign reserves. The relationship of monetary policy and exchange rate policy is investigated by analyzing the sterilization of foreign reveres.

In Chapter1, a detailed literature review is shown for the following subjects. (1) The Survey of Monetary Policy (Policy Rule)--Up until August 2012, there has been in China 235 papers related to the Taylor Rule, but only 15 papers on the McCallum rule. It shows that Chinese economists have paid a lot more attention to the Taylor rule than to the McCallum rule even though there are some problems concerning applying the Taylor rule to China, for instance that the interest rate is decided not by the market but by the PBC. (2)The Survey of Monetary Policy (Effectiveness)--There is not as many papers about Chinese monetary policy as Japanese monetary policy. Prior work has examined money demand in China including tests for causality between money and prices and money and output. (3)The Survey of the Relationship between Exchange Rate Policy and Monetary Policy--Aizenman and Glick (2009) indicated that the sterilization coefficients began rising from roughly 0.6 in 2000 to almost 1.5 in 2006, and then fell to 0.7, which means that China may have reached limits to the extent of its ability to sterilize its massive reserve inflows. However, Wu (2009) stated that the monetary sterilization in China is incomplete, only 0.35 are sterilized for a yuan of foreign exchange reserve that flows into China.

Using both GMM and SVAR, Chapter 2 tackles an important problem in recent Chinese monetary policy: whether the policy is better captured by the Taylor rule or the McCallum rule. The estimations suggest that the McCallum rule is more active than the Taylor rule in China. Furthermore, GMM model gives the formula to predict m2 giving inflation, output, and nominal exchange rate targets, which can nicely track the behavior of actual m2. In order to get more accurate results and to grasp the nuances of the economic variables, monthly data are used. Chapter 2 also includes a comprehensive literature review on Chinese monetary policy rule.

Chapter 3 aims to provide an analysis on the effectiveness of the monetary policy in China during the past two decades by using the time-varying parameter structural vector Autoregression (TVP-VAR) with stochastic volatility. The TVP-VAR model, combined with stochastic volatility, enables us to capture structural changes in underlying structure of the Chinese economy in a flexible and robust manner. The Markov chain Monte Carlo method is employed for the estimation of the TVP-VAR models with stochastic volatility. The effectiveness of the monetary policy is explored from three perspectives: inflation, output and real effective exchange rate in this paper. We come to a conclusion that money supply policy is not effective as inflation rate, economic growth and exchange rate do not respond to money supply shocks. One of the reasons is that there is no trade off between inflation and economic growth in China. The Phillips Curve in China is a vertical curve which suggests that economic growth does not react to the money supply shocks. This paper is the first attempt to use TVP-VAR model to analyze Chinese monetary policy.

In Chapter 4, it is suggested that China has been stockpiling international reserves at an extremely rapid pace since the late1990s and has surpassed Japan to become the largest reserve holder in the world. Chapter 4 undertakes an empirical investigation to assess the extent of de facto sterilization using monthly data between December 1999 and October 2013. We find that China has not been able to successfully sterilize a large portion of these reserve increases. Additionally, by using TVP-VAR model and GMM, the empirical results demonstrate that the sterilization coefficient is affected by inflation rate and exchange rate, but not by output growth rate. PBC only adjusted sterilization coefficients when inflation rate is high and exchange rate is depreciating.

In brief, this dissertation suggests that China's monetary policy can be traced by McCallum rule; China's monetary policy is not an effective policy, as there is no trade-off between inflation and economic growth; the sterilization of foreign reserves is not sufficient, and the sterilization coefficient is only affected by inflation rate and exchange rate.

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Contents

1. Survey of Exchange Rate Policy and Monetary Policy

1.1 The Survey of Monetary Policy (Policy Rule)

Both the literature on basic policy rules and empirical analysis of policy rules in China will be summarized in this part. Particularly emphasized is the literature on empirical analysis of policy rule in China, much of which are in Chinese and until now has not been summarized in English.

1.1.1 The empirical analysis of the Taylor rule

Taylor (1993a) originally presented what would become known as the Taylor rule at the November 1992 Carnegie Rochester Conference on Public Policy, when he suggested that "good policy rules call for changes in the federal funds rate in response to change in the price level and changes in real income" .

$$r = p + 0.5y + 0.5(p-2) + 2 \qquad (1.1.1)$$

where

y = percent deviation of real GDP from the trend

p = rate of inflation over the previous four quarters.

Within a few months of the publication of this conference volume, the Federal Open Market Committee (FOMC) decided to adopt the formula to inform their monetary policy deliberations. Consequently, this allowed Taylor-type rules to serve as the standard by which monetary policy is introduced in macroeconomic models. Taylor-type rules helped policymakers to gain the insight of how policy has been set in the past and how policy should be set in the future, which gradually turned into benchmarks to evaluate the current situation on monetary policy and determine a future policy path.

As Taylor (2011) indicated, thousands of papers have been written on monetary policy rules since the mid-1970s. The staffs of central banks around the world regularly use policy rules in their research and policy evaluation (Orphanides, 2008) as do practitioners in the financial markets.

As "the list of such models is now way too long to even tabulate, let alone discuss" (Taylor 2011), we will list the models which is related to our research only.

(1) By measurement used

A. Inflation

One key issue for simple policy rule is the appropriate measure of inflation to include in the rule. In many models (Levin, Wieland and Williams, 1999, 2003), simple rules that respond to smoothed inflation rates such as the one-year rate typically perform better than those that respond to the one-quarter inflation rate, even though the objective is to stabilize the one-quarter rate. In FRB/US model (Taylor 1999) the rule that responds to the three-year average inflation rate performs the best.

B. Interest rate smoothing

A significant degree of inertia can significantly help improve performance in forward-looking models like FRB/US. As discussed in Levin et al (1999) and Woodford (1999, 2003), inertial rules take advantage of the expectations of future policy and economic development in influencing outcomes.

C. Responding to other variables

A frequently heard criticism of simple monetary policy rule is that they ignore valuable information about the economy. In other words, they are too simple for the real world (Mishkin, 2007; Svensson, 2003)

One specific issue that has attracted a great deal of attention is adding various asset prices, such as the exchange rate or equity prices to the policy rule (Bernanke and Gertler 1999; Clarida, Gali and Gertler, 2001; and Woodford 2003). Researches have shown that the magnitude of the benefits from responding to asset prices is generally small in existing estimated models.

(2) By countries

A. For the historical monetary policy analysis of US

Taylor (1999) examines several eras and episodes of U.S. monetary history from the perspective of recent research on monetary policy rule. It explores the timing and the political economic reasons for changes in monetary policy from one policy rule to another, and it examines the effects of different monetary policy rules on the economy.

Clarida, Gali and Gertler (2000) estimate a forward-looking monetary policy reaction for the postwar United States economy, before and after Volcker's appointment as Fed Chairman in 1979. Their results point to substantial differences in the estimated rule across periods. In practical, interest rate policy in the Volcker-Greenspan period appears to have been much more sensitive to changes in expected inflation than in the pre-Volcker period. They then compare some of the implications of the estimated rules for the equilibrium properties of inflation and output, using a simple macroeconomic model, and show that the Volcker-Greenspan rule is stabilizing.

Orphanides (2003) examines the usefulness of the Taylor-rule framework as an organizing device for describing the policy debate and evolution of monetary policy in the United Sates. Monetary policy during the 1920s and since the 1951 Treasury-Federal Reserve Accord can be broadly interpreted in terms of this framework with rather surprising consistency. In broad terms, during these periods policy has been generally formulated in a forward-looking manner with price stability and economic stability serving as implicit or explicit guides. As early as the 1920s, measures of real economic activity relative to "normal" or "potential" supply appear to have influenced policy analysis and deliberations. Confidence in such measures as guides for activist monetary policy prove counterproductive at times, resulting in excessive activism, such as during the Great Inflation and at the brink of the Great Depression. Policy during the past two decades is broadly consistent with natural growth targeting variants of the Taylor rule that exhibit less activism.

B. For comparison of G3 (US, Europe and Japan) countries

Clarida, Gali and Gertler (1998) report estimates of monetary policy reaction functions for two sets of countries: the G3 (Germany, Japan and the U.S.) and the E3 (UK, France, and Italy). They find that since 1979 each of the G3 central banks has pursued an implicit form of inflation targeting, which may account for the broad success of monetary policy in those countries over this time period. The evidence also suggest that these central banks have been forward looking: they respond to anticipated inflation as opposed to lagged inflation. As for the E3, even prior to the emergence of the "hard ERM", the E3 central banks are heavily influenced by German monetary policy. Further, using the Bundesbank's policy rule as a benchmark, they find that at the time of the EMS collapse, interest rates in each of the E3 countries are much higher than domestic macroeconomic conditions warranted. Taken all together, the results lend support to the view that some form of inflation targeting may under certain circumstances be superior to fixing exchange rates, as a means to gain a nominal anchor for monetary policy.

Clarida (2001) use the empirical framework for formulating and estimating forward looking monetary policy rules developed in Clarida, Gali, Gertler (1998; 1999; 2000; 2001) to assess what they know, don't know, and can't tell about monetary policy making in an open economy with an implicit inflation target. Among the issues discussed are: the relationship between structural VAR models of monetary policy and exchanges rates and estimates of forward looking Taylor rules; the relationship between inflation targeting and leaning again the exchange rate wind; why central bankers are averse to even wide-band target zones; quantifying that stresses and costs of a one size fits all monetary policy for the members of a monetary union or currency bloc.

Gerdesmeier, Mongelli and Roffia (2007) provide a systematic comparison of the Eurosystem, the US Federal Reserve and the Bank of Japan. These monetary authorities exhibit somewhat different status and tasks, which reflect different historical conditions and national characteristics. However, widespread changes in central banking practices in the direction of greater independence and increases transparency, as well as changes in the economic and financial environment over the past 15-20 years, have contributed to reduce the differences among these three world's principal monetary authorities. A comparison based on simple "over-the-counter" policy reaction functions show no striking differences in terms of monetary policy implementation.

C. For China's monetary policy analysis

Up until August 2012, there had been 235 papers related to the Taylor Rule published in China, including master's and Ph.D. dissertations, but only 15 papers related to the McCallum rule. There have been approximately five papers about the Taylor rule published in *Economic Research Journal*, a leading Chinese economics journal. However, there are no papers concerning the McCallum Rule. This reflects the much greater popularity of the Taylor rule in the economic community, especially in developed countries. It also shows that Chinese economists have paid a lot more attention to the Taylor rule than to the McCallum rule, even though there are some problems concerning the application of the Taylor rule to China's monetary policy.

There are many papers containing empirical analysis of China's monetary policy via the Taylor rule. The methods and empirical results of these studies are generally similar. Three of them will be reviewed presently, as these three are particularly important and influential.

Xie and Luo (2002) use historical analysis[1] and reaction function.[2] They suggest that the parameter of inflation in the Taylor rule is 0.81, smaller than 1. That is to say, the monetary policy of China is an unstable system, which may be the main reason for the high inflation in the 1990s and deflation in the early 2000s. Their paper is the first to analyze the Taylor rule based on Chinese economic data, but their estimation method is outdated.

Lu and Zhong (2003), the first to do cointegration analysis on the Taylor rule, suggest that the coefficient of the GDP gap is 0.497, which is very close to the result obtained in Taylor (1993a). But the coefficient of the inflation gap is estimated at only 0.089, which is very small. This result indicates that the PBC put more emphasis on GDP than inflation. In addition, the paper introduces a forward-looking Taylor rule for the cointegration analysis, and finds the coefficient of the GDP gap to be 0.509, while that of CPI expectation is just 0.131. They are close to their traditional Taylor rule estimation. What is worth mentioning is that since the data span from 1992 to 2001, which includes the hyperinflation period of 1993 to 1994, there may be some bias in the estimation.

Fan, Yu and Zhang (2011) use a Vector Error Correction Model (VECM) to analyze the responsiveness and activeness of Chinese monetary policy of 1992-2009 by estimating Taylor rule. The results show that the official interest rate responds passively to inflation and does not respond to real output. By using a smoothed Taylor rule, they draw three conclusions. First, the coefficient of inflation is positive but less than 1. Second, the official interest rate exhibits a statistically significant response to output gap. Third, the coefficient of the real effective exchange rate is negative and not statistically significant. With a VAR model, impulse response and variance decomposition analysis are conducted in two orders $x_t = (\pi_t, y_t, e_t, r_t, m_t)$ and $x_t = (\pi_t, y_t, e_t, m_t, r_t)$. The results show that the responses of the inflation rate, output gap and real effective exchange rate to the official interest rate are near zero for all the horizons.

1 Taylor 1993a, 1999
2 Clarida, Gali and Gertler 1998, 2000

1.1.2 The empirical analysis of the McCallum rule

A. Empirical analysis of general McCallum rule

The McCallum rule proposed by McCallum (1987, 1988, 1993) can be expressed as follows

$$\Delta b_t = \Delta x^* - \Delta v_t^a + 0.5(\Delta x^* - \Delta x_{t-1}) \tag{1.1.2}$$

Δb_t is the change in the log of the adjusted monetary base, (i.e., the growth rate of the base between periods t − 1 and t.)

Δx^* is a target growth rate for nominal GDP (Δx^* is specified as $\pi^* + \Delta y^*$, where Δy^* is the long-run average rate of growth of real GDP.)

Δx_t is the change in the log of nominal GDP

Δv_t^a is the average growth of base velocity over the previous 16 quarters, $v_t = x_t - b_t$ being the log of base velocity

"No suggestion is intended to the effect that historical analysis of Stuart-Taylor type represents the only useful approach to policy-rule evaluation", McCallum (2000) has involved simulations with quantitative structural macroeconomic models (Eq. 1.1.2). By employing McCallum rule, the applications to the U.S, the U.K. and Japan are conducted and compared.

McCallum (2003) discusses the difficulty faced by BOJ (Bank of Japan) because of the zero lower bound study. Then he takes up the McCallum rule and argues that the most promising of these would entail rapid monetary base growth effected largely through purchase of foreign exchange.

B. Empirical analysis of McCallum rule in the case of China:

Song and Li (2007) employ cointegration analysis, impulse response and variance decomposition to check the relationship between money supply and fluctuations in the economy. The distinctive feature of this paper is that money supply is reclassified as in the following equations: MM2=M2-M1, MM1=M1-M0. Further, RM0, RMM1, RMM2 and RINDU are defined as the growth rate of M0, MM1, MM2 and industrial added value, respectively. Using the Granger test, they suggest that the PBC closely controlled the money supply, because RM0 Granger causes RMM1 and RMM2, and that RMM1 Granger causes RMM2. Accordingly, they reach the conclusion that as long as PBC controls M0, it can also keep M1 and M2 under control. Furthermore, since both RMM0 and RMM1 are Granger caused by RINDU, PBC could comply with the McCallum rule to affect economic growth through money supply management. That is to say, they indicate that changes to the money supply could affect economic growth. However, there are several deficiencies in this paper. For instance, some problems arise because their reclassification scheme of the money supply is not commonly used.

Burdekin and Siklos (2008) have modeled post-1990 Chinese monetary policy with an augmented McCallum-type rule using both monetary base and m2. They employ three different models in their research, which are presented as follows. First, by estimating a basic McCallum rule,[3] the coefficients of the GDP gap[4] are -0.42 for m2 and -0.008 for the monetary base. Second, after adding a deflation dummy variable which is set equal to one from 1997 on, the estimated coefficient of the GDP gap remains negative but is statistically insignificant when monetary base is the dependent variable; however, the deflation dummy variable is highly significant and negative. Third, when real exchange rate and foreign exchange reserves are added to the model, the coefficients continue to be negative and are statistically significant for both monetary measures. The coefficient on the real exchange rate is negative and statistically significant for m2, indicating that real exchange rate depreciation leads to a negative monetary policy response. The weaker link between foreign exchange reserves and monetary growth may be indicative of PBC success at sterilizing inflows of foreign exchange. Two techniques are adopted. First, GMM is used to avoid the shortcomings of OLS. Second, for the constant deflation dummy, two lags of each of the variables in the equation, and two lags in export growth were used as instruments with nearly identical results.

Fan, Yu and Zhang (2011) use a VECM model to analyze the responsiveness and activeness of China's monetary policy in 1992-2009 by estimating a McCallum rule. The results show that money supply[5] not only responds actively to both inflation rate and real output, but also has certain effects on future inflation and real output. In the whole sample, the growth rate of money supply is negatively and significantly related to the output gap and inflation rate, but its response to the real effective exchange rate is insignificant. With a dummy variable in the year 2000, what is interesting is that the real money supply in the second subperiod is more responsive to inflation but insensitive to the output gap. The VAR model shows that the

[3] The basic McCallum rule is shown in equation (2.2) on page 3.
[4] GDP gap is the gap between target and actual nominal GDP growth.
[5] Money supply here refers to quarterly observation of the annual growth rate of M1, minus the annual inflation rate.

responses of the inflation rate and output gap to the money supply are significant, but are insignificant with respect to the real effective exchange rate. Instead of the real effective exchange rate, real exchange rate should be used, because the PBC does not watch the real effective exchange rate, but instead watches the nominal exchange rate against the USD.

1.1.3 The problems of previous papers and the contribution of this paper:

Previous research on this subject is plagued with various problems, such as outdated estimation methods, insufficient sample sizes and inappropriate data measurements. In addition, instead of REER and real exchange rate, nominal exchange rate should be used in the model as the target of PBC.

These problems will be addressed in this paper. Both GMM and structural VAR will be used for estimation, and monthly data will be selected to ensure adequate sample size. Along with CPI and output gap, the nominal exchange rate will be included in monetary policy rule estimations.

1.2 The Survey of Monetary Policy (Effectiveness)

There are not as many papers about Chinese monetary policy as Japanese monetary policy. Prior work has examined money demand in China including tests for causality between money and prices and money and output. Sun and Ma (2004) investigated the effectiveness of Chinese monetary policy in two regimes of inflation and deflation, and suggested that monetary policies have become less effective in stabilizing price level in the deflation era that started from 1998. And by employing structural VEC model Zhang and Wan (2004) investigated the output and price fluctuations in China, and found that in the long run money accommodates rather than causes changes in output and prices, while in the short run, price fluctuations are mostly attributable to shocks that have permanent effects on prices and money but not on real output.

After Primiceri (2005)'s introduction of the TVP-VAR model, several papers have analyzed the time-varying structure of the macroeconomy in specific ways. Benati and Mumtaz (2005) estimate the TVP-VAR model for the U.K. data by imposing sign restrictions on the impulse responses to assess the source of the "Great Stability" in the United Kingdom as well as uncertainty for inflation forecasting (see also Benati [2008]). Baumeister, Durinck, and Peersman (2008) estimate the TVP-VAR model for the euro area data to assess the effects of excess liquidity shocks on macroeconomic variables. Nakajima, Kasuya, and Watanabe (2009) and Nakajima (2011) estimate the TVP-VAR model for the Japanese macroeconomic data.

An increasing number of studies have examined the TVP-VAR models to provide empirical evidence of the dynamic structure of the economy. As Sun and Ma (2004) mentioned, there is a big challenge to research Chinese monetary policy, which is the frequent structural changes in Chinese monetary system. To overcome this difficulty, Sun and Ma (2004) applied a rolling estimation approach on the VAR model. But other research papers did not refer to this problem. Given such previous literature and such a challenge to research Chinese monetary policy, we will employ TVP-VAR model to analyze Chinese monetary policy, with emphasis on the analysis of the dynamic exchange rate regime changes. Although they are not based on the optimization problems of economic agents, VARs with time variation of parameters can deal with regime changes, with time variation in the lag structure of the model or with nonlinearities that emerge.

1.3 The Survey of the Relationship between Exchange Rate Policy and Monetary Policy

1.3.1 By analysis methods

(1) OLS (Ordinary Least Squares)

The first group assumes that capital flows are exogenously determined and typically estimate sterilization coefficients by running simple OLS on the monetary reaction function such as the one below:

$$\Delta NDA_t = c_0 + c_1 \Delta NFA_t + X'\beta + u_t \tag{1.3.1}$$

where △NDA and △NFA represents the change in net domestic assets (a proxy for domestic money creation) and net foreign assets (a proxy for international reserves) respectively, and X represents other explanatory variables that might influence a monetary authority's reaction. The coefficients of c_1=-1 represents full monetary sterilization, while c_1=0 implies no sterilization (e.g. Aizenman and Glick, 2009).

(2) VAR (Vector Autoregression)

The second group uses a VAR model to estimate the lagged effects of NDAs and NFAs. The standard form of a VAR model is as follows:

$$\Delta NDA_t = \alpha_{10} + \sum_{i=1}^{k} \alpha_{1i} \Delta NDA_{t-i} + \sum_{i=1}^{k} \beta_{1i} \Delta NFA_{t-i} + e_{1t} \tag{1.3.2}$$

$$\Delta NFA_t = \alpha_{20} + \sum_{i=1}^{k} \alpha_{2i} \Delta NFA_{t-i} + \sum_{i=1}^{k} \beta_{2i} \Delta NDA_{t-i} + e_{2t} \tag{1.3.3}$$

Some papers within this group include additional variables in the model such as the domestic interest rate, price level, or exchange rate (for instance, Cavoli and Rajan, 2006; Christensen, 2004; He et al., 2005; Moreno, 1996). The advantage of a VAR approach is that it allows one to trace out the time path of the various shocks on the variables contained in the VAR system (i.e. the impulse response function). If a shock from foreign assets (say an unexpected increase in foreign assets) is associated with an offsetting decrease in domestic money creation, it can be concluded that the sterilization is significant.

(2) 2SLS (Two-Stage Least Squares)

The third group of studies estimates the contemporaneous relationship between NDAs and NFAs using a set of simultaneous equations. Although the studies in the first group ignore the simultaneous bias by assuming capital flows are exogenously determined (Kwack, 2001), it is important to note that domestic monetary conditions are affected by changes in international capital flows and foreign reserves. Concurrently, international capital flows respond to a change in domestic monetary conditions (e.g. higher domestic interest rates would, ceteris paribus, lead to greater capital inflows). Some early studies, such as Argy and Kouri(1974) and Herring and Marston(1977), have suggested using a simultaneous system to overcome the problem of simultaneity. The typical model specification for a set of simultaneous equations is:

$$\Delta NFA_t = \alpha_{10} + \alpha_{11}\Delta NDA_t + X_1'\beta_1 + u_{1t} \tag{1.3.4}$$

$$\Delta NDA_t = \alpha_{20} + \alpha_{21}\Delta NFA_t + X_2'\beta_2 + u_{2t} \tag{1.3.5}$$

where X_1 and X_2 are the vectors of controls in the balance of payment function and monetary reaction function, respectively. Eq. (3.4) and (3.5) are the balance of payments and the monetary reaction functions, respectively. The former estimates the ‘‘offset coefficient’’. The expected value of the offset coefficient is bound by 0 in the event of no capital mobility and -1 in the event of perfect capital mobility. The latter measures the sterilization coefficient. The expected value of the sterilization coefficient is -1 if reserve buildup is perfectly sterilized and 0 if the central bank does not sterilize at all. In general, the greater the degree of capital mobility, the less effective is monetary sterilization; a small offset coefficient and a large sterilization coefficient generally imply that the central bank has a fairly high degree of monetary policy independence to neutralize the impact of capital flows effectively on a sustained basis.

1.3.2 By countries

(1) General models

Roubini (1988) suggests that the traditional approach to the estimation of the offset and sterilization equations can be criticized for the ad-hoc specification of the reaction function of the monetary authorities and the endogeneity of the domestic credit and foreign reserve variables in the estimated equations. The paper proposes an alternative analytical model where the sterilization and offset equations are derived from an explicit maximization problem solved by the monetary authority. In such a model, the optimal intervention and sterilization policies of the monetary authority are shown to be dependent on the different disturbances hitting the economy and the preferences of the monetary authority. In particular, under a wide range of domestic and foreign disturbances the optimal response of the central bank will lead to negatively correlated comovements of domestic credit and foreign reserves if the cer1tral bank cares more about the interest rate smoothing objective relative to the foreign exchange reserve stabilization goal. Conversely, positive correlations between domestic credit and foreign reserves will be observed if the foreign reserve objective is dominant.

Veriga (1999) discusses the causes of failure of inflation stabilization plans. Following a description of stylized facts of inflation stabilization, a model of Balance-of-Payments crises is presented, highlighting some of the main factors leading to the collapse of stabilizations. Empirical results obtained when estimating a binary probit model over a panel of 34 stabilizations identify real exchange rate appreciation, lack of foreign reserves, and government budget deficits as the main causes of failure of inflation stabilization plans. This is consistent with the model presented in this paper, with the stylized facts of stabilizations, and with some of the models found in the literature.

Kumhof (2004) indicates reductions in international interest rates are a major cause of capital flows to emerging economies. Increases in domestic interest rates are a frequent policy response to the resulting price increases. This is often unsuccessful. The paper suggests a theoretical explanation based on distinctive features of emerging financial markets, including imperfect asset substitutability and imperfect capital mobility for some sectors of the economy. It concludes that the appropriate policy response to capital inflows may be lower interest rates.

Caballero and Krishnamurthy (2001) suggest that during the booms that precede crises in emerging economies, policymakers often struggle to limit capital flows and their expansionary consequences. The main policy tool for this task is a sterilization of capital inflows- essentially a swap of international reserves for public bonds. Despite its widespread use, sterilization is often criticized for its ineffectiveness and, in extreme cases, its potential backfiring. They argue that these concerns are justified when countries experience occasional external crises and domestic financial markets are illiquid. In this context, while standard Mundell-Fleming considerations may determine the impact of the sterilization on short term peso interest rates, a potentially more powerful and offsetting mechanism is triggered by the anticipated reversal of this policy in the event of an external crisis. If the instruments used in the sterilization are illiquid or result in fiscal deficits that reduce the liquidity of the private sector, then the effective dollar cost of capital, which considers the whole path of expected future rates, may be lowered rather than raised by this policy. Most importantly, this dollar cost of capital reduction does not reflect a true increase in the country's international liquidity during the external crisis and reversal, as would be the case with a successful sterilization, but just a decline in domestic private liquidity. The impact of the latter on relative asset prices creates a sort of "international liquidity illusion" which fosters rather than depresses aggregate demand, and exacerbates short term capital inflows.

(2) For Asian and Latin American counties

Flood, Garber and Kramer (1995) indicate that in the literature on speculative attacks on a fixed exchange rate, it is usually assumed that the monetary authority responsible for fixing the exchange rate reacts passively to the monetary disruption caused by the attack. This assumption is grossly at odds with actual experience where monetary-base implications of the attacks are usually sterilized. Such sterilization renders the standard monetary-approach attack model unable to provide intellectual guidance to recent attack episodes. In this paper they describe the problems with the standard model and develop a version of the portfolio-balance exchange rate model that allows the study of episodes with sterilization. Sterilized attacks may be regarded as a laboratory test of the monetary versus portfolio-balance exchange rate models. The monetary model fails the test. These issues are motivated by reference to the December 1994 collapse of the Mexican peso.

Lin and Wang (2005) extend the time consistency model developed by Kydland and Prescott (1977) to incorporate exchange rate stability in the policymaker's objectives. Through the operations in the foreign exchange market by central bank, they are then able to analyze the relation between foreign exchange reserves and inflation rate. They argue that when the foreign exchange reserves increases (or the domestic currency depreciates), the inflation rate will be rising while the trade effect is strong. On the other hand, the inflation rate will be reduced when the monetary surprise effect is more powerful and the weight placed on output stability is not large. Their empirical study uses the data for five East Asian economies to make this argument more clear.

Aizenman (2007) analyzes competing interpretations for the large increases in the hoarding of international reserves by developing countries. While the first phase of the rapid hoarding of reserves in the aftermath of the East Asian crisis has been dominated by self insurance against exposure to foreign shocks, the self insurance motive falls short of explaining the hoarding in

Asia in the 2000s. These developments may be a symptom of an emerging new global financial architecture, which is manifested in the proliferation of decentralized and less cooperative arrangements. The emerging financial configuration of developing countries in the aftermath of the 1990s crises has been growing managed exchange rate flexibility, greater monetary independence, and deeper financial integration. Hoarding international reserves is a key ingredient enhancing the stability of this emerging configuration. While not a panacea, international reserves help by providing self insurance against sudden stops; mitigating REER effects of TOT shocks; smoothing overtime the adjustment to shocks by allowing more persistent current account patterns; and possibly even export promotion, though this mercantilist use of reserves remains debatable due to possible coordination issues. Countries following an export oriented growth strategy may end up with competitive hoarding, akin to competitive devaluations.

Aizenman and Glick (2009) investigate the changing pattern and efficacy of sterilization within emerging market countries as they liberalize markets and integrate with the world economy. They estimated the marginal propensity to sterilize foreign asset accumulation associated with net balance of payments inflows, across countries, and over time. They found that the extent of sterilization of foreign reserve inflows has risen in recent years to varying degrees in Asia as well as in Latin America, consistent with greater concerns about the potential inflationary impact of reserve inflows. They also found that sterilization depends on the composition of balance of payments inflows.

Ouyang, Rajan, and Willett (2010) undertake an empirical investigation to assess the extent of de facto sterilization and capital mobility using monthly data between mid 2000 and late 2008. They find that China has been able to successfully sterilize a large portion of these reserve increases thus making it a reserve sink such as Germany was under the Bretton Wood system. They indicated that most current studies which estimate the extent of sterilization can be classified into three groups.

Ying, Kuan, Tung, and Chang (2013) examined how international capital mobility can be affected by sterilization activities for seven East Asian economies. They develop a model that shows how sterilization measures by a central bank can lead to a reduction in a country's capital mobility. Using data from1980 to 2006, they then derive sterilization intensities and capital mobility estimates for their countries, and discover that conventional measures overstate the degree of capital mobility due to their failure to adjust for sterilization actions. Their findings are important for policy makers since using their modified estimates will help to better understand the magnitude of capital mobility when central banks exercise sterilization to dampen the effect of capital inflows.

Aizenman (2007) investigates the changing pattern and efficacy of sterilization within emerging market countries as they liberalize markets and integrate with the world economy. They estimate the marginal propensity to sterilize foreign asset accumulation associated with net balance of payments inflows, across countries and over time. They find that the extent of sterilization of foreign reserve inflows has risen in recent years to varying degrees in Asia as well as in Latin America, consistent with greater concerns about the potential inflationary impact of reserve inflows. They also find that sterilization depends on the composition of balance of payments inflows.

(3) For China

Xie and Zhang (2003) suggest that there are three conflicts between monetary policy and exchange rate policy since 1994 to 2002. The first conflict is the buildup of foreign exchange reserves and high inflation from 1994 to 1996, and second one is the conflict between the rapid decline of the growth of foreign exchange reserves and the deflation pressure from 1998 to 2002, and the last one is the conflict between the exchange rate stability and the interest rate differentials between domestic and foreign currency since 1998. As for the limit of the PBC data, they will concentrate on the first conflict between buildup of foreign exchange reserves and high inflation from December 1999 to August 2013.

Aizenman (2007) suggests that China may be the winner of a hoarding game. Hoarding international reserves may also be motivated by a desire to deal with vulnerability to internal and external instability, which is magnified by exposure of the banking system to non performing loans. Testing the self insurance and precautionary motives in the context of China may be challenged by a version of the "peso problem." Hoarding international reserves and sterilization have been complementing each other during the last ten years, as developing countries have increased the intensity of both margins.

Aizenman and Glick (2009) indicated that there is a decline in China’s degree of sterilization. According to their empirical results, the sterilization coefficients began rising from roughly 0.6 in 2000 to almost 1.5 in 2006, and then fell to 0.7, which means that China may have reached limits to the extent of its ability to sterilize its massive reserve inflows.

However, Wu (2009) provides a cointegration analysis of incomplete monetary sterilization and autonomy in China when both financial controls and the exchange rate peg exist. According to an estimated long-run equilibrium relation, only 35 cents are sterilized for a yuan of foreign-exchange reserve that flows into China. In response to the movement in foreign-exchange reserves, M2 proves more endogenous than M1; and in theM2 elasticity model, as the forecast horizon extends, the domestic-credit component of the monetary base exhibits its significant endogeneity with respect to the foreign-asset component, whereas the endogeneity of the foreign-asset component also rises with respect to M2.

Glick and Hutchison (2009) indicate that in recent years China has faced an increasing trilemma—how to pursue an independent domestic monetary policy and limit exchange rate flexibility, while at the same time facing large and growing international capital flows. This paper analyzes the impact of the trilemma on China's monetary policy as the country liberalizes its good and financial markets and integrates with the world economy. It shows how China has sought to insulate its reserve money from the effects of balance of payments inflows by sterilizing through the issuance of central bank liabilities. However, they report empirical results indicating that sterilization dropped precipitously in 2006 in the face of the ongoing massive buildup of international reserves, leading to a surge in reserve money growth. They also estimate a vector error correction model linking the surge in China's reserve money to broad money, real GDP, and the price level. They use this model to explore the inflationary implications of different policy scenarios. Under a scenario of continued rapid reserve money growth (consistent with limited sterilization of foreign exchange reserve accumulation) and strong economic growth, the model predicts a rapid increase in inflation. A model simulation using an extension of the framework that incorporates recent increases in bank reserve requirements also implies a rapid rise in inflation. By contrast, model simulations incorporating a sharp slowdown in economic growth such as that seen in late 2008 and 2009 lead to less inflation pressure even with a substantial buildup in international reserves.

Chen and Huang (2012) investigate the transmission effects of foreign exchange reserves on price level in China by utilizing a nonparametric model. First of all, they employ VAR co-integration analysis to obtain the number of lagged periods in every stage. And then they estimate the elasticity of foreign exchange reserves to money supply and the elasticity of money supply to consumer price index respectively with nonparametric estimations. Finally they use the results from nonparametric estimations to calculate the cross elasticity of foreign exchange reserves to consumer price index. They find that an increase in foreign exchange reserves will lead to an increase in money supply, which in turn will result in an increase in price level.

LJUNGWALL, Yi, and Zou (2013) using a unique monthly data set over the period 2000:1–2008:12, presented empirical findings on China's central bank, the People's Bank of China, from the viewpoint of its financial strength and the cost of monetary policy instruments. The results showed that PBC is constrained by the costs of its monetary policy instruments. PBoC tend to use less costly but market-distorting instruments such as the deposit interest rate cap and reserve-ratio requirements, rather than more market-oriented but more costly instruments such as central bank note issuance. These costs remain under control today, but may rise in the future as PBC accumulates more foreign assets. This, in turn, will jeopardize the Chinese monetary authority's capability to maintain price stability.

2. Taylor Rule or McCallum Rule for China's Monetary Policy

Using both GMM (Generalized Method of Moments) and SVAR (Structural Vector Autoregression), this paper aims to tackle an important problem in China's recent monetary policy: whether the policy is better captured by the Taylor rule or the McCallum rule. The estimations suggest that the McCallum rule is more active than the Taylor rule in China. Furthermore, GMM model gives the formula to predict money supply m2 by giving inflation, output, and nominal exchange rate targets, which can nicely track the behavior of actual m2. In order to get more accurate results and to grasp the nuances of the economic variables, monthly data are used. The paper also includes a comprehensive literature review on China's monetary policy rule.

2.1 Introduction

With China's rapid economic development, China's monetary policy is attracting the attention of researchers and investors all over the world. However, compared with developed countries, China's monetary policy has many distinct features. One of the most important features is that the intermediate target of monetary policy in China is not interest rate but money supply, which indicates that rather than the Taylor rule, the McCallum rule must be the more active policy rule in China. In Chapter 2, both the traditional Taylor rule and basic McCallum rule are modified by adding the nominal exchange rate to check their applicability in China.

Although McCallum rule is not as popular as Taylor rule, there is evidence that some countries' monetary policy is a kind of money supply policy rule, i.e. McCallum rule. McCallum (1993) suggests that Japan's monetary policy in 1972-1992 can be explained by McCallum rule; additionally, compared to Taylor rule, the empirical results of McCallum rule of Japan's monetary policy is much more robust. McCallum (2003) also indicates that in order to realize a 4%-5% economic growth and 2% inflation rate, a 10%-15% money supply growth rate should be necessary. Especially, when many of the developed countries Japan, US, UK have be caught in a zero interest rate trap, instead of Taylor rule, McCallum rule should be shed more light on. As the intermediate target of monetary policy in China is not interest rate but money supply, McCallum rule will be analyzed in this chapter.

The Chinese central bank of China is the People's Bank of China (PBC). Having assumed the role of central bank in 1984, it is still young compared with other major central banks across the world. According to the *Law of the People's Bank of China*, the monetary policy of the PBC has two targets: maintaining the stability of the currency and promoting economic growth. Maintaining the stability of the currency is achieved by simultaneously controlling inflation and stabilizing the exchange rate. Therefore, the PBC has three de facto targets: rapid economic growth, low inflation, and a stable nominal exchange rate. Each of these three variables will be included in the empirical analysis.

There are empirical analyses on the monetary policy rules of China, but since most of the Chinese macro data are only available from the early 1990s, the sample size is still quite small, even if quarterly data is used. To solve this problem, in this paper monthly data are used. In order to measure monthly economic growth, three output measurements are used. These are generated electricity, fixed asset investment and industrial added value growth rate. In prior research, the real effective exchange rate (REER) and real exchange rate were used as targets of the Taylor rule and the McCallum rule models, but there have not been any robust results thus far.[6] Considering the de facto dollar-peg exchange rate regime in China, instead of REER and real exchange rate, empirical analysis with the nominal exchange rate against the United States Dollar (USD) is likely to be significant. This idea will be explored in the third and fourth parts of this chapter.

Instead of monetary base, money supply m2 will be employed in the empirical analyses for several reasons below. China's Annual Government Work Report is announced by China's Prime Minister in March or April every year. m2 target is one of the most important content of this report as well as GDP growth rate target and inflation target. From Table 2.1.1, we can discover that the gap between target m2 growth rate and real m2 growth rate is shrinking, which means real m2 growth rate is getting close to target m2 growth rate.

Moreover, although target m2 growth rate is an annual target, m2 growth rate is adjusted among the whole year to response to economic growth or inflation changes. For instance, the target m2 growth rate in 2009 is 17%, but Chinese economy is risking recession among that year, therefore, the real m2 growth reached 27% by the prompt adjustment of Chinese government. In a word, although m2 target is an annual target, it would be adjusted according to the macroeconomic changes.

6 Refer to Fan, Yu and Zhang (2011) , Burdekin and Siklos (2008)

Table 2.1.1 The target m2 and real m2 growth rate in China from 2001 to 2012

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Target m2	*15%-16%	13%	16%	17%	15%	16%	16%	16%	17%	17%	16%	14%
Real m2	14.4%	16.8%	19.6%	14.7%	17.6%	17.0%	16.7%	17.8%	27.7%	19.7%	13.6%	13.8%
Gap	-1.1%	3.8%	3.6%	-2.3%	2.6%	1.0%	0.7%	1.8%	10.7%	2.7%	-2.4%	-0.2%

Source: China's Annual Government Work Report and National Bureau of Statistics of China

A great deal of attention is adding exchange rate to the policy rule, such as Bernanke & Gertler (1999), Clarida, Gali, and Gertler (2001) and Woodford (2003). For example, Clarida, Gali, and Gertler (2001) extend their research to the case of small open economy. Openness complicates the problem of monetary management to the extent the central bank must take into account the impact of the exchange rate.

Both GMM (Generalized Method of Moments) and SVAR (Structural Vector Autoregression) are used for estimation, and both indicate that the McCallum rule is an active policy rule and the Taylor rule is not, and that the McCallum rule can trace actual m2 effectively.

The GMM estimation suggests that the requirements for an active Taylor rule cannot be satisfied, because for a unit change in inflation and output gap, the change in interest rate is not significant enough compared with the U.S; moreover, the nominal exchange rate is statistically insignificant in most cases. In contrast, the McCallum rule suggests that policy to affect the money supply in China not only focuses on inflation and economic growth, but also targets the nominal exchange rate. Such an active monetary policy is consistent with the actual situation in China.

The empirical results of structural VAR are almost consistent with the GMM estimations for both the Taylor rule and McCallum rule. The results suggest that the interest rate responds actively to Consumer Price Index (CPI) but passively to output gap and exchange rate, while money supply responds actively to both CPI and output.

From 1996 to 2011, China's monetary policy experienced various challenges: inflation (in the early 1990s, 2007-2008, and 2010-2011), deflation in the early 2000s and economic recession following the Asian Financial Crisis of 1998 and the Subprime Crisis of 2008, all of which can be seen in Figure 2.3.1.

2.2 Literature Review

The literature on basic policy rules and empirical analysis of policy rules in China is summarized in this part. Particular emphasis is given to the literature on empirical analysis of policy rule in China, most of which is written in Chinese and has not been reviewed in English so far.

2.2.1 Theoretical aspects of the Taylor rule and the McCallum rule

Taylor (1993a) originally presented what would become known as the Taylor rule at the November 1992 Carnegie Rochester Conference on Public Policy, when he suggested that “good policy rules call for changes in the federal funds rate in response to change in the price level and changes in real income” .

$$r = p + 0.5y + 0.5(p - 2) + 2 \qquad (2.2.1)$$

where

y = percent deviation of real GDP from the trend

p = rate of inflation over the previous four quarters.

Within a few months of the publication of this conference volume, the Federal Open Market Committee (FOMC) decided to adopt the formula to inform their monetary policy deliberations. Consequently, this allowed Taylor-type rules to serve as the standard by which monetary policy is introduced in macroeconomic models. Taylor-type rules helped policymakers to gain the insight of how policy has been set in the past and how policy should be set in the future, which gradually turned into benchmarks to evaluate the current situation on monetary policy and determine a future policy path.

The McCallum rule proposed by McCallum (1987, 1988, 1993), can be expressed as follows

$$\Delta b_t = \Delta x^* - \Delta v_t^a + 0.5(\Delta x^* - \Delta x_{t-1}) \qquad (2.2.2)$$

Δb_t is the change in the log of the adjusted monetary base, (i.e., the growth rate of the base between periods t − 1 and t).

Δx^* is a target growth rate for nominal GDP (Δx^* is specified as $\pi^* + \Delta y^*$, where Δy^* is the long-run average rate of growth of real GDP).

Δx_t is the change in the log of nominal GDP.

Δv_t^a is the average growth of base velocity over the previous 16 quarters, $v_t = x_t - b_t$ being the log of base velocity.

2.2.2 The empirical analysis of the Taylor rule and McCallum rule in China

Up until August 2012, there had been 235 papers related to the Taylor Rule published in China, including master's and Ph.D. dissertations, but only 15 papers related to the McCallum rule. There have been approximately five papers about the Taylor rule published in *Economic Research Journal*, a leading Chinese economics journal. However, there are no papers concerning the McCallum Rule. This reflects the much greater popularity of the Taylor rule in the economic community, especially in developed countries. It also shows that Chinese economists have paid a lot more attention to the Taylor rule than to the McCallum rule, even though there are some problems concerning the application of the Taylor rule to China's monetary policy.[7]

Empirical analysis of Taylor rule in the case of China:

There are many papers containing empirical analysis of China's monetary policy via the Taylor rule. The methods and empirical results of these studies are generally similar. Three of them will be reviewed presently, as these three are particularly important and influential.

Xie and Luo (2002) use historical analysis[8] and reaction function.[9] They suggest that the parameter of inflation in the Taylor rule is 0.81, smaller than 1. That is to say, the monetary policy of China is an unstable system, which may be the main reason for the high inflation in the 1990s and deflation in the early 2000s. Their paper is the first to analyze the Taylor rule based on Chinese economic data, but their estimation method is outdated.

Lu and Zhong (2003), the first to do cointegration analysis on the Taylor rule, suggest that the coefficient of the GDP gap is 0.497, which is very close to the result obtained in Taylor (1993a). But the coefficient of the inflation gap is estimated at only 0.089, which is very small. This

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7 For instance, problems arising from the manipulation of the interest rate by the PBC.

8 Taylor 1993a, 1999

9 Clarida, Gali and Gertler 1998, 2000

result indicates that the PBC put more emphasis on GDP than inflation. In addition, the paper introduces a forward-looking Taylor rule for the cointegration analysis, and finds the coefficient of the GDP gap to be 0.509, while that of CPI expectation is just 0.131. They are close to their traditional Taylor rule estimation. What is worth mentioning is that since the data span from 1992 to 2001, which includes the hyperinflation period of 1993 to 1994, there may be some bias in the estimation.

Fan, Yu and Zhang (2011) use a Vector Error Correction Model (VECM) to analyze the responsiveness and activeness of Chinese monetary policy of 1992-2009 by estimating Taylor rule. The results show that the official interest rate responds passively to inflation and does not respond to real output. By using a smoothed Taylor rule, they draw three conclusions. First, the coefficient of inflation is positive but less than 1. Second, the official interest rate exhibits a statistically significant response to output gap. Third, the coefficient of the real effective exchange rate is negative and not statistically significant. With a VAR model, impulse response and variance decomposition analysis are conducted in two orders $x_t = (\pi_t, y_t, e_t, r_t, m_t)$ and $x_t = (\pi_t, y_t, e_t, m_t, r_t)$. The results show that the responses of the inflation rate, output gap and real effective exchange rate to the official interest rate are near zero for all the horizons.

Empirical analysis of McCallum rule in the case of China:

Song and Li (2007) employ cointegration analysis, impulse response and variance decomposition to check the relationship between money supply and fluctuations in the economy. The distinctive feature of this paper is that money supply is reclassified as in the following equations: MM2=M2-M1, MM1=M1-M0. Further, RM0, RMM1, RMM2 and RINDU are defined as the growth rate of M0, MM1, MM2 and industrial added value, respectively. Using the Granger test, they suggest that the PBC closely controlled the money supply, because RM0 Granger causes RMM1 and RMM2, and that RMM1 Granger causes RMM2. Accordingly, they reach the conclusion that as long as PBC controls M0, it can also keep M1 and M2 under control. Furthermore, since both RMM0 and RMM1 are Granger caused by RINDU, PBC could comply with the McCallum rule to affect economic growth through money supply management. That is to say, they indicate that changes to the money supply could affect economic growth. However, there are several deficiencies in this paper. For instance, some problems arise because their reclassification scheme of the money supply is not commonly used.

Burdekin and Siklos (2008) have modeled post-1990 Chinese monetary policy with an augmented McCallum-type rule using both monetary base and m2. They employ three different models in their research, which are presented as follows. First, by estimating a basic McCallum rule,[10] the coefficients of the GDP gap[11] are -0.42 for m2 and -0.008 for the monetary base. Second, after adding a deflation dummy variable which is set equal to one from 1997 on, the estimated coefficient of the GDP gap remains negative but is statistically insignificant when monetary base is the dependent variable; however, the deflation dummy variable is highly significant and negative. Third, when real exchange rate and foreign exchange reserves are added to the model, the coefficients continue to be negative and are statistically significant for both monetary measures. The coefficient on the real exchange rate is negative and statistically significant for m2, indicating that real exchange rate depreciation leads to a negative monetary policy response. The weaker link between foreign exchange reserves and monetary growth may be indicative of PBC success at sterilizing inflows of foreign exchange. Two techniques are adopted. First, GMM is used to avoid the shortcomings of OLS. Second, for the constant deflation dummy, two lags of each of the variables in the equation, and two lags in export growth were used as instruments with nearly identical results.

Fan, Yu and Zhang (2011) use a VECM model to analyze the responsiveness and activeness of China's monetary policy in 1992-2009 by estimating a McCallum rule. The results show that money supply[12] not only responds actively to both inflation rate and real output, but also has certain effects on future inflation and real output. In the whole sample, the growth rate of money supply is negatively and significantly related to the output gap and inflation rate, but its response to the real effective exchange rate is insignificant. With a dummy variable in the year 2000, what is interesting is that the real money supply in the second subperiod is more responsive to inflation but insensitive to the output gap. The VAR model shows that the responses of the inflation rate and output gap to the money supply are significant, but are insignificant with respect to the real effective exchange rate. Instead of the real effective exchange rate, real exchange rate should be used, because the PBC does not watch the real effective exchange rate, but instead watches the nominal exchange rate against the USD.

The problems of previous papers and the contribution of this paper:

Previous research on this subject is plagued with various problems, such as outdated

[10] The basic McCallum rule is shown in equation (2.2) on page 3.
[11] GDP gap is the gap between target and actual nominal GDP growth.
[12] Money supply here refers to quarterly observation of the annual growth rate of M1, minus the annual inflation rate.

estimation methods, insufficient sample sizes and inappropriate data measurements. In addition, instead of REER and real exchange rate, nominal exchange rate should be used in the model as the target of PBC.

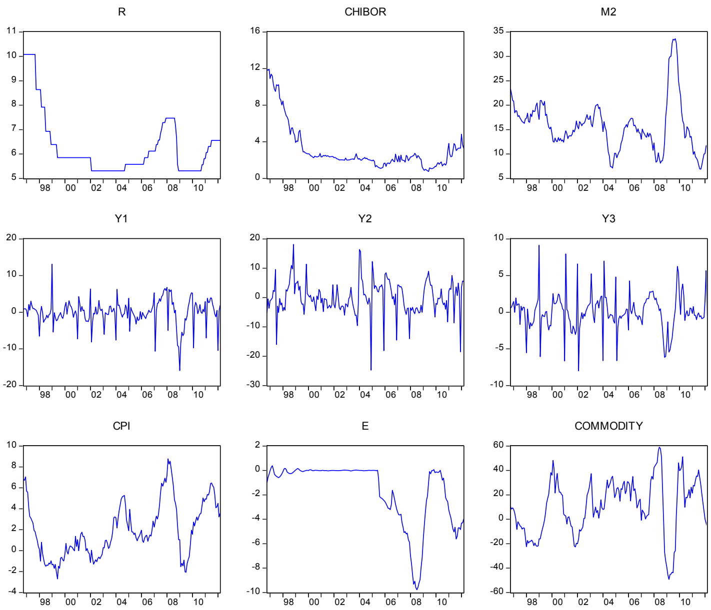
These problems will be addressed in this paper. Both GMM and structural VAR will be used for estimation, and monthly data will be selected to ensure adequate sample size. Along with CPI and output gap, the nominal exchange rate will be included in monetary policy rule estimations.

2.3 The empirical analysis of Taylor rule and McCallum rule in China

2.3.1 Data

The People's Bank of China (PBC) has a very short history, as it assumed the role of central bank in 1984. Because most available data begins from the year 1996, the sample in this paper is from 1996M10 to 2012M3, yielding 186 observations.

Figure 2.3.1: Time series of macroeconomic variables in China (1996M10-2012M3)



Note: Census X-11(Historical) is used for seasonal adjustment

For Taylor rule and McCallum rule, monetary policy analysis, both interest rate and money supply, will be taken into consideration. China Interbank Offered Rate (Chibor) is used as the market interest rate (source: Wind[13]). r refers to the official one-year lending rate (source: PBC), and m2 is the annual growth rate of the money supply m2 (source: PBC) minus the annual inflation rate.[14] The reason m2 is used to measure money supply is not only that the growth rate of m2 is one of the most important targets of both PBC and the government, but also because the results of the estimations of m2 are more robust than those from using m1 or m0.[15] As to output gap, since monthly GDP data are not available, three measurements are used for the estimation. The output gaps are estimated by generated electricity[16] and real fixed asset investment[17] (source: National Bureau of Statistics of China (NBS)). These are named y1 and y2, respectively. y3 refers to the output gap estimated by the industrial added value (source: NBS). The output gap data are calculated by using Hodrick-Prescott filter. CPI is the monthly observation of the annual Consumer Price Index (Source: NBS), and e is the rate of change of the nominal exchange rate of CNY (Chinese Yuan) against USD (source: IFS). Commodity is the commodity price index series from IMF.

Figure 2.3.1 shows the monthly time-series plots of the macroeconomic variables in percentages. Many economic features are apparent in this figure. First, both Chibor and policy interest rates lack much volatility, and the growth rate of m2 is quite high, the average of which is about 17%. Second, due to a monthly sampling rate, the output data are quite volatile. There are differences between y1 and y2: y1 is less volatile from 1996 to 2008, but y2 is less volatile from 1998 to 2004. Third, regarding inflation, the most notable features are the deflation during 1998-2000 and the high inflation of 1996, 2008 and 2010. The nominal exchange rate also lacks fluctuation despite appreciation in two periods, July 2005 to July 2008 and May 2010 to March 2012.

2.3.2 GMM analysis of Taylor rule

In line with Clarida, Gali and Gertler (1998), we assume that within each operating period the PBC has a target for the nominal short term interest rate r_t^*, that is based on the state of the economy. In the baseline case, we assume that the target depends on both expected inflation and output. Specifically,

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13 Wind is a leading database in China.

14 Real money supply, rather than the nominal one, better reflects the true economic situation, unmasked by inflation. McCallum (2000), Esanov et al. (2005) both use similar measures of real money supply in their analyses.

15 The results will not be shown in this paper. If you have an interest in them, please email the author directly.

16 In fact, instead of generated electricity, electricity consumption should be used to simulate GDP gap. However, collection of monthly electricity consumption data began from the year 2006, and the two data types are quite close to each other, so generated electricity is used instead.

17 The fixed asset investment is adjusted to real value based on the inflation measurement CPI.

$$r_t^* = \bar{r} + a_{cpi}\left[E\left(cpi_t|\Omega_t\right) - cpi^*\right] + a_y(E\left[y_t|\Omega_t\right] - y_t^*) \qquad (2.3.1)$$

where $\bar{r}$ is the long-run equilibrium nominal rate, cpi_t is the realized annual inflation rate at t, y_t is real output, and cpi^* and y_t^* are respective bliss points for inflation and output. We assume that y_t^* is given by potential output, defined as the level that would arise if wages and prices were perfectly flexible. In addition, E is the expectation operator and Ω_t is the information available to the central bank at the time it sets interest rates.

It is instructive to consider the implied target for the ex-ante real interest rate, $rr_t \equiv r_t - E(cpi_t|\Omega_t)$. Rearranging Eq. (2.3.1) yields

$$rr_t^* = \overline{rr} + (a_{cpi} - 1)(E\left[cpi_t|\Omega_t\right] - \pi^*) + a_y(E\left[y_t|\Omega_t\right] - y_t^*) \qquad (2.3.2)$$

where $\overline{rr}$ is the long-run equilibrium real rate of interest. Given the economic environment, we are presuming that purely real factors determine $\overline{rr}$. According to Eq. (2.3.2), the target real rate adjusts relative to its natural rate in response to departures of either expected inflation or output from their respective targets. The magnitude of the parameter a_{cpi} is the key to determining whether the policy rule is active or not. If $a_{cpi} > 1$, the target real rate adjusts to stabilize inflation. With $a_{cpi} < 1$, it instead moves to accommodate changes in inflation, meaning that though the central bank raises the nominal rate in response to an expected rise in inflation, it is not sufficient to keep the real rate from declining.

In practice, central banks tend to maintain smoothness in the actual interest rate. Alternatively, central banks may sometimes compromise the market forces reflected in the existing interest rate. In the literature, it is commonly assumed that the actual interest rate r_t is a weighted average of the target rate r_t^* and the existing interest rate r_{t-1}, plus a noise term ε_t, due to other random factors at the same time. This smoothing behavior is represented by Eq. (2.3.3).

$$r_t = (1-\rho)r_t^* + \rho r_{t-1} + \varepsilon_t \qquad (2.3.3)$$

where $0 \le \rho < 1$. The case of $\rho = 0$ corresponds to the original Taylor rule without smoothing.

To obtain an estimable equation, we define $a_c \equiv \bar{r} - a_{cpi}cpi^*$ and $x_t \equiv y_t - y_t^*$. We then rewrite Eq. (2.3.1) as

$$r_t^* = a_c + a_{cpi}\left[E\left(cpi_t|\Omega_t\right)\right] + a_y(E\left[x_t|\Omega_t\right]) \qquad (2.3.4)$$

Combining the target model (2.3.4) with the partial adjustment mechanism (2.3.3) yields

$$r_t = (1-\rho)a_c + (1-\rho)a_{cpi}\left[E\left(cpi_t \middle| \Omega_t\right)\right] + (1-\rho)a_y\left(E\left[x_t \middle| \Omega_t\right]\right) + \rho r_{t-1} + \varepsilon_t \quad (2.3.5)$$

Finally, we eliminate the unobserved forecast variables from the expression by rewriting the policy rule in terms of realized variables as follows:

$$r_t = (1-\rho)a_c + (1-\rho)a_{cpi}cpi_t + (1-\rho)a_y x_t + \rho r_{t-1} + v_t \quad (2.3.6)$$

where the error term $v_t \equiv -(1-\rho)\left\{a_{cpi}(cpi_t - E\left[cpi_t \middle| \Omega_t\right]) + a_y(x_t - E\left[x_t \middle| \Omega_t\right])\right\} + \varepsilon_t$ is a linear combination of the forecast errors of inflation and output and the exogenous disturbance ε_t.

It is quite possible that there may be other important factors that influence rate setting besides those captured in the baseline model in Eq. (2.3.6). For example, some central banks may pursue monetary policies to maintain exchange rates within reasonable bounds. According to Clarida, Gali and Gertler (1998), this scenario was pertinent to some European countries' central banks prior to the collapse of the ERM in 1992. Having mentioned in Section 1 that the exchange rate is one of the targets of PBC, the relation for the target Eq. (2.3.6) could be replaced with the following equation, where e_t is the nominal exchange rate of CNY against USD at t:

$$r_t = (1-\rho)(a_c + a_{cpi}cpi_t + a_y x_t + a_e e_t) + \rho r_{t-1} + v_t \quad (2.3.7)$$

where the error term

$v_t \equiv -(1-\rho)\left\{a_{cpi}(cpi_t - E\left[cpi_t \middle| \Omega_t\right]) + a_y(x_t - E\left[x_t \middle| \Omega_t\right]) + a_e(e_t - E[e_t|\Omega_t])\right\} + \varepsilon_t$ is a linear combination of the forecast errors of inflation, output, exchange rate and the exogenous disturbance ε_t. Let u_t be a vector of variables within the central bank's information set at the time it chooses the interest rate ($u_t \in \Omega_t$), that are orthogonal to v_t. Possible elements of u_t include any lagged variables that help forecast inflation, output, exchange rate and any contemporaneous variables that are uncorrelated with the current interest rate shock ε_t. Then, since $E\left[v_t \middle| u_t\right] = 0$, Eq. (2.3.7) implies the following set of orthogonality conditions that we exploit for estimation:

$$E\left[r_t - (1-\rho)a_c - (1-\rho)a_{cpi}cpi_t - (1-\rho)a_y x_t - (1-\rho)a_e e_t - \rho r_{t-1} \middle| u_t\right] = 0 \quad (2.3.8)$$

To estimate the parameter vector $\left[a_c, a_{cpi}, a_y, a_e, \rho\right]$ we use a GMM.[18] The instrument set

[18] The composite disturbance term for our model has an MA(n-1) representations. In this case, the GMM estimator

u_t includes lagged values of output, inflation and interest rates. Each of these variables are potentially useful for forecasting inflation, output and exchange rate, and are exogenous with respect to the interest rate, given our identifying assumptions.[19]

In Eq. (2.3.2) $a_{cpi} > 1$ is the key to determining whether the policy rule is active or not. But here in Eq. (2.3.7), besides $a_{cpi} > 1$, $a_y > 0$ and $a_e > 0$ are also keys to determining the activeness of policy rule. The reason is that when the economy gets overheated or the CNY depreciates, which means x_t or e_t is increasing, the interest rate must be raised to cool the economy or to induce investors to buy more CNY. As a result, both of the macro variables will return to their equilibrium level.

$$a_{cpi} > 1,\ a_y > 0 \text{ and } a_e > 0 \qquad (2.3.9)$$

Table 2.3.1: The estimation of Taylor rule with policy interest rate r on sample (1996M10-2012M3)

Taylor Rule	a_c	a_{cpi}	a_{y1}	a_{y2}	a_{y3}	a_e	ρ	R^2
Regression	5.49***	0.3469*	0.2145*			0.1584	0.9426***	0.9732
(1.1)	(0.3301)	(0.1798)	(0.1152)			(0.1518)	(0.0126)	
Regression	5.20***	0.6027***		0.0652		0.2930*	0.9483***	0.9728
(1.2)	(0.4144)	(0.2151)		(0.1280)		(0.1691)	(0.0126)	
Regression	5.36***	0.3989**			0.3731*	0.1561	0.9472***	0.9731
(1.3)	(0.3560)	(0.1839)			(0.2205)	(0.1630)	(0.0124)	

Note: The instruments are y_{t-1}, y_{t-2}, y_{t-3}, y_{t-4}, y_{t-5}, y_{t-6}, cpi_{t-1}, cpi_{t-2}, cpi_{t-3}, cpi_{t-4}, cpi_{t-5}, cpi_{t-6}, r_{t-1}, r_{t-2}, r_{t-3}, r_{t-4}, r_{t-5}, r_{t-6}, e_{t-1}, e_{t-2}, e_{t-3}, e_{t-4}, e_{t-5}, e_{t-6}, $Commodity_{t-1}$, $Commodity_{t-2}$, $Commodity_{t-3}$, $Commodity_{t-4}$, $Commodity_{t-5}$, $Commodity_{t-6}$
*** indicates that the coefficient is statistically significant at 1% level, ** at the 5% level and * at the 10% level

Two estimations of the Taylor rule are shown in Table 2.3.1 and 2.3.2, given by Eq. (2.3.7). The traditional Taylor rule insists that the market interest rule should be used to estimate the Taylor rule. But in China, instead of the market, the PBC determines the interest rate. For clarity, both the policy interest rate (one-year lending rate) (Table 2.3.1) and market interest rate (Chibor) (Table 2.3.2) are used for estimation.

In Table 2.3.1, the results of three regressions are given for y1, y2 and y3, respectively. Let's check the sign of the parameters and then evaluate the activeness of the Taylor rule for China's

of the parameter vector is a two-step nonlinear two-stage least squares estimator when the model is overidentified (Clarida et al 1998).

[19] Our econometric approach relies on the assumption that, within our short samples, short-term interest rate and inflation rate are *I*(0). Please refer to Table 4.1.

monetary policy. According to the Taylor rule, $a_{cpi} > 0$ and $a_y > 0$ must be met. During the entire sample period, the regressions show that official interest rate responds positively and significantly to both CPI and output gap in Regression (1.1) and Regression (1.3). For Regression (1.2), official interest rate responds significantly to inflation rate alone.

$a_{cpi} > 1$ represents an active interest rate policy. Official interest rate responds significantly to inflation rate in Regression (1.1), (1.2) and (1.3), however, $a_{cpi} = 1$ could be rejected with 10% Wald Test.

For $a_e > 0$, a_e turns out to be significantly positive in Regression (1.2) and insignificant in Regression (1.1) and (1.3).

It is worth mentioning that a_c is higher than that of the U.S. (which is 2%), which indicates that the long-term equilibrium nominal interest rate is higher than that of the U.S. Considering the high inflation rate in China, the long-term equilibrium nominal rate is at about 5%, which indicates Regression (1.1), (1.2) and (1.3) are reliable.

Table 2.3.2: The estimation of Taylor rule with market interest rate Chibor on sample (1996M10-2012M3)

Taylor Rule	a_c	a_{cpi}	a_{y1}	a_{y2}	a_{y3}	a_e	ρ	R^2
Regression	1.59**	0.6573*	-0.2799			0.3851	0.9406***	0.9667
(2.1)	(0.7094)	(0.3650)	(0.2687)			(0.2869)	(0.0134)	
Regression	1.96***	0.3380		-0.1004		0.2292	0.9387***	0.9669
(2.2)	(0.6621)	(0.2762)		(0.2130)		(0.2443)	(0.0133)	
Regression	1.70***	0.6978**			-0.7167*	0.4800*	0.9378***	0.9652
(2.3)	(0.6528)	(0.3195)			(0.3721)	(0.2780)	(0.0137)	

Note: The instruments are y_{t-1}, y_{t-2}, y_{t-3}, y_{t-4}, y_{t-5}, y_{t-6}, cpi_{t-1}, cpi_{t-2}, cpi_{t-3}, cpi_{t-4}, cpi_{t-5}, cpi_{t-6}, $Chibor_{t-1}$, $Chibor_{t-2}$, $Chibor_{t-3}$, $Chibor_{t-4}$, $Chibor_{t-5}$, $Chibor_{t-6}$, e_{t-1}, e_{t-2}, e_{t-3}, e_{t-4}, e_{t-5}, e_{t-6}, $Commodity_{t-1}$, $Commodity_{t-2}$, $Commodity_{t-3}$, $Commodity_{t-4}$, $Commodity_{t-5}$, $Commodity_{t-6}$
*** indicates that the coefficient is statistically significant at 1% level, ** at the 5% level and * at the 10% level

In Table 2.3.2, the market interest rate, Chibor, is used instead. Among these three regression results in Table 2.3.2, Regression (2.3) is the most robust. In Regression (2.3), a_{cpi}, a_y and a_e are all statistically significant. However, a_y is negative, and $a_{cpi} = 1$ could be rejected with 10% Wald Test.

From these three outcomes, we conclude that among all of the regressions in Table 2.3.1 and Table 2.3.2, none can meet the active requirements of the Taylor rule. That is to say that the estimation of Taylor rule suggests that the interest rate policy of China is not an active one, so we cannot trace China's interest rate policy by using Taylor rule.

2.3.3 GMM analysis of McCallum rule when velocity is constant

Much like the Taylor rule, the specialized McCallum rule for the targeted growth rate of the real money supply is a function of inflation, output gap, and nominal exchange rate. That is,

$$m_t^* = \overline{m} + b_{cpi}\left[E(cpi_t|\Omega_t) - cpi^*\right] + b_y(E(y_t|\Omega_t) - y_t^*) + b_e(E(exchange_t|\Omega_t) - exchange_t^*) \tag{2.3.10}$$

where $\overline{m}$ is the long-run equilibrium nominal rate, cpi_t is the realized annual inflation rate at t, y_t is real output, and cpi^* and y_t^* are respective bliss points for inflation and output. We assume that y_t^* is given by potential output, defined as the level that would arise if wages and prices were perfectly flexible. In addition, E is the expectation operator and Ω_t is the information available to the central bank at the time it sets interest rates.

In practice, central banks tend to maintain smoothness in money supply. In the literature, it is commonly assumed that the actual interest rate m_t is a weighted average of the target rate m_t^* and the existing interest rate m_{t-1}, plus a noise term ε_t, due to other random factors at the same time. This smoothing behavior is represented by Eq. (2.3.11).

$$m_t = (1-\phi)m_t^* + \phi m_{t-1} + \varepsilon_t \tag{2.3.11}$$

where $0 \le \phi < 1$. The case of $\phi = 0$ corresponds to the original Taylor rule without smoothing.

To obtain an estimable equation, we define $b_c \equiv \overline{m} - b_{cpi}cpi^*$, $x_t \equiv y_t - y_t^*$ and $e_t \equiv exchange_t - exchange_t^*$. We then rewrite Eq. (3.10) as

$$m_t^* = b_c + b_{cpi}\left[E(cpi_t|\Omega_t)\right] + b_y(E[x_t|\Omega_t]) + b_e(E[e_t|\Omega_t]) \tag{2.3.12}$$

Combining the target model (2.3.12) with the adjustment mechanism (2.3.11) yields

$$m_t = (1-\phi)\left[b_c + b_{cpi}\left[E(cpi_t|\Omega_t)\right] + b_y(E[x_t|\Omega_t]) + b_e(E[e_t|\Omega_t])\right] + \phi m_{t-1} + \varepsilon_t \tag{2.3.13}$$

Finally, we eliminate the unobserved forecast variables from the expression by rewriting the policy rule in terms of realized variables as follows:

$$m_t = (1-\phi)\left[b_c + b_{cpi}cpi_t + b_y x_t + b_e e_t\right] + \phi m_{t-1} + \nu_t \tag{2.3.14}$$

where the error term

$v_t \equiv -(1-\phi)\{b_{cpi}(cpi_t - E[cpi_t|\Omega_t]) + b_y(x_t - E[x_t|\Omega_t]) + b_e(e_t - E[e_t|\Omega_t])\} + \varepsilon_t$ is a linear combination of the forecast errors of inflation, output, exchange rate and the exogenous disturbance ε_t. Let u_t be a vector of variables within the central bank's information set at the time it chooses the interest rate ($u_t \in \Omega_t$) that is orthogonal to v_t. Possible elements of u_t include any lagged variables that help forecast inflation, output, exchange rate and any contemporaneous variables that are uncorrelated with the current interest rate shock ε_t. Then, since $E[v_t|u_t]=0$, Eq. (2.3.14) implies the following set of orthogonality conditions that we exploit for estimation:

$$E[m_t - (1-\phi)(b_c + b_{cpi}cpi_t + b_y x_t + b_e e_t) - \phi m_{t-1}|u_t] = 0 \quad (2.3.15)$$

To estimate the parameter vector $[b_c, b_{cpi}, b_y, b_e, \phi]$ we use GMM.[20] The instrument set u_t includes lagged values of output, inflation, exchange rate and money growth. Each of these variables are potentially useful for forecasting inflation, output and exchange rate, and are exogenous with respect to the interest rate, given our identifying assumptions.[21]

Again following the Taylor rule, a stabilized rule for money supply is supposed to be counter-cyclical. Therefore, the active McCallum rule hypothesis is

$$b_{cpi} < 0, \quad b_y < 0 \quad \text{and} \quad b_e < 0 \quad (2.3.16)$$

This is because when the inflation rate increases, output increases and the CNY depreciates. In this instance, the money supply should be reduced to control inflation, to prevent an overheated economy or to stabilize the nominal exchange rate.

The estimation of the McCallum rule is shown in Table 2.3.3. In Table 2.3.3, equation (2.3.11) is used for estimation and the sample period is from 1996M10 to 2012M3.

The hypothesis $b_{cpi} < 0$ is statistically significant for all the regressions in Table 2.3.3, which indicates that the money supply rule does focus on the inflation target. b_{cpi} is -2.98 in Regression (3.1), which means that with a 1% increase in inflation, the real money supply

[20] The composite disturbance term for our model has an MA(n-1) representations. In this case, the GMM estimator of the parameter vector is a two-step nonlinear two-stage least squares estimator when the model is overidentified (Clarida et al 1998).

[21] Our econometric approach relies on the assumption that, within our short samples, money growth rate and inflation rate are *I*(0). Please refer to Table 4.1.

growth rate would be reduced by 2.98%.

Table 2.3.3: The estimation of McCallum rule with sample (1996M10-2012M3)

McCallum Rule	b_c	b_{cpi}	b_{y1}	b_{y2}	b_{y3}	b_e	ϕ	R^2
Regression	16.54***	-2.9814***	-2.3653**			-2.2473**	0.9226	0.9480
(3.1)	(1.5997)	(0.9060)	(1.0630)			(0.9044)	(0.0221)	
Regression	16.78***	-3.3093***		1.2688**		-2.5586***	0.8937***	0.9348
(3.2)	(1.2888)	(0.7572)		(0.5109)		(0.7773)	(0.0245)	
Regression	16.85***	-3.8952**			-7.1859	-2.8392*	0.9492***	0.9407
(3.3)	(2.4761)	(1.5950)			(4.5095)	(1.6435)	(0.0253)	

Note: The instruments are y_{t-1}, y_{t-2}, y_{t-3}, y_{t-4}, y_{t-5}, y_{t-6}, cpi_{t-1}, cpi_{t-2}, cpi_{t-3}, cpi_{t-4}, cpi_{t-5}, cpi_{t-6}, m_{t-1}, m_{t-2}, m_{t-3}, m_{t-4}, m_{t-5}, m_{t-6}, e_{t-1}, e_{t-2}, e_{t-3}, e_{t-4}, e_{t-5}, e_{t-6}, $Commodity_{t-1}$, $Commodity_{t-2}$, $Commodity_{t-3}$, $Commodity_{t-4}$, $Commodity_{t-5}$, $Commodity_{t-6}$
*** indicates that the coefficient is statistically significant at 1% level, ** at the 5% level and * at the 10% level

Afterwards in Regression (3.1), hypothesis $b_y < 0$ is significantly met, while in Regression (3.2) b_y is significantly positive. In Regression (3.3), b_y is statistically insignificant.

The hypothesis $b_e < 0$ is met for all the regressions in Table 2.3.3. As the absolute values of parameters b_e all exceed 2, the money supply would fall by about 2% if the nominal exchange rate were to increase by 1%. b_c is notably high, indicating that the long-term money supply growth rate is about 17%, consistent with the PBC's annual m2 target.

Among the three regressions in Table 2.3.3, Regression (3.1) is the most robust, and can satisfy the entire active money supply policy hypothesis. In China, money supply management can not only prevent inflation and stabilize economic growth, but respond to nominal exchange rate changes as well. Compared with interest rate policy, money supply policy is much more active.

To measure how well our model can explain the behavior of PBC, we plot the implied target policy interest rate versus the actual interest rate and target m2 versus the actual m2 in Figure 2.3.2 and 2.3.3. As Regression (1.1) and (3.1) are the most robust results for Taylor rule and McCallum rule respectively, we employ them for the comparison. Both the target interest rate implied by Regression (1.1) and the target m2 implied by Regression (3.1) nicely tracked the behavior of actual interest rate and actual m2 from 1996 to 2012. If we know the targets of CPI, output gap and nominal exchange rate for PBC, we can use Regression (1.1) and (3.1) to predict policy interest rate and m2.

Figure 2.3.2 Target r and Actual r

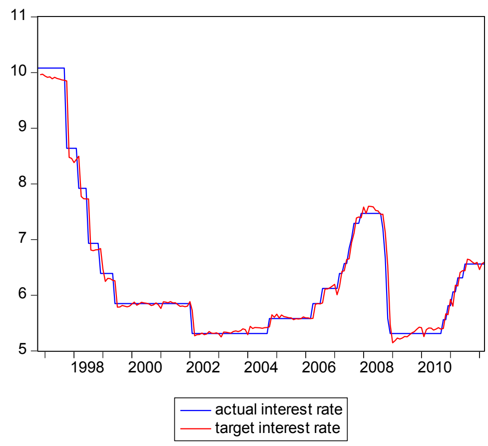
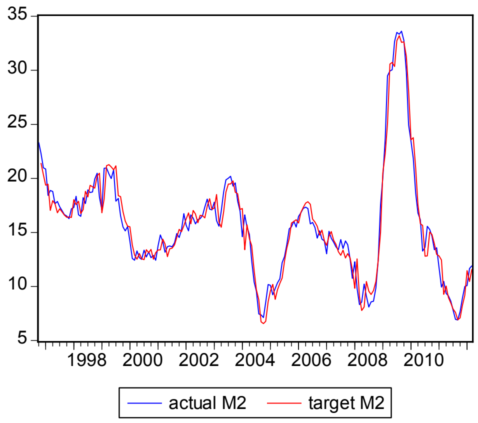


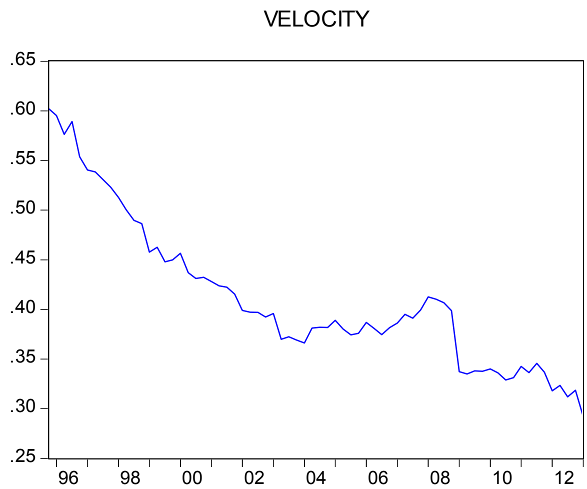
Figure 2.3.3 Target m2 and Actual m2



Our conclusion is that money supply management in China not only focuses on inflation and economic growth, but also takes the nominal exchange rate into account. China's money supply policy is an active policy rule. In order to respond to the appreciation of the CNY, the growth rate of money supply remains high, which leads to excess liquidity during 2007-2008. Again, the McCallum rule better explains China's monetary policy than the Taylor rule.

2.3.4 GMM analysis of McCallum rule when velocity is not constant

Figure 2.3.1 The velocity of m2 (1996Q4 to 2012Q1)



In section 2.3.3, we assume the velocity of m2 is constant. But the velocity is not constant but keeps falling from 1995 to 2013 according to Figure 2.3.1. The velocity of m2 here is calculated by dividing m2 from nominal GDP. As GDP data is quarterly data, quarter on quarter data (1996Q4 to 2012Q1) will be used. The GDP data in Table 2.3.4 is the GDP Gap calculated by using HP filter.

A velocity term is added to the specialized McCallum rule to allow for money supply growth to adjust upward in the face of the money demand expansion implied by declining velocity of circulation. This is in keeping with the rationale for the non-inflationary loosening of Federal Reserve policy in the face of the falling velocity and rising money demand in the early 1980s.

$$m_t^* + v_t = \overline{m} + b_{cpi}\left[E(cpi_t|\Omega_t) - cpi^*\right] + b_y(E(y_t|\Omega_t) - y_t^*) + b_e(E(exchange_t|\Omega_t) - exchange_t^*) \tag{2.3.17}$$

where $\overline{m}$ is the long-run equilibrium nominal rate, v_t is the velocity of m2, cpi_t is the realized annual inflation rate at t, y_t is real output, and cpi^* and y_t^* are respective bliss points for inflation and output. We assume that y_t^* is given by potential output, defined as the level that would arise if wages and prices were perfectly flexible. In addition, E is the expectation operator and Ω_t is the information available to the central bank at the time it sets interest rates.

In practice, central banks tend to maintain smoothness in money supply. In the literature, it is commonly assumed that the actual interest rate m_t is a weighted average of the target rate m_t^* and the existing interest rate m_{t-1}, plus a noise term ε_t, due to other random factors at the same time. This smoothing behavior is represented by Eq. (2.3.18).

$$m_t = (1-\phi)m_t^* + \phi m_{t-1} + \varepsilon_t \tag{2.3.18}$$

where $0 \le \phi < 1$. The case of $\phi = 0$ corresponds to the original Taylor rule without smoothing.

To obtain an estimable equation, we define $b_c \equiv \overline{m} - b_{cpi}cpi^*$, $x_t \equiv y_t - y_t^*$ and $e_t \equiv exchange_t - exchange_t^*$. We then rewrite Eq. (2.3.17) as

$$m_t^* = b_c - v_t + b_{cpi}\left[E(cpi_t|\Omega_t)\right] + b_y(E[x_t|\Omega_t]) + b_e(E[e_t|\Omega_t]) \tag{2.3.19}$$

Combining the target model (3.19) with the adjustment mechanism (2.3.18) yields

$$m_t = (1-\phi)\left[b_c - v_t + b_{cpi}\left[E(cpi_t|\Omega_t)\right] + b_y(E[x_t|\Omega_t]) + b_e(E[e_t|\Omega_t])\right] + \phi m_{t-1} + \varepsilon_t \tag{2.3.20}$$

Finally, we eliminate the unobserved forecast variables from the expression by rewriting the policy rule in terms of realized variables as follows:

$$m_t = (1-\phi)\left[b_c - v_t + b_{cpi}cpi_t + b_y x_t + b_e e_t\right] + \phi m_{t-1} + \delta_t \tag{2.3.21}$$

where the error term

$\delta_t \equiv -(1-\phi)\{b_{cpi}(cpi_t - E[cpi_t|\Omega_t]) + b_y(x_t - E[x_t|\Omega_t]) + b_e(e_t - E[e_t|\Omega_t])\} + \varepsilon_t$ is a linear combination of the forecast errors of inflation, output, exchange rate and the exogenous disturbance ε_t. Let u_t be a vector of variables within the central bank's information set at the time it chooses the interest rate ($u_t \in \Omega_t$) that is orthogonal to v_t. Possible elements of u_t include any lagged variables that help forecast inflation, output, exchange rate and any contemporaneous variables that are uncorrelated with the current interest rate shock ε_t. Then, since $E[\delta_t|u_t] = 0$, Eq. (2.3.22) implies the following set of orthogonality conditions that we exploit for estimation:

$$E\left[m_t - (1-\phi)\left(b_c - v_t + b_{cpi}cpi_t + b_y x_t + b_e e_t\right) - \phi m_{t-1} \middle| u_t\right] = 0 \tag{2.3.22}$$

To estimate the parameter vector $[b_c, b_{cpi}, b_y, b_e, \phi]$ we use GMM.[22] The instrument set u_t includes lagged values of output, inflation, exchange rate and money growth. Each of these variables are potentially useful for forecasting inflation, output and exchange rate, and are exogenous with respect to the interest rate, given our identifying assumptions.[23]

Again following the Taylor rule, a stabilized rule for money supply is supposed to be counter-cyclical. Therefore, the active McCallum rule hypothesis is

$$b_{cpi} < 0, \quad b_y < 0 \quad \text{and} \quad b_e < 0 \tag{2.3.23}$$

This is because when the inflation rate increases, output increases and the CNY depreciates. In this instance, the money supply should be reduced to control inflation, to prevent an overheated economy or to stabilize the nominal exchange rate.

The estimation of the McCallum rule is shown in Table 2.4.3. In Table 2.4.3, equation (2.3.21) is used for estimation and the sample period is from 1996Q4 to 2012Q1. Regression

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[22] The composite disturbance term for our model has an MA(n-1) representations. In this case, the GMM estimator of the parameter vector is a two-step nonlinear two-stage least squares estimator when the model is overidentified (Clarida et al 1998).

[23] Our econometric approach relies on the assumption that, within our short samples, money growth rate and inflation rate are *I*(0). Please refer to Table 4.1.

(4.1) assumes the velocity of m2 is constant, while Regression (4.2) assumes that the velocity is not constant.

The only difference of Regression (4.1) and Regression (3.1) is that quarterly data is used in Regression (4.1), while monthly data is employed in Regression (3.1). If the empirical results of Regression (4.1) are compared with Regression (3.1), most of them are consistent but the significance of b_{gdp}, as different output data are used for quarterly data and monthly data respectively. b_{gdp} is insignificantly in both Regressions (4.1) and (4.2).

Afterwards, Regression (4.1) and (4.2) will be compared to investigate the effects of considering velocity.

The hypothesis $b_{cpi} < 0$ is statistically significant for all the regressions in Table 2.3.4, which indicates that the money supply rule does focus on the inflation target. b_{cpi} is -4.07 in Regression (4.1), which means that with a 1% increase in inflation, the real money supply growth rate would be reduced by 4.06%. In Regression (4.2), $b_{cpi} < 0$ is statistically significantly met, but the absolute value of b_{cpi} is much smaller than (4.1).

Table 2.3.4: The estimation of McCallum rule with sample (1996Q4-2012Q1)

McCallum Rule	b_c	b_{cpi}	b_{gdp}	b_e	ϕ	R^2
Regression (4.1)	18.24***	-4.0707***	-0.0572	-2.4510**	0.7585***	0.8534
Regression (4.2)	11.90***	-1.0005*	-0.0212	-1.2194**	0.6000***	0.8724

Note: The instruments are y_{t-1}, y_{t-2}, y_{t-3}, y_{t-4}, y_{t-5}, y_{t-6}, cpi_{t-1}, cpi_{t-2}, cpi_{t-3}, cpi_{t-4}, cpi_{t-5}, cpi_{t-6}, m_{t-1}, m_{t-2}, m_{t-3}, m_{t-4}, m_{t-5}, m_{t-6}, e_{t-1}, e_{t-2}, e_{t-3}, e_{t-4}, e_{t-5}, e_{t-6}, $Commodity_{t-1}$, $Commodity_{t-2}$, $Commodity_{t-3}$, $Commodity_{t-4}$, $Commodity_{t-5}$, $Commodity_{t-6}$. The instruments in Regression (4.2) also include $velocity_{t-1}$, $velocity_{t-2}$, $velocity_{t-3}$, $velocity_{t-4}$, $velocity_{t-5}$, $velocity_{t-6}$.
*** indicates that the coefficient is statistically significant at 1% level, ** at the 5% level and * at the 10% level

The hypothesis $b_e < 0$ is met for both regressions in Table 2.3.4. The absolute value of parameters b_e exceeds 2 in Regression (4.1), and much bigger than that of Regression (4.2).

b_c are significant in both Regressions (4.1) and (4.2), and that in Regression (4.2) is much smaller than (4.1).

In brief, if the velocity is not taken into account, the coefficients of the model will be overstated. In other words, the Regression (4.2) is more accurate to measure the reaction of money supply to macroeconomic variables: output gap, inflation rate and exchange rate changes.

2.4 The simulation of Taylor rule and McCallum Rule with VAR model

Having analyzed GMM estimation of both Taylor and McCallum rules in the third part of this paper, the same rules will now be estimated with a Structural VAR (SVAR) model. The SVAR model can be used to trace the dynamic effects of shocks of monetary policy on inflation, output and exchange rate. Because VAR models involve current and lagged values of multiple time series, they capture comovements that cannot be detected in univariate or bivariate models.

2.4.1Variables included in the SVAR

We will use a simple SVAR model to analyze the relationship among interest rates, money supply, inflation, output gap and nominal exchange rate. The interest rate and money supply are policy instruments. Let $z_t = \{ cpi_t ,\ y_t ,\ e_t ,\ r_t ,\ m_t \}$ be 5-element vectors of endogenous variables. According to the results of Taylor and McCallum rules in GMM models, the estimations with output gap estimated by electricity y1 are the most robust, so y1 will be used in the VAR models. The lag order is 6 months, since in monetary policy analysis 6 month lag is commonly used.

2.4.2 Identification

According to Amisano and Giannini (1997), the SVAR model equation takes the form shown in equation (2.4.1):

$$Az_t = A_1^* z_{t-1} + A_2^* z_{t-2} + \cdots + A_p^* z_{t-6} + B\varepsilon_t = \sum_{i=1}^{6} A_i^* z_{t-i} + B\varepsilon_t \qquad (2.4.1)$$

For simplicity, constant terms, deterministic terms, and exogenous variables are ignored. Matrix A (5*5) is invertible, and summarize the contemporaneous (instantaneous) relationship among the variables. The A_i^* s are (5*5) coefficient matrices. Structural shocks are properly identified from the error terms of the estimated reduced form with the appropriate identifying restrictions. Zone-zero off-diagonal elements of matrix B (5*5) allow some shocks to affect more than one endogenous variable in the system directly. ε_t is a vector of structural disturbance postulated to follow a white-noise process. Their linear combinations are assumed to be white-noise processes with zero means and constant variances, and are serially uncorrelated individually. The variance-covariance matrix of ε_t is usually restricted to be diagonal.

The reduced form is obtained by premultiplying with A^{-1}, provided that A is non-singular:

$$z_t = A_1 z_{t-1} + A_2 z_{t-2} + \cdots A_6 z_{t-6} + u_t \tag{2.4.2}$$

where $A_j = A^{-1}A_j^*$ (j=1,…6), $u_t = A^{-1}B\varepsilon_t$, describes the relation between the reduced form disturbances (u_t) and underlying structure shocks (ε_t). Thus, we obtain

$$E(u_t u_t') = A^{-1}BE(\varepsilon_t \varepsilon_t')B'A^{-1} \tag{2.4.3}$$

Moreover, assuming that the variance of each disturbance is standardized, and substituting population moments with the sample moments, we have

$$\sum u = A^{-1}BB'A^{-1}$$

$\sum u$ contains k*(k+1)/2 different elements, so k*(k+1)/2 is the maximum number of identifiable parameters in matrices A and B. Therefore, a necessary condition for identification is that the maximum number of parameters of A and B should equal the number of unknowns in equation (2.4.3). Here, the total number of elements of the structural form matrices A and B is $2k^2$. Thus,

$$2k^2 - k*(k+1)/2 = k^2 + k*(k-1)/2 \tag{2.4.4}$$

restrictions should be imposed for identification. If one of the matrices A or B is an identity matrix, then k*(k-1)/2 restrictions are left to be imposed. Hence, identification necessitates the imposition of some identifying restrictions on the parameters of A and B. In practice, the four most common patterns for identifying restrictions are A model ($B=I_k$), B model ($A=I_k$), AB model ($Au_t = B\varepsilon_t$), and the long run restrictions, such as Blanchard and Quah (1989).

We have the basic structural VAR (SVAR) specification based on an A model ($B=I_k$), and the system of equations can be written in the following matrix form:

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ a_{ycpi} & 1 & 0 & 0 & 0 \\ a_{ecpi} & a_{ey} & 1 & 0 & 0 \\ a_{rcpi} & a_{ry} & a_{re} & 1 & 0 \\ a_{mcpi} & a_{my} & a_{me} & a_{mr} & 1 \end{pmatrix} \begin{pmatrix} cpi_t \\ y_t \\ e_t \\ r_t \\ m_t \end{pmatrix} = c + A(L) \begin{pmatrix} cpi_t \\ y_t \\ e_t \\ r_t \\ m_t \end{pmatrix} + \begin{pmatrix} \varepsilon_{cpi} \\ \varepsilon_y \\ \varepsilon_e \\ \varepsilon_r \\ \varepsilon_m \end{pmatrix} \tag{2.4.5}$$

This is the case of just-identification restriction. In this model, the structural shocks to money supply m2 are assumed to be related to the reduced form innovations in inflation and output gap according to the McCallum rule. The five-variable VAR is ordered as: inflation rate cpi, GDP gap y, nominal exchange rate e, policy interest rate r and money supply m2. Various orderings have been tried, and the results turn out to be the same.

In the case of interest rate, a_{rcpi} is -0.0086, a_{ry} is -0.0060, a_{re} is 0.0534. All of them are much smaller than the corresponding parameters estimated by GMM model, which are listed in Table 2.3.1. This is because the 4^{th} equation in Equation (2.4.5) indicates that r is not only affected by current realizations of macroeconomic variables such as CPI, output gap and exchange rate, but is also affected by their past six months realizations.

Since a_{rcpi}, $a_{ry,}$ a_{re} are on the left side of Equation (2.4.5), the signs should be opposite to GMM model. The sign of a_{rcpi}, a_{ry} are negative, consistent with GMM model. As to a_{re}, the sign is positive, inconsistent with GMM model. However, considering that a_{re} is statistically insignificant in both GMM (displayed in Regression 1.1 in Table 2.3.1) and SAVR (displayed in the first row third column in Figure 2.4.1), when discussing the response of interest rate to nominal exchange rate, there is no need to take the sign of a_{re} into consideration.

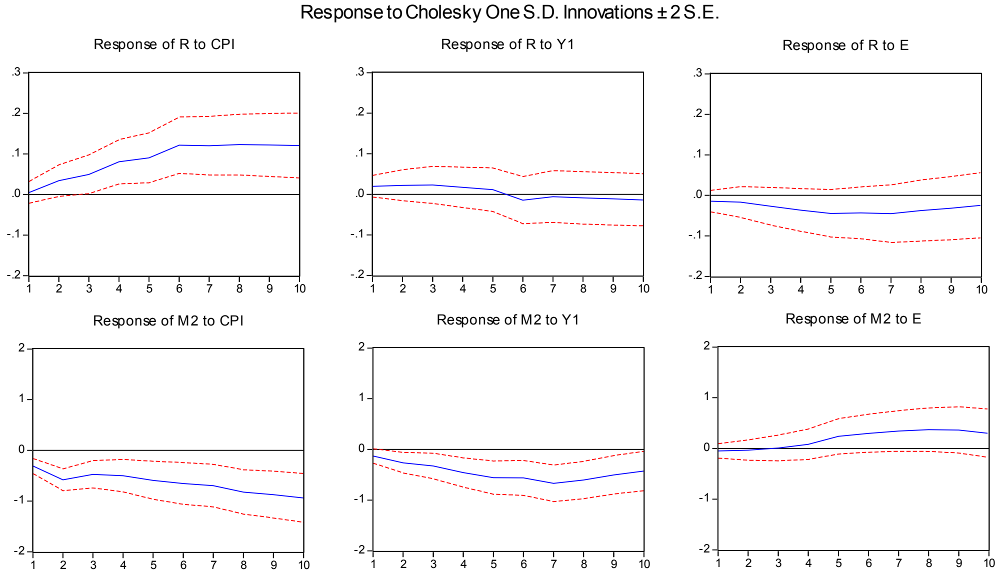
Similarly, in the case of money supply, a_{mcpi} is 0.5446, a_{my} is 0.0441, and a_{me} is 0.1992. All of them are smaller than the corresponding parameters estimated by GMM model, listed in Regression 3.1 in Table 2.3.3. The reason is the same as the case of interest rate above. Furthermore, a_{mcpi}, a_{my}, a_{me} are on the left side of Eq. (2.4.5), so the signs (negative) are consistent with GMM, illustrating that McCallum rule is an active policy rule.

2.4.3 Impulse responses

Impulse responses trace out the response of current and future values of each of the variables to a one-unit increase in the current value of one of the VAR errors, assuming that this error returns to zero in subsequent periods and that all other errors are equal to zero.

The impulse responses for the SVAR, ordered cpi, y, e, r, and m2 are plotted in Figure 2.4.1. In SVAR model, the criterion to measure whether the impulse response is statistically significant or not is the position of both ±2 standard-error bands. The impulse response function is statistically significant as long as both standard-error bands are above or below zero on the y-axis. The following analysis is carried out based on this criterion.

Figure 2.4.1 Impulse responses in the five-variable SVAR



In the case of Taylor rule, three figures in the first row show the responses of interest rate r to an unexpected one percentage point increase of three macroeconomic variables. The first figure suggests that when inflation rate increases, interest rate r will move upwards. On this point, it is consistent with the result of GMM model in Regression 1.1 in Table 2.3.1. The third figure illustrates that the response of interest rate to nominal exchange rate is statistically insignificant, which is also consistent with the result of GMM model. It is necessary to point out that, the second figure indicates that the response of interest rate to output gap is insignificant, while it is significant in the GMM model.

In the case of McCallum rule, three figures in the second row show the responses of money supply m2 to an unexpected one percentage point increase of three macroeconomic variables. The first two figures suggest that when inflation rate increases or the GDP output gap rises, money supply m2 will move downwards, which is consistent with the result of GMM model. However, the third figure shows that the response of m2 to nominal exchange rate is positive, which is opposite to GMM results in Regression 3.1 in Table 2.3.3.

There is also an inconsistency between the results of the GMM and SVAR models, as seen in the top-middle and bottom-right plots of Figure 2.4.1. In both cases, the GMM results are significant while the SVAR results are not. Since the SVAR model has many more parameters than the GMM, each parameter in SVAR is less likely to achieve statistical significance.

In conclusion, the results of GMM are statistically convincing, compared with SVAR model. Besides, money supply m2 is more active and responds better to CPI and output gap than interest rate in both GMM model and SVAR model.

2.5 Concluding remarks

The GMM estimation suggests that the requirements for an active Taylor rule are not satisfied for several reasons. First, for a unit change of inflation rate and output gap, the response of the interest rate is not large enough. Second, in many cases of the Regressions, both the inflation and the output gap are not statistically significant. In addition, as explanatory variables in the Taylor rule, nominal exchange rate is statistically insignificant in most cases.

Compared with the Taylor rule, the McCallum rule is more active and can be more effectively used to trace China's monetary policy. It is because all of the active requirements are met, such that money supply m2 responds significantly and negatively to CPI, output gap and nominal exchange rate.

The results of SVAR are consistent with the GMM estimations of the Taylor rule and McCallum rule. Money supply responds to CPI and economic growth significantly negatively, so targeting the money supply is a better device to trace China's monetary policy.

3. Active Policy Rule versus Ineffective Monetary Policy

TVP-VAR Analysis of Chinese Monetary Policy from1994 to 2012

3.1 Introduction

China's rising prominence in the world economy has meant that the efficacy of its macroeconomic management has taken on considerable importance, not just from a domestic perspective but also from broader regional and international perspectives. Although Chinese economy is the second largest economy in the world, as monetary management used to be residual component of central planning in China and China's financial system is still partly dominated by four big state banks, Chinese monetary policy is quite different from developing countries such as US, Europe and Japan.

Although China's government deficit and public debt to GDP ratios are quite low by international standards, the existence of large contingent fiscal liabilities implies that there may be less room for maneuver on fiscal policy especially after the 4 trillion RMB(Renminbi) government stimulus plan from the end of 2008 to the end of 2010. Thus, monetary policy has a particularly important role to play in buffering the economy from domestic and external shocks.

In the absence of further financial liberalization, however, interest rates remained largely administratively determined even in 2010's, making their influence on money demand hard to interpret with. Liu (2014) indicated that the interest rate to be insignificant in influencing money demand in the post-reform period. Therefore, instead of interest rate, the effectiveness of money supply policy will be explored in this paper.

There are not as many papers about Chinese monetary policy as Japanese monetary policy. Prior work has examined money demand in China including tests for causality between money and prices and money and output. Sun and Ma (2004) investigated the effectiveness of Chinese monetary policy in two regimes of inflation and deflation, and suggested that monetary policies have become less effective in stabilizing price level in the deflation era that started from 1998. And by employing structural VEC model Zhang and Wan (2004) investigated the output and price fluctuations in China, and found that in the long run money accommodates rather than causes changes in output and prices, while in the short run, price fluctuations are mostly attributable to shocks that have permanent effects on prices and money but not on real output.

There are many constraints which may make the Chinese monetary policy ineffective; one of them is the de facto fixed exchange rate regime. China had a dual exchange rate regime in the early 1990s. The exchange rate regime was unified in 1994 and, since 1995, the RMB has been maintained at a fixed parity relative to the US dollar. This regime was in principle classified as a managed float since a narrow fluctuation band around the US dollar was permitted. In practice, however, the renminbi has been maintained at an essentially fixed level relative to the US dollar since the mid-1990s. But on 21 July 2005, the renminbi was revalued by 2.1% relative to the US dollar, and the government announced that its value would henceforth be set with reference to a basket of currencies, although neither the currency composition of the basket nor the basket weights have been publicly disclosed. The new regime also allows for fluctuations of up to 0.3% around the reference rate. In principle, this could mean that the exchange rate is allowed to drift up (or down) by 0.3% each day, which could amount to a significant appreciation (or depreciation) over a period of time. In practice, however, the renminbi has barely moved against the dollar since July 2005; its lack of movement is also not consistent with variations that may have been expected based on various plausible assumptions about the currency composition of the reference basket. Thus, the regime still qualifies as a de facto fixed exchange rate.

In Chapter 3 we would like to know whether the effectiveness of the Chinese monetary policy has been affected by the exchange rate regimes changes. The effectiveness of Chinese monetary policy here refers to the macroeconomic (economic growth, inflation and exchange rate) impact of the monetary easing or tightening policies, which is a kind of money supply policy in China.

After Primiceri (2005)'s introduction of the TVP-VAR model, several papers have analyzed the time-varying structure of the macroeconomy in specific ways. Benati and Mumtaz (2005) estimate the TVP-VAR model for the U.K. data by imposing sign restrictions on the impulse responses to assess the source of the "Great Stability" in the United Kingdom as well as uncertainty for inflation forecasting (see also Benati [2008]). Baumeister, Durinck, and Peersman (2008) estimate the TVP-VAR model for the euro area data to assess the effects of excess liquidity shocks on macroeconomic variables. Nakajima, Kasuya, and Watanabe (2009) and Nakajima (2011) estimate the TVP-VAR model for the Japanese macroeconomic data.

An increasing number of studies have examined the TVP-VAR models to provide empirical evidence of the dynamic structure of the economy. As Sun and Ma (2004) mentioned, there is a big challenge to research Chinese monetary policy, which is the frequent structural changes in Chinese monetary system. To overcome this difficulty, Sun and Ma (2004) applied a rolling estimation approach on the VAR model. But other research papers did not refer to this problem. Given such previous literature and such a challenge to research Chinese monetary policy, we will employ TVP-VAR model to analyze Chinese monetary policy, with emphasis on the analysis of the dynamic exchange rate regime changes. Although they are not based on the optimization problems of economic agents, VARs with time variation of parameters can deal with regime changes, with time variation in the lag structure of the model or with nonlinearities that emerge.

3.2 Time-Varying Parameter VAR model with Stochastic Volatility

3.2.1 Data

A four-variable (p, x, e, m) TVP-VAR model is estimated for monthly data from 1994M1 to 2012M12. p is the inflation rate (Consumer Price Index); and x is the real output (industrial added value growth rate minus inflation rate), e is the REER of CNY (Real Effective Exchange Rate); and m is real M0 (growth rate minus inflation rate), which is cash plus reserve money. All of the data are taken logs and then first differences.

3.2.2 Model

Our model and estimation approach follows Nakajima (2011). The important feature of the model is that it allows coefficient (β), shock variances (h) and simultaneous relation of the structural shocks (α) to change over time. The lag is one.

The TVP-VAR is defined as

$$A_t y_t = F_{1t} y_{t-1} + u_t \qquad t = 1+1, \cdots, n \qquad (3.2.1)$$

where y_t is the 4*1 vector of observed variables (p_t, x_t, e_t, m_t), and A_t, F_{1t} are 4*4 matrices of coefficients. The disturbance is a 4*1 structural shock and we assume that $u_t \sim N(0, \Sigma_t \Sigma_t')$, where

$$\Sigma_t = \begin{pmatrix} \sigma_{1t} & 0 & 0 & 0 \\ 0 & \sigma_{2t} & 0 & 0 \\ 0 & 0 & \sigma_{3t} & 0 \\ 0 & 0 & 0 & \sigma_{4t} \end{pmatrix}$$

We specify the simultaneous relations of the structural shock by recursive identification, assuming that A is lower-triangular,

$$A_t = \begin{pmatrix} 1 & 0 & 0 & 0 \\ a_{21t} & 1 & 0 & 0 \\ a_{31t} & a_{32t} & 1 & 0 \\ a_{41t} & a_{42t} & a_{43t} & 1 \end{pmatrix}$$

We rewrite model (1) as the following reduced form VAR model:

$$y_t = B_{1t} y_{t-1} + A_t^{-1} \sum\nolimits_t \varepsilon_t \qquad \varepsilon_t \sim N(0, I_k) \qquad (3.2.2)$$

where $B_{1t} = A_t^{-1} F_{1t}$. Stacking the elements in the rows of the B_{it}'s to form $\beta\,((4^2 * 1)\times 1$ vector), and defining $X_t = I_k \otimes (y'_{t-1})$, where $\otimes$ denotes the Kronecker product, the model can be written as

$$y_t = x_t \beta_t + A_t^{-1} \Sigma_t \, \varepsilon_t \qquad t = 1+1, \cdots, n \tag{3.2.3}$$

where the coefficients β_t and the parameters A_t and Σ_t are all time varying. There are many ways to model the process for these time-varying parameters. Following Primiceri (2005), let $a_t = (a_{21t}, a_{31t}, a_{32t}, a_{41t}, a_{42t} a_{43t})'$ be a stacked vector of the lower-triangular elements in A_t, and $h_t = (h_{1t}, \cdots h_{4t})'$ with $h_{jt} = \log \sigma_{jt}^2$, for $j = 1, \cdots 4, t = 1+1, \cdots n.$ We assume that the parameter in (3) follows a random walk process as follows:

$$\beta_{t+1} = \beta_t + u_{\beta t}, \quad a_{t+1} = a_t + u_{at}, \quad h_{t+1} = h_t + u_{ht}$$

$$\begin{pmatrix} \varepsilon_t \\ u_{\beta t} \\ u_{at} \\ u_{ht} \end{pmatrix} \sim N\left(0, \begin{pmatrix} I & 0 & 0 & 0 \\ 0 & \Sigma_\beta & 0 & 0 \\ 0 & 0 & \Sigma_a & 0 \\ 0 & 0 & 0 & \Sigma_h \end{pmatrix}\right)$$

for $t = 1+1, \cdots, n$, where $\beta_{s+1} \sim N(\mu_{\beta 0}, \Sigma_{\beta 0}), a_{s+1} \sim N(\mu_{a0}, \Sigma_{a0}), h_{s+1} \sim N(\mu_{h0}, \Sigma_{h0})$.

3.2.3 Estimation Methodology

The estimation procedure for the TVP-VAR model is illustrated by extending several parts of the algorithm for the TVP regression model. Let $y = \{y_t\}_{t=1}^n$, and $\omega = (\Sigma_\beta, \Sigma_a, \Sigma_h)$. We set the prior probability density as $\pi(\omega)$ for ω. Given the data y, we draw samples from the posterior distribution, $\pi(\beta, a, h, \omega | y)$ by the following MCMC algorithm:

(1)Initialize $\beta, a, h,$ and ω

(2)Sample $\beta | a, h, y$

(3)Sample $\Sigma_\beta | \beta$

(4)Sample $a | \beta, h, \Sigma_a, y$

(5) Sample $\Sigma_a | a$

(6) Sample $h | \beta, a, \Sigma_h, y$

(7) Sample $\Sigma_h | h$

(8) Go to (2)

The number of the VAR lags is 1, and we assume that Σ_β is a diagonal matrix for simplicity. Some experiences indicate that this assumption is not sensitive for the results[24]. The following priors are assumed for the *i*-th diagonals of the covariance matrices:

$$\Sigma_\beta \sim IW(25, 10^{-4} I), \omega_{a_i}^2 \sim IG(4, 10^{-4}), \omega_{h_i}^2 \sim IG(4, 10^{-4})$$

For the initial state of the time-varying parameter, rather flat priors are set $\Sigma_{\beta_0} = \Sigma_{a_0} = \Sigma_{h_0} = 10 \times I$, and $\mu_{\beta_0} = \mu_{a_0} = \mu_{h_0} = 0$. To compute the posterior estimates, we draw M=30,000 samples after the initial 3,000 samples are discarded. The details of the procedure are illustrated in Appendix B.

3.3 Empirical Results for the Chinese Monetary Policy

As mentioned above, this section uses the TVP-VAR model to analyze the effectiveness of the Chinese monetary policy.

Table 3.3.1 and Figure 3.3.1 report the estimation results for selected parameters of the TVP-VAR model for the variable set (p, x, e, m). The results show that the MCMC algorithm produces posterior draws efficiently.

Table 3.3.1 gives the estimates for posterior means, standard deviations, and 95 percent credit intervals, the convergence diagnostics (CD) of Geweke (1992), and inefficiency factors, which are computed using the MCMC sample. In the estimated result, the null hypothesis of the convergence to the posterior distribution is not rejected for the parameters at the 5 percent

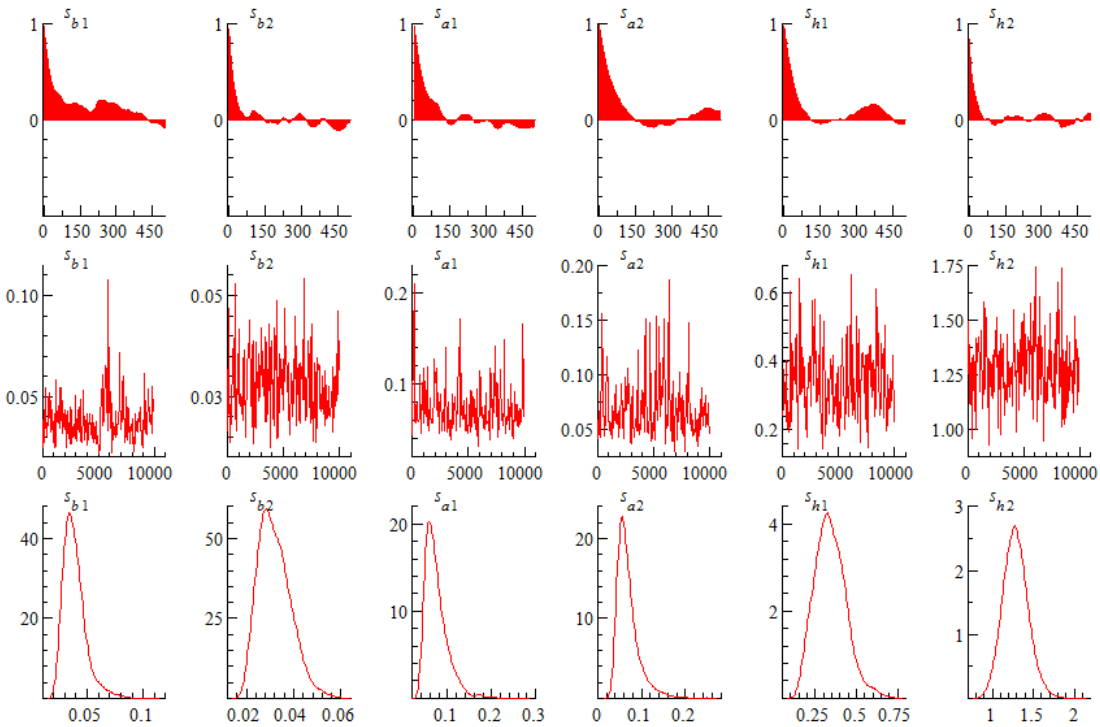
[24] Nakajima et al (2011)

significance level based on the CD statistics (p value). And the inefficient factors are quite low, which indicated an efficient sampling for the parameters and state variables.

Table 3.3.1: Estimating Results of Selected Parameters in the TVP-VAR Model for the Variable Set of (p, x, e, m)

Parameter	Mean	Stdev	95%L	95%U	Geweke	Inefficiency
$(\Sigma_\beta)_1$	0.039	0.010	0.024	0.065	0.500	97.17
$(\Sigma_\beta)_2$	0.032	0.007	0.021	0.047	0.952	42.47
$(\Sigma_a)_1$	0.074	0.026	0.041	0.137	0.508	76.82
$(\Sigma_a)_2$	0.070	0.026	0.039	0.140	0.736	87.46
$(\Sigma_h)_1$	0.342	0.095	0.180	0.556	0.367	68.24
$(\Sigma_h)_2$	1.284	0.153	0.999	1.602	0.756	31.58

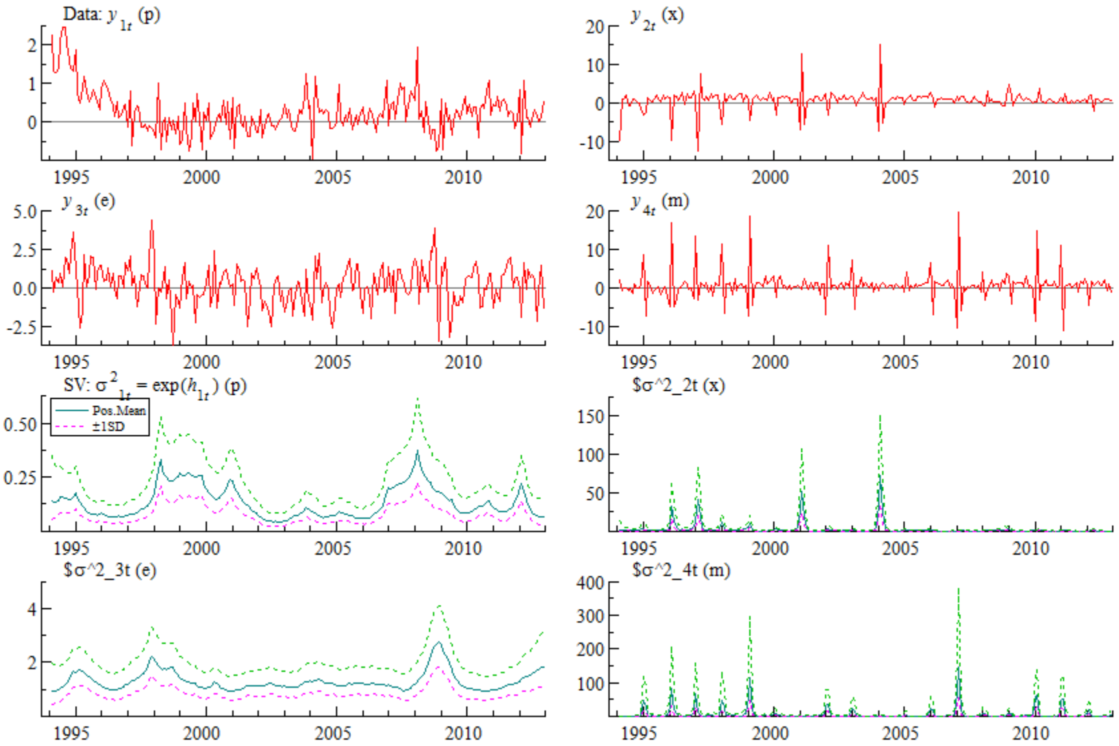
Figure 3.3.1: Estimation Results of Selected Parameters in the TVP-VAR Model for the Variable Set of (p, x, e, m)



Note: Sample autocorrelations (top), sample paths (middle) and posterior densities (bottom).

Figure 3.3.1 shows the sample autocorrelation function, the sample paths, and the posterior densities for the selected parameters. After discarding the samples in the burn-in period (initial 3,000 samples), the sample paths look stable, and the sample autocorrelations drop stably, indicating that our sampling method efficiently produce the samples with low autocorrelation.

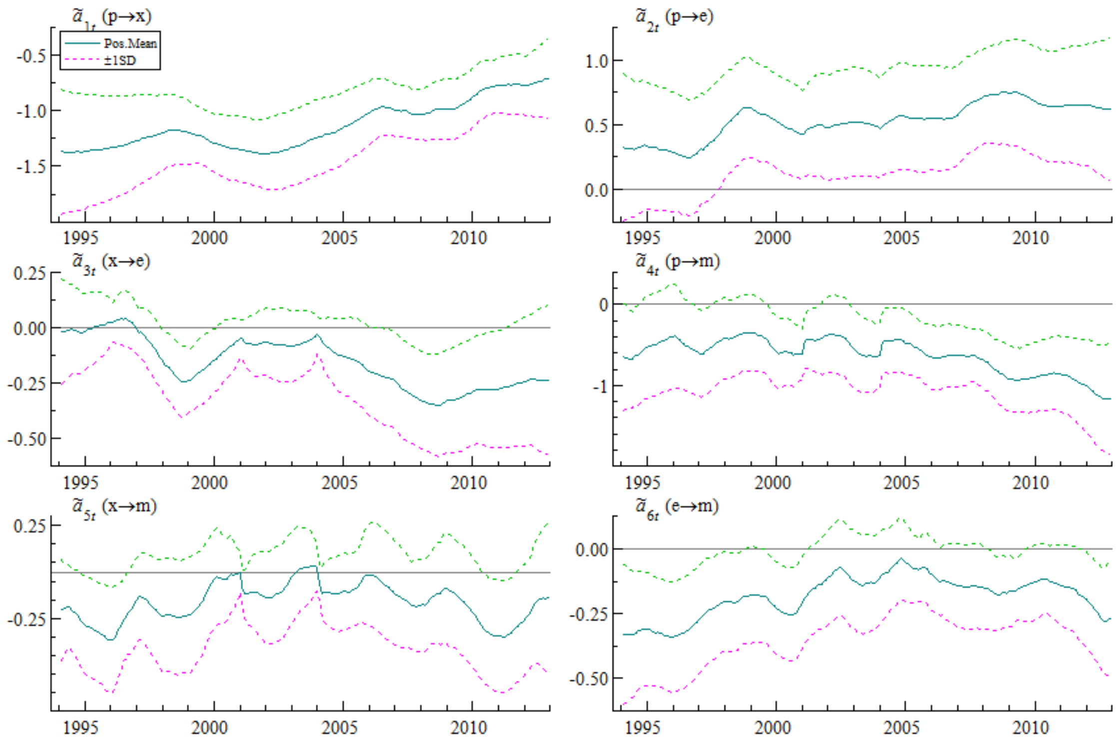
Figure 3.3.2: Estimating Results of Selected Parameters in the TVP-VAR Model for the Variable Set of (p, x, e, m) and Stochastic Volatility of the Structural Shock, $\sigma_{it} = \exp(h_{it}/2)$



Note: Posterior mean (solid line) and 95 percent credible intervals (dotted line)

The simulated state variables (p, x, e, m) are plotted in the first two rows of Figure 3.3.2. The last two rows of Figure 3.3.2 plots the posterior estimates of stochastic volatility. Stochastic volatility of inflation (p) exhibits four spikes in 1994-1995, 1998-2002, 2007-2008 and 2012, which gives a good description of the inflation-deflation situation in China. During these four periods, all the other three are inflation periods, but 1998-2002 is a deflation period. Stochastic volatility of output (x) remains unchanged, except 1998, 2001, 2003-2004. As industrial production index is used as output, this result may be limited. The high output volatility in 1998 is for Asian Economic Crisis, high volatility in 2001 is for joining WTO (the World Trade Organization), and high volatility in 2004 is for SARS. Although Figure 3.3.2 does not show the subprime loan crisis in 2008, we can also find out many features of Chinese economic changes. Stochastic volatility of real effective exchange rate (e) exhibits one spike in 1994. The exchange rate regime was unified in 1994 and RMB depreciated 50% (from 5.80 to 8.70) against US dollar simultaneously. Compared with this spike, the changes in 2008 and 2010 are too small to find out in Figure 3.3.2. Stochastic volatility of money supply (m) is volatile during 1994 to 2012, which indicated that the Chinese money supply policy is not a stable monetary policy.

Figure 3.3.3: Posterior Estimates for Simultaneous Relation, $\tilde{\alpha}_{it}$, for the Variable Set of (p, x, e, m)



Note: Posterior mean (solid line) and 95 percent credible intervals (dotted line)

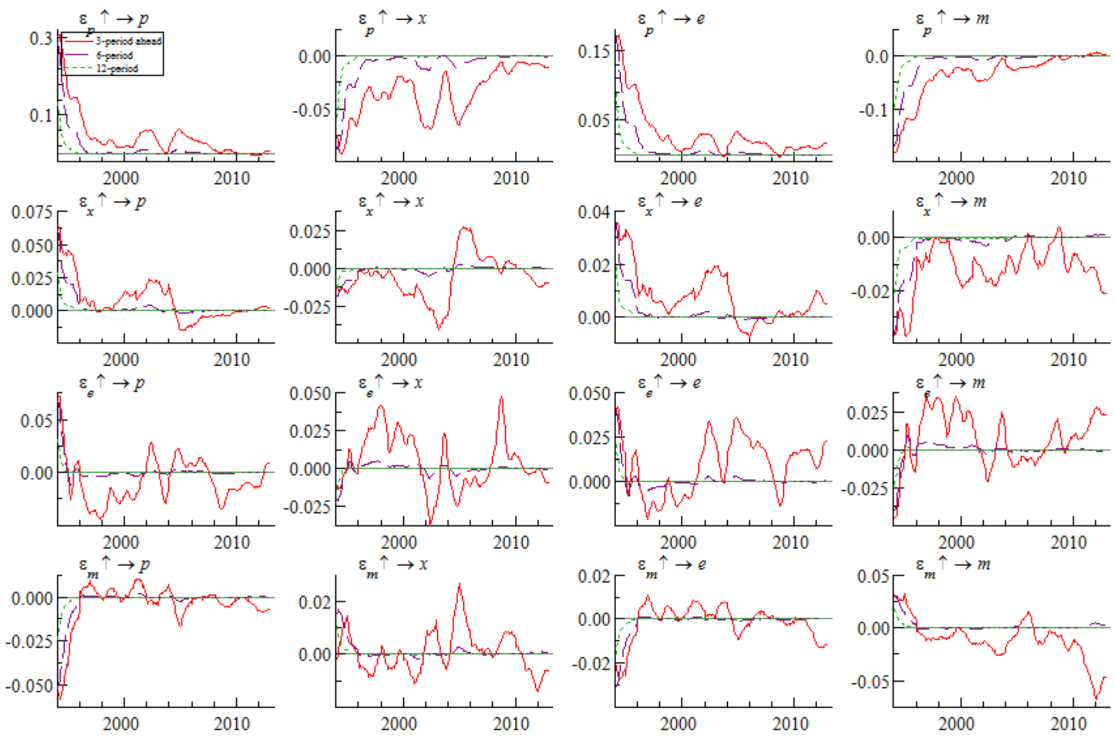
Figure 3.3.3 plots the posterior estimates of the simultaneous relation. The time-series plots consist of the posterior draws on each data. As for the simultaneous relation, which is specified by the lower triangular matrix A_t , the posterior estimates of the free elements in A_t^{-1} , denoted $\tilde{\alpha}_{it}$, are plotted. This implies the size of the simultaneous effect of other variables to one unit of the structural shock based on the recursive identification.

The time-varying simultaneous relation is one of the characteristics in the TVP-VAR model. The simultaneous relation of the output to the inflation shock (p→ x) is negative from 1990s and then turn positive from 2008, which means inflation is bad for the economic growth in China. The simultaneous relation of money supply to the inflation shock (p→ m) stays negative until the 2010, which means the money supply policy in China is a kind of inflation-preventing monetary policy. Similarly, the simultaneous relation of money supply to the output shock (x→m) mainly stays negative, which indicates that Chinese money supply policy can keep economic growth from overheated.

The impulse response is a basic tool to see the macroeconomic dynamics captured by the estimated VAR system. For a standard SVAR model whose parameters are all time-invariant, the impulse responses are drawn for each set of two variables. By contrast, for the TVP-VAR model, the impulse responses are computed at all points in time using the estimated time-varying parameters. In this case, we have several ways to simulate the impulse responses based on the parameter estimates of the TVP-VAR model.

In this paper two kinds of impulse responses will be shown. Firstly, considering the comparability over time, we compute the impulse responses by fixing an initial shock size equal to the time-series average of stochastic volatility over the same period, and using the simultaneous relation at each point in time. To compute the recursive innovation of the variable, the estimated time-varying coefficients are used from the current data to future periods. Around the end of the sample period, the coefficients are set constant in future periods for convenience. A three-dimensional plot can be drawn for the time-varying impulse responses in Figure 3.3.4. And a time series of impulse responses for selected period are exhibited in Figure 3.3.5.

Figure 3.3.4: Impulse Response of TVP-VAR Models for the Variables Set of (p, x, m)



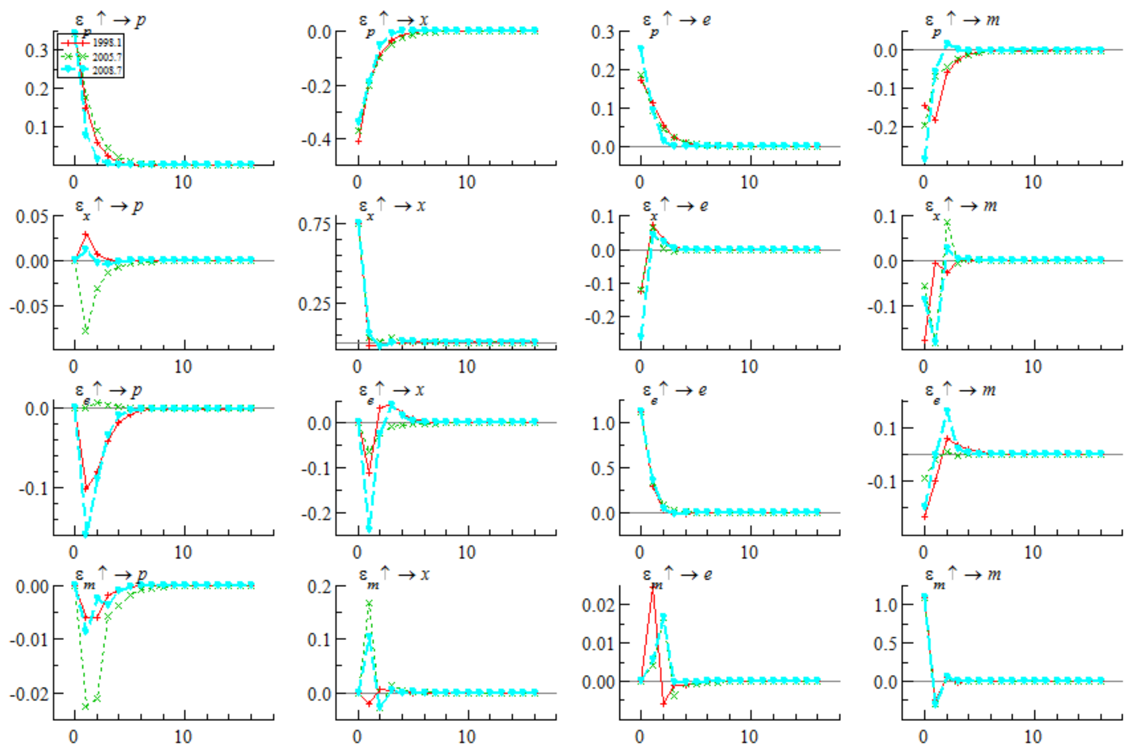
Note: Time-Varying responses for 3 months (red), 6 months (purple), 12 months (green) horizons

Figure 3.3.4 shows the impulse responses for the TVP-VAR model, which are drawn in a time-series manner by showing the size of the impulses for 3 months, 6 months and 12 months.

From a perspective of the policy rule, the impulse responses of money supply to a positive inflation shock ($\varepsilon_p \rightarrow$ m) stays negative, which shows the money supply policy is an active monetary policy to control inflation. The impulse responses of money supply to a positive output shock ($\varepsilon_x \rightarrow$ m) stays negative although volatile during the sample, which also shows the money supply policy is an active monetary policy to control overheated economy. The impulse responses of money supply to a positive REER shock ($\varepsilon_e \rightarrow$ m) are mainly positive during the sample except 1994-1996, 2002, and 2005, which also means the money supply policy is an active monetary policy to offset the influences of deprecations or appreciations of RMB.

From a perspective of the effectiveness of monetary policy, the impulse responses of inflation rate to a positive money supply shock ($\varepsilon_m \rightarrow$ p) is negative in 1994 and then turn positive in 1998 and then turn negative in 2005, which shows the money supply policy M0 is not very effective to control inflation. In contrast, the impulse responses of output to a positive money supply shock ($\varepsilon_m \rightarrow$ x) is positive in 1994 and then turn negative in 1996 and then turn positive in 2002, which shows the money supply policy M0 is not very effective to affect output growth. Similarly, the impulse responses of REER to a positive money supply shock ($\varepsilon_m \rightarrow$ e) is more or less the same as ($\varepsilon_m \rightarrow$ x).

Figure 3.3.5: Impulse Response of TVP-VAR Models for the Variables Set of (p, x, m)



Note: Time-Varying responses for January 1998 (red), July 2005 (green), July 2008 (blue) horizons

Figure 3.3.5 shows a time series of impulse responses for selected periods January 1998, July 2005, and July 2008. There are several reasons why these three periods are selected. In January 1998 is because PBC began to use monetary policy instead of administrative tools such as credit control from January 1998. Additionally, January 1998 is in the middle of Asian Financial Crisis. We can find out some features of this period. On 21 July 2005, the RMB was revalued by 2.1% relative to the US dollar, and the government announced that its value would henceforth be set with reference to a basket of currencies, although neither the currency composition of the basket nor the basket weights have been publicly disclosed. In July 2008 US subprime loan crisis broke out, RMB stopped appreciating and began to pegging US dollar again.

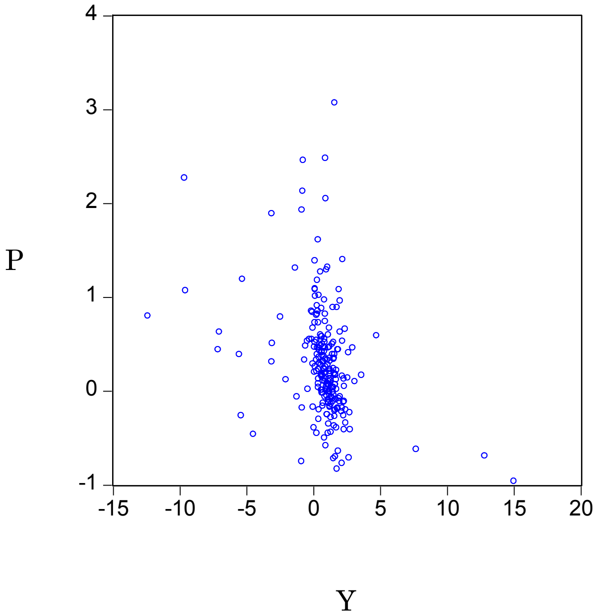
From a perspective of the policy rule, the impulse responses of money supply to a positive inflation shock ($\varepsilon_p \rightarrow$ m) stays negative, and the responses are similar among the three periods. The impulse responses of money supply to a positive output shock ($\varepsilon_x \rightarrow$ m) are mainly negative, but part of the responses of 2005 and 2008 turned to positive temporarily. The impulse responses of money supply to a positive REER shock ($\varepsilon_e \rightarrow$ m) are part positive and part negative among all there periods, which is hard to say whether the money supply policy is an active monetary policy to offset the influences of deprecations or appreciations of RMB or not.

From a perspective of the effectiveness of monetary policy, the impulse responses of inflation rate to a positive money supply shock ($\varepsilon_m \rightarrow$ p) are all negative for three periods, which shows a price puzzle. In contrast, the impulse responses of output to a positive money supply shock ($\varepsilon_m \rightarrow$ x) are positive for 2005 and 2008, but negative for 1998, which means the money supply policy M0 is more effective after the RMB exchange rate reform in 2005. The impulse responses of REER to a positive money supply shock ($\varepsilon_m \rightarrow$ e) are mainly positive for all three periods, which is inconsistent with the economic theory.

3.4 Conclusions

We come to a conclusion that money supply policy is an active monetary policy rule but it is not effective. One of the reasons is the trade-off of inflation and economic growth. Figure 3.4.1 indicates that there is no trade off between inflation and economic growth in China. The Phillips Curve in China is a vertical curve which suggests that in order to realize a relatively high economic growth, inflation rate is sacrificed.

Figure 3.4.1: The Trade-off of Inflation p and Economic Growth y



Appendix 3.A: China's monetary policies 1992-2012

Time	Economic situation	Monetary policy	The change of interest rate and reserve requirement rate
1990-1992	Inflation was in control	From tight to moderately ease	One-year deposit and lending rates was decreased three times to 8.10% RRR did not change
1993-1994	Inflation caused by real estate boom	Tight	One-year deposit and lending rates was increased twice RRR did not change
1995-1997	Inflation rate remained high	Appropriately tight	One-year deposit and lending rates was decreased 3 times RRR did not change
1998-2007	1998-2003 deflation and recession 2004-2007 excess liquidity and inflation	Prudential[25] (From ease to tight)	1998-2003 One-year deposit and lending rates was reduced 5 times, RRR was reduced twice 2004-2007 One-year deposit and lending rates was raised 8 times, and RRR was raised 15 times RMB was reformed in 2005, and began to appreciate
2008-2009	Subprime crisis and recession	From tight to moderately ease	RRR was raised 5 times during tight monetary policy in2008 One-year deposit interest rate was reduced 3 times and RRR was reduced 3 times
2010-2012	Excess credit and inflation	Prudential[26] (tight)	one-year deposit interest rate was raised 5 times and RRR was raised 11 times

Source: Dai 2000 and PBoC Quarterly Monetary Policy Report

[25]Prudential monetary policy may mean either the ease monetary policy or the tight monetary policy. We can identify the direction of China's monetary policy by checking the changes of the policy interest rates and the reserve requirement rate.

[26]Please refer to footnote 25.

Appendix 3.B: MCMC algorithm for the TVP regression Model

1. Sample β

The state space model with respect to β_t as the state variable is written as

$$y_t = X_t\beta_t + A_t^{-1}\Sigma_t\varepsilon_t \qquad , t=s+1\ldots n,$$

$$\beta_{t+1} = \beta_t + u_{\beta t} \qquad , t=s\ldots n-1,$$

where $\beta_s = \mu_{\beta_0}$, and $\mu_{\beta_s} \sim N(0, \Sigma_{\beta_0})$

We run the simulation smoother as follows:

$$Z_t = X_t, G_t = (A_t^{-1}\Sigma_t, 0_p)$$

$$T_t = I_p, H_t = (0_k, \Sigma_\beta^{1/2}), H_s = (0_k, \Sigma_{\beta_0}^{1/2})$$

where p =k2s

2. Sample a

The state space model with respect to β_t as the state variable is written as

$$\hat{y}_t = \hat{X}_t a_t + A_t^{-1}\Sigma_t\varepsilon_t \quad , t=s+1, \ldots, n.,$$

$$a_{t+1} = a_t + u_{at} \quad , t=s,\ldots, n-1,$$

where $a_s = \mu_{a_0}, u_{a_s} \sim N(0, \Sigma_{a_s}), \hat{y}_t = y_t - X_t\beta_t$

$$\hat{X}_t = \begin{pmatrix} 0 & \cdots & & & & & & 0 \\ -\hat{y}_{1t} & 0 & 0 & \cdots & & & & \vdots \\ 0 & -\hat{y}_{1t} & -\hat{y}_{2t} & 0 & \cdots & & & \\ 0 & 0 & 0 & -\hat{y}_{1t} & \cdots & & & \\ \vdots & & & & \ddots & 0 & \cdots & 0 \\ 0 & \cdots & & & 0 & -\hat{y}_{1t} & \cdots & -\hat{y}_{k-1,t} \end{pmatrix} \quad \text{for } t=s+1, \ldots, n.$$

We run simulation smoother to sample a

$$Z_t = \hat{X}_t, G_t = (\Sigma_t, 0_q) \quad , \quad T_t = I_q, H_t = (0_k, \Sigma_a^{1/2}), H_s = (0_k, \Sigma_{a_0}^{1/2})$$

where q=k*(k-1)/2

3. Sample h

We assume $\sum h$ and $\sum h_0$ are diagonal matrices.

Let y_{it}^* denote the i-th element of $A_t\hat{y}_t$, Then, we can write:

$$y_{it}^{*} = \exp(h_{it}/2)\varepsilon_{it} \quad \text{, t=s+1, …, n,}$$

$$h_{t+1} = h_t + u_{ht} \quad \text{, t=s, …, n-1,}$$

$$\begin{pmatrix} \varepsilon_{it} \\ \eta_{it} \end{pmatrix} \sim \left(0, \begin{pmatrix} 1 & 0 \\ 0 & \upsilon_i^2 \end{pmatrix} \right)$$

Where $\eta_{is} \sim N(0, \upsilon_{i_0}^2)$, and υ_i^2 and $\upsilon_{i_0}^2$ are the i-th diagonal elements of Σh and Σh0 .

4. Sample ∑β

We assume the following priors for ∑β

$$\Sigma_\beta \sim IW(\mathrm{n}_0, S_0)$$

By using Bayes' theorem,

$$\pi(\Sigma_\beta | \beta) \propto f(\beta | \Sigma_\beta)\pi(|\Sigma_\beta|)$$

$$= \prod_{t=s+1}^{n-1} |\Sigma_\beta|^{-\frac{1}{2}} \exp\left\{ -\frac{1}{2}(\beta_{t+1} - \beta_t)' \Sigma_\beta^{-1} (\beta_{t+1} - \beta_t) \right\} \times |\Sigma_\beta|^{-\frac{n_0+p+1}{2}} \exp\left\{ -\frac{1}{2} tr(S_0^{-1} \Sigma_\beta^{-1}) \right\}$$

$$= |\Sigma_\beta|^{-\frac{\hat{n}+p+1}{2}} \exp\left\{ -\frac{1}{2} tr(\hat{S}^{-1} \Sigma_\beta^{-1}) \right\}$$

Then, the posterior distribution of ∑β is

$$\Sigma_\beta | \beta \sim IW(\hat{\mathrm{n}}, \hat{S})$$

Where $\hat{n} = n_0 + n - s - 1, \hat{S}^{-1} = \hat{S}_0^{-1} + \sum_{t=s+1}^{n-1} (\beta_{t+1} - \beta_t)(\beta_{t+1} - \beta_t)'$

5. Sample ∑ a

The following prior is assumed for the i-th diagonals of ∑a

$$\omega_{ai}^2 \sim IG(\upsilon_{a_0}/2, V_{a_0}/2)$$

By using Bayes' theorem,

$$\pi(\omega_{ai}^2 | a_i) \propto f(a_i | \omega_{ai}^2)\pi(\omega_{ai}^2)$$

$$= \left(\frac{1}{\sqrt{2\pi\omega_{ai}^2}} \right)^{n-s-1} \exp\left[\sum_{t=s+1}^{n-1} \left\{ -\frac{(a_{i,t+1} - a_{i,t})^2}{2\omega_{ai}^2} \right\} \right] \times \left(\frac{1}{\omega_{ai}^2} \right)^{\frac{\upsilon_{a_0}}{2}-1} \exp\left\{ -\frac{V_{a_0}}{2\omega_{ai}^2} \right\}$$

$$= \left(\frac{1}{\omega_{ai}^2} \right)^{\frac{\upsilon_{a_0}+n-s-1}{2}-1} \exp\left\{ -\frac{V_{a_0} + \sum_{s+1}^{n-1} (a_{i,t+1} - a_{i,t})^2}{2\omega_{ai}^2} \right\}$$

Then, the posterior distribution is obtained

$$\omega_{ai}^2 | a_i \sim IG(\hat{\upsilon}_a / 2, \hat{V}_{a_i} / 2)$$

Where $\hat{\upsilon}_a = \upsilon_{a_0} + n - s - 1, \hat{V}_{a_i} = V_{a_0} + \sum_{s+1}^{n-1} \left(a_{i,t+1} - a_{i,t}\right)^2$

6. Sample ∑h

The following prior is assumed for the i-th diagonals of ∑h

$$\omega_{hi}^2 \sim IG(\upsilon_{h_0} / 2, V_{h_0} / 2)$$

The same as sampling Σα, we can obtain the posterior distribution of ∑h

where $\omega_{hi}^2 | h_i \sim IG(\hat{\upsilon}_h / 2, \hat{V}_{h_i} / 2)$

$$\hat{\upsilon}_h = \upsilon_{h_0} + n - s - 1, \hat{V}_{h_i} = V_{h_0} + \sum_{s+1}^{n-1} \left(h_{i,t+1} - h_{i,t}\right)^2$$

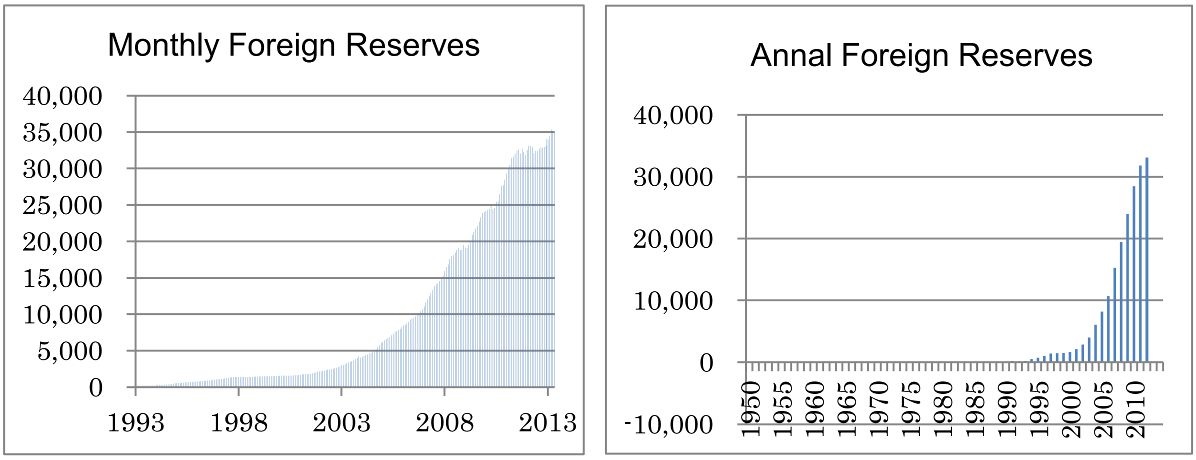
4. Sterilization, Exchange Rate Regime and Monetary Policy in China

4.1 Introduction

China has been stockpiling international reserves at an extremely rapid pace since the late1990s and has surpassed Japan to become the largest reserve holder in the world. This paper undertakes an empirical investigation to assess the extent of de facto sterilization using monthly data between December 1999 and October 2013. We find that China has not been able to successfully sterilize a large portion of these reserve increases.

China has experienced large and growing surpluses on both the capital and current accounts since 2001, while even the errors and omissions balance (a broad proxy for capital flight by residents) turned positive. Thus, reserves increased markedly during this period. An interesting dynamic appears to have taken hold in China (as well as in many other Asian economies) during this period. Large reserves are viewed as a sign that the domestic currency will eventually appreciate. They also tend to be taken as an indication of ''strong fundamentals,'' hence leading to an upgrading of the country's credit ratings. This expectation of future capital gains and lower risk perceptions motivated large-scale capital inflows and added to the country's stock of reserves as central banks have mopped up excess US dollars. As the result, China has become the world's largest foreign exchange reserve holder, having amassed almost US$ 3.5 trillion of international reserves by June of 2013.

Figure 4.1.1 Monthly and Annual Foreign Reserves of China (US $)

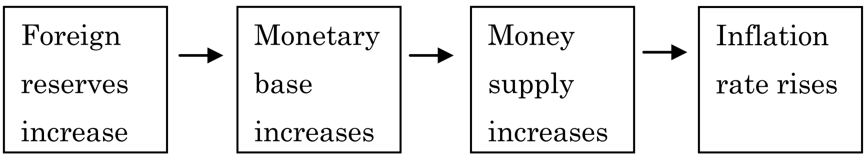


Source: The State Administration of Foreign Exchange (SAFE)

The rapid accumulation of reserves has generated several controversies. One concern is whether this continuing balance of payments surplus signals the need for a substantial revaluation or appreciation of the Chinese Yuan (CNY) to protect China both from the inflationary consequences of the liquidity buildup and a misallocation of resources as well as to help ease global economic imbalances. But in this paper, our focus is not the appreciation of CNY, but the conflict between the exchange rate regime and monetary policy in China.

Xie and Zhang (2003) suggested that there are three conflicts between monetary policy and exchange rate policy since 1994 to 2002. The first conflict is the buildup of foreign exchange reserves and high inflation from 1994 to 1996, and second one is the conflict between the rapid decline of the growth of foreign exchange reserves and the deflation pressure from 1998 to 2002, and the last one is the conflict between the exchange rate stability and the interest rate differentials between domestic and foreign currency since 1998. As for the limit of the PBC data, we will concentrate on the first conflict between buildup of foreign exchange reserves and high inflation from December 1999 to August 2013.

Figure.4.1.1 Inflation Transmission Mechanism



Aizenman and Glick (2009) indicated that there is a decline in China's degree of sterilization. According to their empirical results, the sterilization coefficients began rising from roughly 0.6 in 2000 to almost 1.5 in 2006, and then fell to 0.7, which means that China may have reached limits to the extent of its ability to sterilize its massive reserve inflows. Additionally, Ouyang, Rajan, and Willett (2010) pointed out that China has been able to successfully sterilize a large portion of these reserve increases such as Germany under the Bretton Wood system.

However, Wu (2009) stated that the monetary sterilization in China is incomplete, only 0.35 are sterilized for a yuan of foreign exchange reserve that flows into China. What is more, many Chinese researchers mentioned that PBC does not have enough monetary instruments to make sterilization effective, such as Zhang (2003).

It is still not clear, whether the degree of sterilization in China is high or not. What is more, there is no research on how the sterilization is achieved by PBC. In order to find out the answers to these questions, the PBC's balance sheet will be analyzed in this paper. Based on the balance sheet analyses, we find out there are some problem with the former researches such as the definition of the domestic credit is not accurate. It will also be settled in this paper. Additionally, we will analyze whether the change of exchange rate system in July 2005 has any effect on sterilization.

4.2 The analysis of PBC's balance sheet

From the late 1990s and early 2000s, the current account surplus leads to the large foreign reserve in China. Because of the obligatory foreign exchange-selling system, everyone has to sell the foreign exchange to PBC (People's Bank of China), which made the foreign assets of PBC keep expanding. In order to control the monetary base from increasing too fast, PBC have to resort to the sterilization policy to decrease the lending to financial corporations and sell the government bonds.

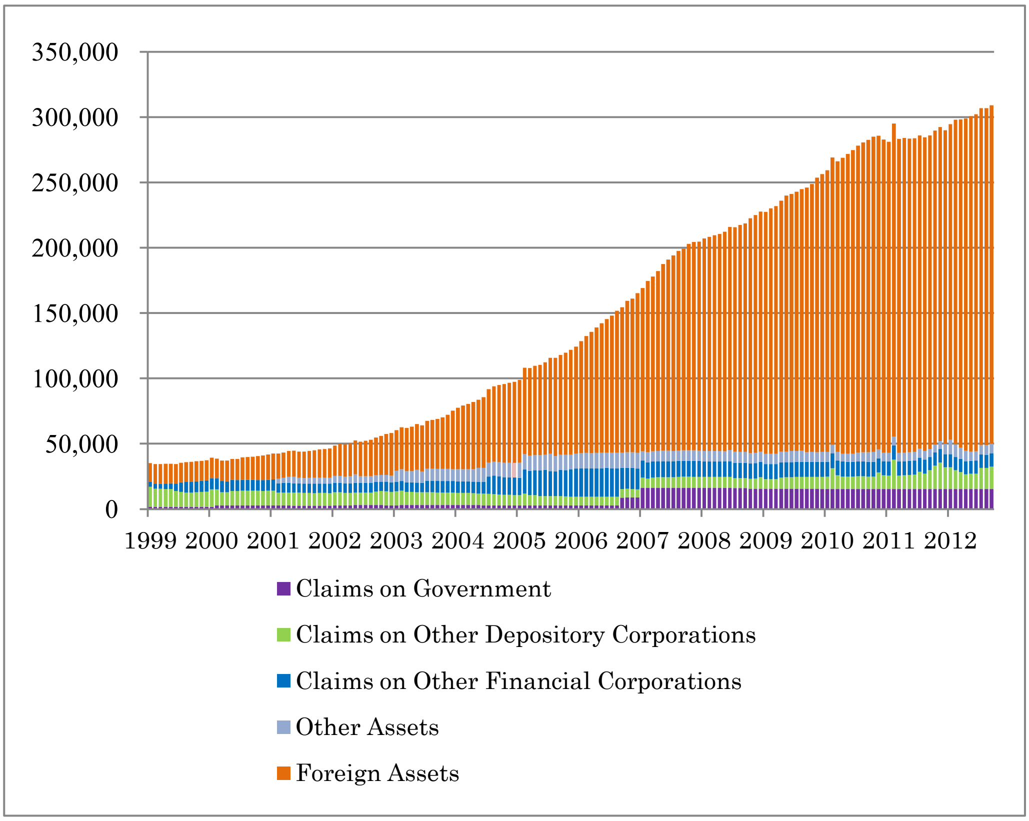
The foreign Assets accounted for 11.8% of Monetary Base in 1993, 50% in 2002, and by the end of August 2013, the Foreign Assets exceeds the Monetary Base to 25,888 billion CNY. However, the lending to financial companies occupied 75.0% of total assets in 1993, 6.3% in 2002 and 8.8% in August 2013. Similarly, the government bond made up 12.0% in total assets in 1993, 6.3% in 2002 and 5.0% in August 2013. The changes of these ratios indicate that PBC has made great efforts to decrease the lending to financial corporations and the holding of government bonds to control the expanding of monetary base.

Table 4.2.1 The Balance Sheet of People's Bank of China

Assets	**Liabilities**
Claims on Government	Monetary Base
Claims on Financial Corporations	Currency Issue
Claims on Non-financial Sectors	Bond Issue
Foreign Assets	Foreign Liabilities
Foreign Reserves	Deposits of Government
Other Assets	Others
Total Assets	**Total Liabilities**

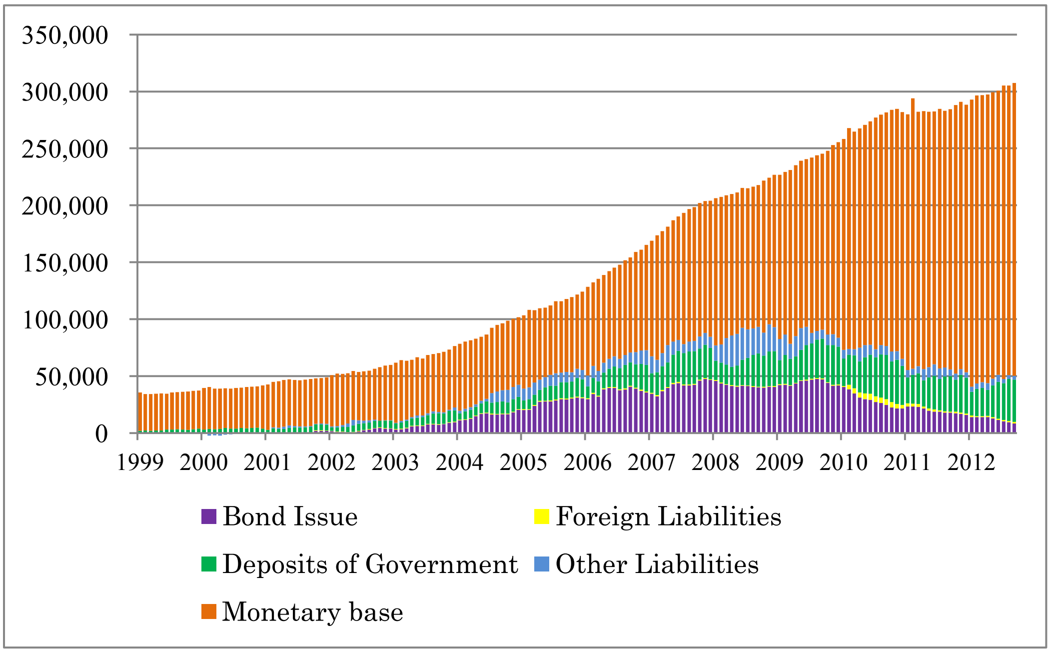
Source: The People's Bank of China network

Figure 4.2.1 The Assets of PBC (December 1999-August 2013) (95% of the foreign assets are foreign reserves) (Unit: 100 Million Yuan)



Source: The People's Bank of China network

Figure.4.2.2 The Liabilities of PBC(Unit: 100 Million Yuan)



Source: The People's Bank of China network

But because the foreign assets take up 83.8% of total assets of PBC, and the lending to financial companies and the holding of government bonds are too small to implement sterilization policy. Under this condition, a special monetary instrument central bank bill was first issued in 2002. It is called central bank bill because it is a kind of short-term bill, from 3 months to 3 years. The central bank bill is created not for raising money but for controlling the monetary base.

This new monetary instrument settled the monetary base problem to a certain extent, but there are some weaknesses of this monetary instrument. (1) Compared to reserve requirement ratio (RRR), rediscount, and window guidance, central bank bill have interest expenses. (2) As the pressure of expanding foreign exchange reserve still exists, when the central bank bill expires, the central bank has to pay principal and interest, and simultaneously issue new central bank bill or extend the former central bank bill, which makes the central bank bill amount larger and larger.

In section 4.4.3, a simple regression is provided for this point of view. The empirical result of Equation (4.4.4) suggests that when foreign reserves increase by 1%, bond issue will increase by 4% to sterilize the money supply. Then bond issue is relatively a common used tool of sterilization.

4.3 Estimating the extent of sterilization: methodological and empirical issues

Most current studies which estimate the extent of sterilization can be classified into three groups.

The first group assumes that capital flows are exogenously determined and typically estimate sterilization coefficients by running simple OLS on the monetary reaction function such as the one below:

$$\Delta NDA_t = c_0 + c_1 \Delta NFA_t + X'\beta + u_t \tag{4.3.1}$$

where △NDA and △NFA represents the change in net domestic assets (a proxy for domestic money creation) and net foreign assets (a proxy for international reserves) respectively, and X represents other explanatory variables that might influence a monetary authority's reaction. The coefficients of c_1=-1 represents full monetary sterilization, while c_1=0 implies no sterilization. For example Aizenman and Glick (2009).

The second group uses a VAR model to estimate the lagged effects of NDAs and NFAs. The standard form of a VAR model is as follows:

$$\Delta NDA_t = \alpha_{10} + \sum_{i=1}^{k} \alpha_{1i} \Delta NDA_{t-i} + \sum_{i=1}^{k} \beta_{1i} \Delta NFA_{t-i} + e_{1t} \tag{4.3.2}$$

$$\Delta NFA_t = \alpha_{20} + \sum_{i=1}^{k} \alpha_{2i} \Delta NFA_{t-i} + \sum_{i=1}^{k} \beta_{2i} \Delta NDA_{t-i} + e_{2t} \tag{4.3.3}$$

Some papers within this group include additional variables in the model such as the domestic interest rate, price level, or exchange rate (for instance, Cavoli and Rajan, 2006; Christensen, 2004; He et al., 2005; Moreno, 1996). The advantage of a VAR approach is that it allows one to trace out the time path of the various shocks on the variables contained in the VAR system (i.e. the impulse response function). If a shock from foreign assets (say an unexpected increase in foreign assets) is associated with an offsetting decrease in domestic money creation, it can be concluded that the sterilization is significant. An important limitation of the VAR approach is that it tends to treat all variables as symmetrically endogenous. As equations (3.2) and (3.3) show, a standard form of the VAR model only yields the estimated values of lagged NDAs and NFAs due to the issue of identification. Consequently, the model cannot estimate the contemporary effect of variables without restrictions.

The third group of studies estimates the contemporaneous relationship between NDAs and NFAs using a set of simultaneous equations. Although the studies in the first group ignore the simultaneous bias by assuming capital flows are exogenously determined (Kwack, 2001), it is important to note that domestic monetary conditions are affected by changes in international capital flows and foreign reserves. Concurrently, international capital flows respond to a change in domestic monetary conditions (e.g. higher domestic interest rates would, ceteris paribus, lead to greater capital inflows). Some early studies, vsuchas Argy and Kouri(1974) and Herring and Marston(1977), have suggested usinga simultaneous system to overcome the problem of simultaneity. The typical model specification for a set of simultaneous equations is:

$$\Delta NFA_t = \alpha_{10} + \alpha_{11} \Delta NDA_t + X_1' \beta_1 + u_{1t} \tag{4.3.4}$$

$$\Delta NDA_t = \alpha_{20} + \alpha_{21} \Delta NFA_t + X_2' \beta_2 + u_{2t} \tag{4.3.5}$$

where X_1 and X_2 are the vectors of controls in the balance of payment function and monetary reaction function, respectively. Eqs. (3.4) and (3.5) are the balance of payments and the monetary reaction functions, respectively. The former estimates the“offsetcoefficient”. The expected value of the offset coefficient is bound by 0 in the event of no capital mobility and -1 in the event of perfect capital mobility. The latter measures the sterilization coefficient. The expected value of the sterilization coefficient is -1 if reserve buildup is perfectly sterilized and 0 if the central bank doesnot sterilize at all. In general, the greater the degree of capital mobility, the less effective is monetary sterilization; a small offset coefficient and a large sterilization coefficient generally imply that the central bank has a fairly high degree of monetary policy independence to neutralize the impact of capital flows effectively on a sustained basis.

In the late 1980s and early 1990s, emerging market countries embraced growing financial liberalization and openness. However, by also trying to maintain some degree of both exchange rate stability and monetary independence, many of these countries experienced severe financial crises. In the aftermath of these crises, many emerging markets have adopted a policy configuration involving greater, though still managed, exchange rate flexibility, together with ongoing financial integration and some degree of domestic monetary independence. Hoarding of international reserves has become a key ingredient enhancing the stability of this new pattern. Concerns about the cost of maintaining monetary stability with this new policy mix suggest the need to support hoarding international reserves with more aggressive sterilization. Apprehensions about the opportunity costs of accumulating reserves and the fiscal and distortionary financial costs of sterilization, in turn, have raised questions about the long-run viability of this new policy mix, particularly the efficacy of sterilization.

Recent literature has analyzed various aspects of recent developments, such as the nature and extent of greater exchange rate flexibility, monetary autonomy, and financial integration by emerging market countries (e.g. Fischer, 2001; Aizenman and Lee, 2008). In this paper we focus on concerns about the extent of sterilization by estimating the marginal propensity to sterilize foreign asset accumulation over time for selected countries in Asia and Latin America.

4.4 Empirical results of OLS

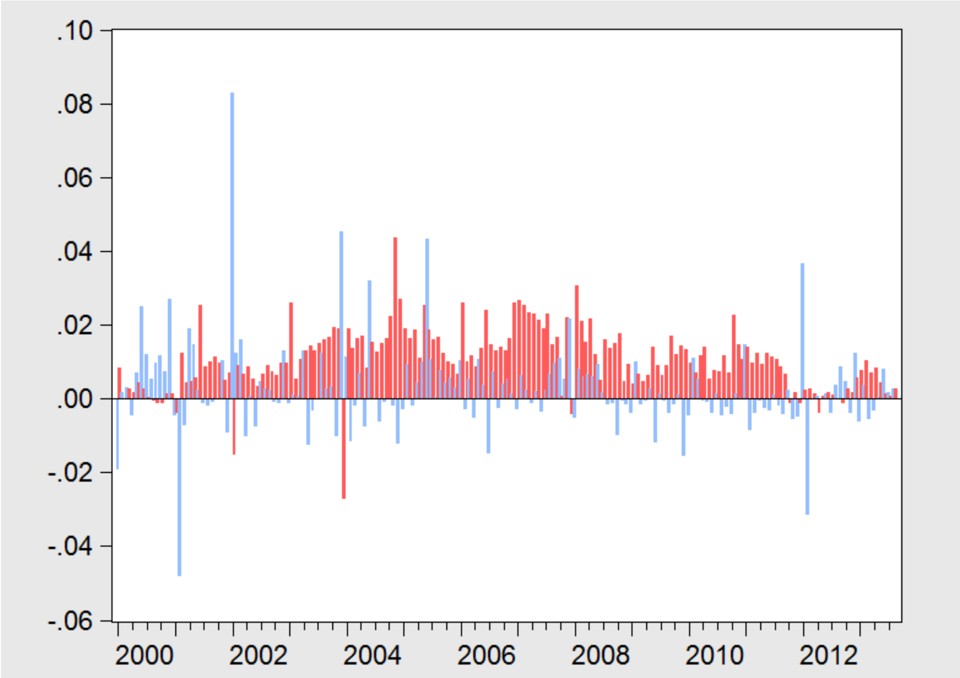
4.4.1 Simple regression

Figure 4.1 plots monthly changes in People's Bank of China foreign reserve changes (FR) and domestic credit changes (DC), each scaled by the Total Assets of PBC (TA). Foreign reserves are obtained from the balance sheet of PBC. Domestic credit (DC) is defined as the Total Assets of PBC (TA) minus foreign reserves (FR). As according to Table 2.1 and Figure 2.3, we can find out that on the liability side, besides monetary base, there are still a big amount of liabilities, that's why we use total assets minus FR as DC instead.

Positive values of foreign reserve accumulation by the central bank correspond to foreign reserve inflows. Negative values of net domestic credit correspond to reductions in domestic assets held by the monetary authorities.

We now turn to quantitatively estimating changes in the degree of sterilization. We estimate the extent of sterilization by a simple regression of the money authorities' change in domestic assets on the change in foreign assets held on its balance sheet, where the change is scaled by the level of total assets of PBC.

Figure 4.4.1 Foreign reserve and domestic credit changes of the People's Bank of China



Note: red: △FR/Total Assets, blue: △DC/Total Assets

$$\Delta DC / TA = \alpha + \beta_0 \Delta FR / TA + Z \tag{4.4.1}$$

β_0=-1 represents full monetary sterilization of reserve changes, while β_0=0 implies no sterilization. A value of the sterilization coefficient between these levels, $-1<\beta_0<0$, indicates partial sterilization.

β_0=-0.3851***

4.4.2 Formal regression

The formal regression assessed the significance of breaks in sterilization behavior.

$$\Delta DC / TA = \alpha_0 + \alpha_1 (DumBreak) + \beta_0 (\Delta FR / TA) + \beta_1 (\Delta FR / TA)(DumBreak) + \beta_2 \Delta \ln(INFL) + \beta_3 \Delta \ln(INFL)(DumBreak) \tag{4.4.2}$$

Table 4.4.1 shows the empirical results of both equation (4.4.1) and (4.4.2). The fist column of Table 4.4.1 is the regression results of equation (4.4.1) and the second column and third column are the regression results for equation (4.4.2) and the difference is the time of dummy break. In Column (4.4.2) dummy break is June 2002 and in Column (4.4.2)' dummy break is July 2006. When this two dummy was selected is because during 2001~2013, there are two big events for foreign reserves in China, which are joining WTO in December 2001 and exchange rate regime reform in July 2005. As the influence of these two events to foreign reserves take some time, we assume the time lag is one year, that's why the dummy breaks are 2002 and 2006 respectively.

In both (4.4.2) and (4.4.2)', α_1 and β_1 are statistically significant, and β_0 is bigger than β_1 in both cases, which means the sterilization coefficient is becoming smaller from 2001 to 2013. The empirical results in (4.4.2) suggest that β_1 is 1.81, the speed of the domestic credit declining become slower from China joins WTO.

Table 4.4.1 The empirical results of Equation (4.4.1) and Equation (4.4.2)

Explanatory variable	(4.4.1)	(4.4.2)	(4.4.2)'
α_1		-0.0138***	-0.0103***
β_0	-0.3851***	-2.0477***	-0.6490***
β_1		1.8112***	0.4451*
β_2		-0.0108	0.0028
β_3		0.0151**	0.0030
$H_0 : \beta_0 = -1$	0.0000	0.0028	0.0207
$H_0 : \beta_0 + \beta_1 = -1$		0.0000	0.0000
Adjusted R-squared	0.0682	0.2337	0.1511
Break date		2002M12	2006M7

Sample period	2000M1-2013M8	2001M1-2013M8	2001M1-2013M8

4.4.3 Regressions for bond issue

$$\Delta MB / TA = \alpha + \beta \times \Delta FR / TA \quad (4.4.3)$$

$$\Delta BI / TA = \alpha + \beta \times \Delta FR / TA \quad (4.4.4)$$

MB is monetary base and BI is bond issue in Equation (4.4.3) and (4.4.4). The empirical results in Table 4.4.2 indicate that if foreign reserve increases by 1%, money supply will increase 2%, while when foreign reserve increase 1%, bond issue will increase 4%.

Table 4.4.2 The empirical results of Equation (4.4.3) and Equation (4.4.4)

Equation	Equation (4.4.3)	Equation (4.4.4)
β	0.2291***	0.4085*
Adjusted R-squared	0.0168	0.1106
Sample period	2000M1-2013M8	2002M10-2013M8

4.5 Time-Varying Parameter VAR with Stochastic Volatility

A four-variable (FR, MB, M2, P) TVP-VAR model is estimated for monthly data from 2001M1 to 2013M9. FR is the foreign reserves (Source: PBC), MB is the monetary base (Source: PBC), M2 is the money supply m2 (Source: PBC and Bloomberg), and p is inflation rate (Source: NBS[27]). All of the data are year on year growth rate.

4.5.1 Model

Our model and estimation approach follows Nakajima (2011). The important feature of the model is that it allows coefficient (β), shock variances (h) and simultaneous relation of the structural shocks (α) to change over time. The lag is one.

The TVP-VAR is defined as

$$A_t y_t = F_{1t} y_{t-1} + u_t \qquad t = 1+1, \cdots, n \quad (4.5.1)$$

[27] National Bureau of Statistics of China

where y_t is the 4*1 vector of observed variables (FR_t, MB_t, $M2_t$,P_t), and A_t, F_{1t} are 4*4 matrices of coefficients. The disturbance is a 4*1 structural shock and we assume that $u_t \sim N(0, \Sigma_t \Sigma_t')$, where

$$\Sigma_t = \begin{pmatrix} \sigma_{1t} & 0 & 0 & 0 \\ 0 & \sigma_{2t} & 0 & 0 \\ 0 & 0 & \sigma_{3t} & 0 \\ 0 & 0 & 0 & \sigma_{4t} \end{pmatrix}$$

We specify the simultaneous relations of the structural shock by recursive identification, assuming that A is lower-triangular,

$$A_t = \begin{pmatrix} 1 & 0 & 0 & 0 \\ a_{21t} & 1 & 0 & 0 \\ a_{31t} & a_{32t} & 1 & 0 \\ a_{41t} & a_{42t} & a_{43t} & 1 \end{pmatrix}$$

We rewrite model (4.5.1) as the following reduced form VAR model:

$$y_t = B_{1t} y_{t-1} + A_t^{-1} \sum_t \varepsilon_t \qquad \varepsilon_t \sim N(0, I_k) \tag{4.5.2}$$

where $B_{1t} = A_t^{-1} F_{1t}$. Stacking the elements in the rows of the B_{it}'s to form $\beta((4^2 * 1) \times 1$ vector), and defining $X_t = I_k \otimes (y_{t-1}'),$ where $\otimes$ denotes the Kronecker product, the model can be written as

$$y_t = x_t \beta_t + A_t^{-1} \Sigma_t \varepsilon_t \qquad t = 1+1, \cdots, n \tag{4.5.3}$$

where the coefficients β_t and the parameters A_t and $\sum_t$ are all time varying. There are many ways to model the process for these time-varying parameters. Following Primiceri (2005), let $a_t = (a_{21t}, a_{31t}, a_{32t}, a_{41t}, a_{42t} a_{43t})'$ be a stacked vector of the lower-triangular elements in A_t, and $h_t = (h_{1t}, \cdots h_{4t})'$ with $h_{jt} = \log \sigma_{jt}^2$, for $j = 1, \cdots 4, t = 1+1, \cdots n.$ We assume that the parameter in (5.3) follows a random walk process as follows:

$$\beta_{t+1} = \beta_t + u_{\beta t}, \quad a_{t+1} = a_t + u_{at}, \quad h_{t+1} = h_t + u_{ht} \qquad (4.5.4)$$

$$\begin{pmatrix} \varepsilon_t \\ u_{\beta t} \\ u_{at} \\ u_{ht} \end{pmatrix} \sim N\left(0, \begin{pmatrix} I & 0 & 0 & 0 \\ 0 & \Sigma_\beta & 0 & 0 \\ 0 & 0 & \Sigma_a & 0 \\ 0 & 0 & 0 & \Sigma_h \end{pmatrix} \right)$$

for $t = 1+1, \cdots, n$, where $\beta_{s+1} \sim N(\mu_{\beta 0}, \Sigma_{\beta 0}), a_{s+1} \sim N(\mu_{a0}, \Sigma_{a0}), h_{s+1} \sim N(\mu_{h0}, \Sigma_{h0})$.

4.5.2 Estimation Methodology

The estimation procedure for the TVP-VAR model is illustrated by extending several parts of the algorithm for the TVP regression model. Let $y = \{y_t\}_{t=1}^n$, and $\omega = (\Sigma_\beta, \Sigma_a, \Sigma_h)$. We set the prior probability density as $\pi(\omega)$ for ω. Given the data y, we draw samples from the posterior distribution, $\pi(\beta, a, h, \omega | y)$ by the following MCMC algorithm:

(1)Initialize $\beta, a, h,$ and ω

(2)Sample $\beta | a, h, y$

(3)Sample $\Sigma_\beta | \beta$

(4)Sample $a | \beta, h, \Sigma_a, y$

(5) Sample $\Sigma_a | a$

(6) Sample $h | \beta, a, \Sigma_h, y$

(7) Sample $\Sigma_h | h$

(8) Go to (2)

The number of the VAR lags is 1, and we assume that Σ_β is a diagonal matrix for simplicity.

Some experiences indicate that this assumption is not sensitive for the results[28]. The following priors are assumed for the *i*-th diagonals of the covariance matrices:

$$\Sigma_\beta \sim IW(25,10^{-4}I), \omega_{a_i}^2 \sim IG(4,10^{-4}), \omega_{h_i}^2 \sim IG(4,10^{-4})$$

For the initial state of the time-varying parameter, rather flat priors are set $\Sigma_{\beta_0} = \Sigma_{a_0} = \Sigma_{h_0} = 10 \times I$, and $\mu_{\beta_0} = \mu_{a_0} = \mu_{h_0} = 0$. To compute the posterior estimates, we draw M=30,000 samples after the initial 3,000 samples are discarded. The details of the procedure are illustrated in Appendix A.

4.5.3 Empirical Results for TVP-VAR

As mentioned above, this section uses the TVP-VAR model to analyze the effectiveness of the Chinese monetary policy.

Table 4.5.1 and Figure 4.5.1 report the estimation results for selected parameters of the TVP-VAR model for the variable set (FR, MB, M2, P). The results show that the MCMC algorithm produces posterior draws efficiently.

Table 4.5.1: Estimating Results of Selected Parameters in the TVP-VAR Model for the Variable Set of (FR, MB, M2, P)

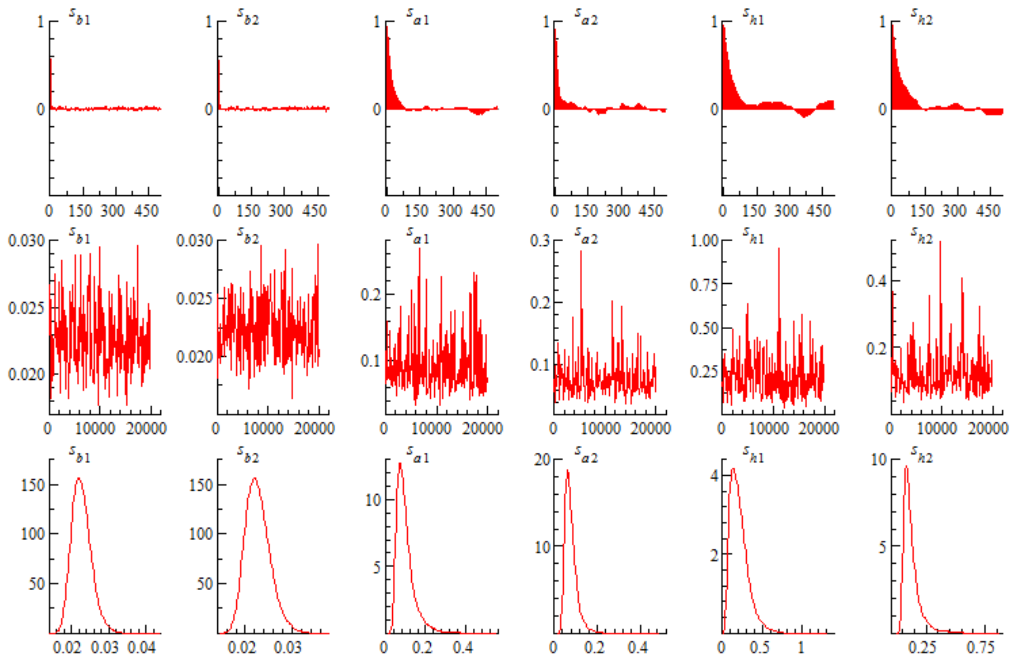
Parameter	Mean	Stdev	95%L	95%U	Geweke	Inefficiency
$(\Sigma_\beta)_1$	0.0228	0.0026	0.0184	0.0286	0.8170	2.99
$(\Sigma_\beta)_2$	0.0227	0.0026	0.0183	0.0286	0.5030	2.28
$(\Sigma_a)_1$	0.0989	0.0472	0.0448	0.2242	0.3900	38.44
$(\Sigma_a)_2$	0.0779	0.0287	0.0418	0.1492	0.8320	26.40
$(\Sigma_h)_1$	0.2136	0.1164	0.0669	0.5043	0.8000	70.39
$(\Sigma_h)_2$	0.1249	0.0765	0.0496	0.3317	0.5240	73.19

Table 4.5.1 gives the estimates for posterior means, standard deviations, and 95 percent credit intervals, the convergence diagnostics (CD) of Geweke (1992), and inefficiency factors, which

[28] Nakajima et al (2011)

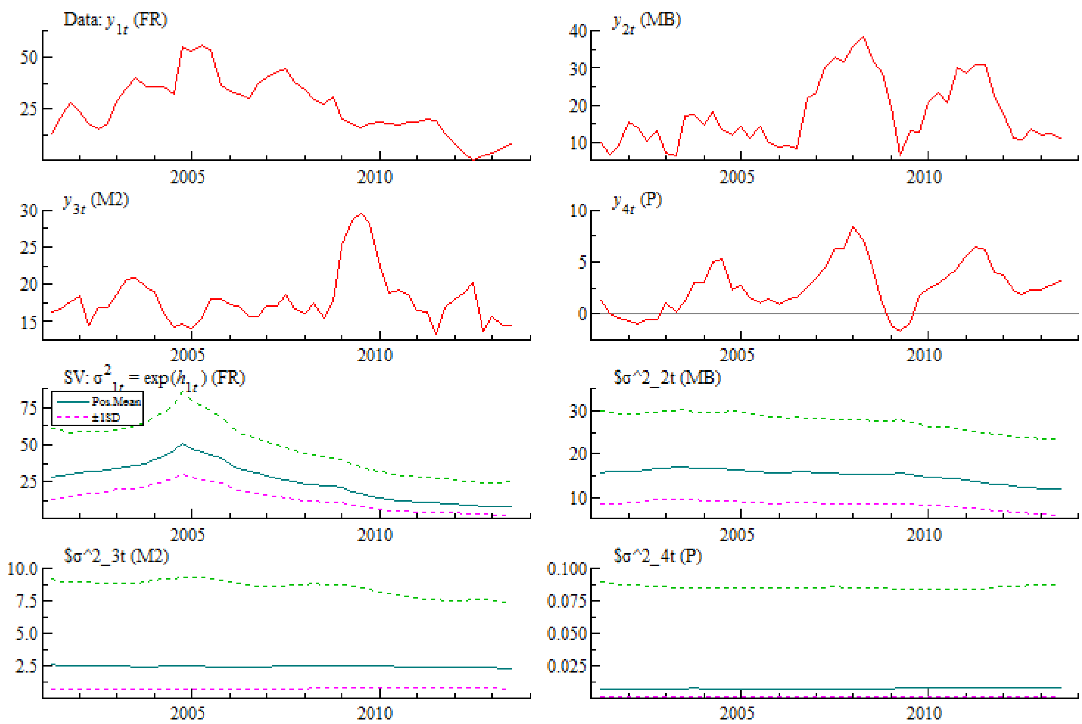
are computed using the MCMC sample. In the estimated result, the null hypothesis of the convergence to the posterior distribution is not rejected for the parameters at the 5 percent significance level based on the CD statistics (p value). And the inefficient factors are quite low, which indicated an efficient sampling for the parameters and state variables.

Figure 4.5.1: Estimation Results of Selected Parameters in the TVP-VAR Model for the Variable Set of (FR, MB, M2, P)



Note: Sample autocorrelations (top), sample paths (middle) and posterior densities (bottom).

Figure 4.5.2: Estimating Results of Selected Parameters in the TVP-VAR Model for the Variable Set of (FR, MB, M2, P) and Stochastic Volatility of the Structural Shock, $\sigma_{it} = \exp(h_{it}/2)$

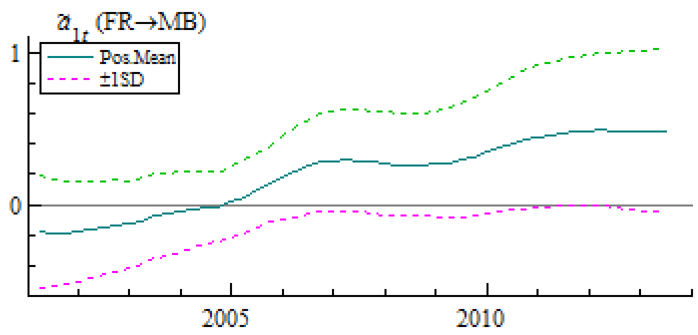


Note: Posterior mean (solid line) and 95 percent credible intervals (dotted line)

Figure 4.5.1 shows the sample autocorrelation function, the sample paths, and the posterior densities for the selected parameters. After discarding the samples in the burn-in period (initial 3,000 samples), the sample paths look stable, and the sample autocorrelations drop stably, indicating that our sampling method efficiently produce the samples with low autocorrelation.

The simulated state variables (FR, MB, M2, P) are plotted in the first two rows of Figure 4.5.2. The last two rows of Figure 4.5.2 plots the posterior estimates of stochastic volatility. Stochastic volatility of money supply (FR) is volatile during 1999 to 2008, which indicated that the Chinese money supply policy is not a stable monetary policy. Stochastic volatility of output (MB) exhibits three spikes in 2001, 2007 and 2010. Stochastic volatility of inflation (P) exhibits two spikes in 2006 and 2008, which gives a good description of the inflation-deflation situation in China.

Figure 4.5.3: Posterior Estimates for Simultaneous Relation, $\tilde{\alpha}_{it}$, for the Variable Set of (FR, MB, M2, P)



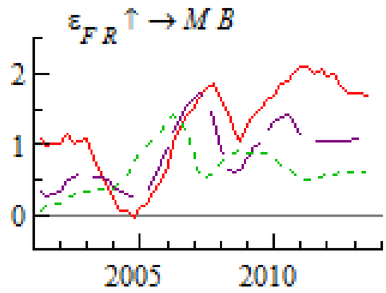
Note: Posterior mean (solid line) and 95 percent credible intervals (dotted line)

Figure 4.5.3 plots the posterior estimates of the simultaneous relation. The time-series plots consist of the posterior draws on each data. As for the simultaneous relation, which is specified by the lower triangular matrix A_t , the posterior estimates of the free elements in A_t^{-1}, denoted $\tilde{\alpha}_{it}$, are plotted. This implies the size of the simultaneous effect of other variables to one unit of the structural shock based on the recursive identification.

The time-varying simultaneous relation is one of the characteristics in the TVP-VAR model. The simultaneous relation of the monetary base to the foreign reserves shock (FR→ MB) is positive, which means foreign reserves increases monetary base in China.

The impulse response is a basic tool to see the macroeconomic dynamics captured by the estimated VAR system. For a standard SVAR model whose parameters are all time-invariant, the impulse responses are drawn for each set of two variables. By contrast, for the TVP-VAR model, the impulse responses are computed at all points in time using the estimated time-varying parameters. In this case, we have several ways to simulate the impulse responses based on the parameter estimates of the TVP-VAR model.

Figure 4.5.4: Impulse Response of TVP-VAR Models for the Variables Set of (FR, MB, M2, P)



4.6 The Influence Factor of Sterilization Coefficient

As in previous parts, we discussed the foreign reserve changes and whether it caused inflation. We discovered that the foreign reserves may be not affected by the inflation rate. Even if the inflation rate is high, PBC does not intend to reduce the foreign reserves. For example, in 2008, when the inflation rate rose to 8%, the bond issue did not increase any more (Figure 4.2.3).

In this part, we will consider the influence factor of foreign reserves whether the foreign reserves are decided by inflation rate, output growth rate and exchange rate.

We assume that within each operating period the PBC has a target for the sterilization coefficients, β_t^* (from Figure 5.3), that is based on the state of the economy. In the baseline case, we assume that the target depends on both expected inflation and output. Specifically,

$$\beta_t^* = \beta_0 + a_{cpi}\left[E\left(\pi_t|\Omega_t\right) - \pi^*\right] + a_y(E\left[y_t|\Omega_t\right] - y_t^*) \tag{4.6.1}$$

where β_0 is the constant, π_t is the realized annual inflation rate at t, y_t is real output, and π^* and y_t^* are respective bliss points for inflation and output. We assume that y_t^* is given by potential output, defined as the level that would arise if wages and prices were perfectly flexible. In addition, E is the expectation operator and Ω_t is the information available to the central bank at the time it sets interest rates.

In practice, central banks tend to maintain smoothness. This smoothing behavior is represented by Eq. (4.4.2).

$$\beta_t = (1-\rho)\beta_t^* + \rho\beta_{t-1} + \varepsilon_t \tag{4.6.2}$$

where $0 \le \rho < 1$. The case of $\rho = 0$ corresponds to the original Taylor rule without smoothing.

To obtain an estimable equation, we define $a_c \equiv \beta_0 - a_\pi \pi^*$ and $x_t \equiv y_t - y_t^*$. We then rewrite Eq. (4.4.1) as

$$\beta_t^* = a_c + a_\pi \left[E(\pi_t|\Omega_t)\right] + a_y (E[x_t|\Omega_t]) \tag{4.6.3}$$

Combining the target model (6.3) with the partial adjustment mechanism (4.6.2) yields

$$\beta_t = (1-\rho)a_c + (1-\rho)a_\pi \left[E(\pi_t|\Omega_t)\right] + (1-\rho)a_y (E[x_t|\Omega_t]) + \rho\beta_{t-1} + \varepsilon_t \tag{4.6.4}$$

Finally, we eliminate the unobserved forecast variables from the expression by rewriting the policy rule in terms of realized variables as follows:

$$\beta_t = (1-\rho)a_c + (1-\rho)a_\pi \pi_t + (1-\rho)a_y x_t + \rho\beta_{t-1} + v_t \tag{4.6.5}$$

where the error term $v_t \equiv -(1-\rho)\{a_\pi(\pi_t - E[\pi_t|\Omega_t]) + a_y(x_t - E[x_t|\Omega_t])\} + \varepsilon_t$ is a linear combination of the forecast errors of inflation and output and the exogenous disturbance ε_t.

As the exchange rate is one of the targets of PBC, the relation for the target Eq. (4.6.5) is replaced with the following, where e_t is the nominal exchange rate of CNY against US dollar at t:

$$\beta_t = (1-\rho)(a_c + a_\pi \pi_t + a_y x_t + a_e e_t) + \rho\beta_{t-1} + v_t \tag{4.6.6}$$

where the error term

$v_t \equiv -(1-\rho)\{a_{cpi}(cpi_t - E[cpi_t|\Omega_t]) + a_y(x_t - E[x_t|\Omega_t]) + a_e(e_t - E[e_t|\Omega_t])\} + \varepsilon_t$ is a linear combination of the forecast errors of inflation, output, exchange rate and the exogenous disturbance ε_t. Let u_t be a vector of variables within the central bank's information set at the time it chooses the interest rate ($u_t \in \Omega_t$) that are orthogonal to v_t. Possible elements of u_t include any lagged variables that help forecast inflation, output, exchange rate as well as any contemporaneous variables that are uncorrelated with the current interest rate shock ε_t. Then, Eq. (4.6.7) implies the following set of orthogonality conditions that we exploit for estimation:

$$E\left[\beta_t - (1-\rho)a_c - (1-\rho)a_\pi \pi_t - (1-\rho)a_y x_t - (1-\rho)a_e e_t - \rho\beta_{t-1} | u_t\right] = 0 \tag{4.6.7}$$

To estimate the parameter vector $\lfloor a_c, a_\pi, a_y, a_e, \rho \rfloor$ we use generalized method of moments (GMM)[29]. The instrument set u_t includes lagged values of output, inflation, exchange rate and foreign reserves growth rate.

If the PBC intended to control foreign reserves from increasing too fast, the coefficients in Equation (4.6.6) must meet the following condition.

$$a_\pi < 0,\ \ a_y < 0 \text{ and } a_e < 0 \qquad (4.6.8)$$

$a_\pi < 0$ means if there is inflation, the foreign reserves will be reduced to lower inflation rate. For $a_y < 0$ and $a_e < 0$, it is the same.

Table 4.6.1: The GDP growth rate target and inflation target of China (2000-2013)

	GDP growth rate target	Inflation rate target
2000	NA	NA
2001	7.0%	NA
2002	7.0%	NA
2003	7.0%	NA
2004	7.0%	NA
2005	8.0%	4.0%
2006	8.0%	3.0%
2007	8.0%	3.0%
2008	8.0%	4.8%
2009	8.0%	4.0%
2010	8.0%	3.0%
2011	8.0%	4.0%
2012	7.5%	4.0%
2013	7.5%	3.5%

Source: The annual Government Work Report of Chinese State Council
http://www.gov.cn/test/2006-02/16/content_200719.htm

Table 4.6.2 and Table 4.6.3 show the responses of sterilization coefficient to macroeconmic variables by using monthly data and quarterly respectively. In Table 4.6.2 and Table 4.6.3 all the coefficients are statistically significant, but α_y is positive, which is opposite to our hypothesis in equation (4.6.8). Meanwhile, α_π and α_e are negatively significant, which is coincident with our assumption. It tells when inflation rate is high or CNY is depreciating, PBC has tried to keep the

29 The composite disturbance term for our model has an MA(n-1) representations. In this case, the GMM estimator of the parameter vector is a two-step nonlinear two-stage least squares estimator when the model is overidentified (Clarida et al 1998).

sterilization coefficient from increasing too fast. However, when GDP growth rate is high, PBC did not control the foreign reserves but increased the foreign reserves, which showed a trend that GDP growth rate the faster, the better during the 2010s.

Table 4.6.2: The estimation of foreign reserve (2000M12-2013M9)

	a_c	a_π	a_{y1} [30]	a_{y2} [31]	a_e	ρ	R^2
Regression (1.1)	-0.0662***	-0.0016***	0.0006**		0.0061***	1.0302***	0.9961
Regression (1.2)	-0.0756***	-0.0011***		0.0003*	0.0076***	1.0363	0.9960

Note: The instruments are y_{t-1}, y_{t-2}, y_{t-3}, y_{t-4}, y_{t-5}, y_{t-6}, cpi_{t-1}, cpi_{t-2}, cpi_{t-3}, cpi_{t-4}, cpi_{t-5}, cpi_{t-6}, β_{t-1}, β_{t-2}, β_{t-3}, β_{t-4}, β_{t-5}, β_{t-6}, e_{t-1}, e_{t-2}, e_{t-3}, e_{t-4}, e_{t-5}, e_{t-6},
*** indicates that the coefficient is statistically significant at 1% level (** 5% level and *10% level)

Table 4.6.3: The estimation of foreign reserve (2000Q4-2013Q3)

	a_c	a_π	a_y [32]	a_e	ρ	R^2
Regression (2.1)	-0.0197***	-0.0050***	0.0108***		1.0273***	0.9925
Regression (2.2)	-0.0180***	-0.0051***	0.0089***	-0.0915***	1.0127***	0.9925

Note: The instruments are y_{t-1}, y_{t-2}, y_{t-3}, y_{t-4}, y_{t-5}, y_{t-6}, cpi_{t-1}, cpi_{t-2}, cpi_{t-3}, cpi_{t-4}, cpi_{t-5}, cpi_{t-6}, β_{t-1}, β_{t-2}, β_{t-3}, β_{t-4}, β_{t-5}, β_{t-6}.
*** indicates that the coefficient is statistically significant at 1% level (** 5% level and *10% level)

4.7. Conclusion

Chapter 4 indicated that the sterilization policy is inefficient. You can find this point from Figure 4.2.1 and Figure 4.2.2. Table 4.4.1 not only shows the inefficiency of sterilization policy in China, also shows that joining the WTO affected the sterilization policy much more than the exchange rate regime reform in July 2005.

In the fifth part and sixth part of this paper, by using TVP-VAR model and GMM, the empirical results demonstrates that the sterilization coefficient is affected by inflation rate and exchange rate, but not by output growth rate. PBC only adjusted sterilization coefficients when inflation rate is high and exchange rate is depreciating.

[30] Industrial Added Value
[31] Electric Generation
[32] GDP growth rate

Appendix 4: MCMC algorithm for the TVP regression Model

1. Sample β

The state space model with respect to β_t as the state variable is written as

$$y_t = X_t\beta_t + A_t^{-1}\Sigma_t\varepsilon_t \qquad \text{, t=s+1… n,}$$

$$\beta_{t+1} = \beta_t + u_{\beta t} \qquad \text{, t=s… n-1,}$$

where $\beta_s = \mu_{\beta_0}$, and $\mu_{\beta_s} \sim N(0, \Sigma_{\beta_0})$

We run the simulation smoother as follows:

$$Z_t = X_t, G_t = (A_t^{-1}\Sigma_t, 0_p)$$

$$\mathrm{T_t} = I_p, H_t = (0_k, \Sigma_\beta^{1/2}), H_s = (0_k, \Sigma_{\beta_0}^{1/2})$$

where p =k2s

2. Sample a

The state space model with respect to β_t as the state variable is written as

$$\hat{y}_t = \hat{X}_t a_t + A_t^{-1}\Sigma_t\varepsilon_t \quad \text{, t=s+1, …, n.,}$$

$$a_{t+1} = a_t + u_{at} \quad \text{, t=s,…, n-1,}$$

where $a_s = \mu_{a_0}, u_{a_s} \sim N(0, \Sigma_{a_s}), \hat{y}_t = y_t - X_t\beta_t$

$$\hat{X}_t = \begin{pmatrix} 0 & \cdots & & & & & & 0 \\ -\hat{y}_{1t} & 0 & 0 & \cdots & & & & \vdots \\ 0 & -\hat{y}_{1t} & -\hat{y}_{2t} & 0 & \cdots & & & \\ 0 & 0 & 0 & -\hat{y}_{1t} & \cdots & & & \\ \vdots & & & & \ddots & 0 & \cdots & 0 \\ 0 & \cdots & & & 0 & -\hat{y}_{1t} & \cdots & -\hat{y}_{k-1,t} \end{pmatrix} \quad \text{for t=s+1, …, n.}$$

We run simulation smoother to sample a

$$\mathrm{Z_t} = \hat{X}_t, G_t = (\Sigma_t, 0_q) \quad , \quad T_t = I_q, H_t = (0_k, \Sigma_a^{1/2}), H_s = (0_k, \Sigma_{a_0}^{1/2})$$

where q=k*(k-1)/2

3. Sample h

We assume ∑h and $\sum h_0$ are diagonal matrices.

Let y_{it}^* denote the i-th element of $A_t\hat{y}_t$, Then, we can write:

$$y_{it}^{*} = \exp(h_{it}/2)\varepsilon_{it} \quad \text{, t=s+1, …, n,}$$

$$h_{t+1} = h_t + u_{ht} \quad \text{, t=s, …, n-1,}$$

$$\begin{pmatrix} \varepsilon_{it} \\ \eta_{it} \end{pmatrix} \sim \left(0, \begin{pmatrix} 1 & 0 \\ 0 & \upsilon_i^2 \end{pmatrix}\right)$$

Where $\eta_{is} \sim N(0, \upsilon_{i_0}^2)$, and υ_i^2 and $\upsilon_{i_0}^2$ are the i-th diagonal elements of Σh and Σh0 .

4. Sample ∑β

We assume the following priors for ∑β

$$\Sigma_\beta \sim IW(\mathrm{n}_0, S_0)$$

By using Bayes' theorem,

$$\pi(\Sigma_\beta|\beta) \propto f(\beta|\Sigma_\beta)\pi(|\Sigma_\beta|)$$

$$= \prod_{t=s+1}^{n-1} |\Sigma_\beta|^{-\frac{1}{2}} \exp\left\{-\frac{1}{2}(\beta_{t+1}-\beta_t)'\Sigma_\beta^{-1}(\beta_{t+1}-\beta_t)\right\} \times |\Sigma_\beta|^{-\frac{n_0+p+1}{2}} \exp\left\{-\frac{1}{2}tr(S_0^{-1}\Sigma_\beta^{-1})\right\}$$

$$= |\Sigma_\beta|^{-\frac{\hat{n}+p+1}{2}} \exp\left\{-\frac{1}{2}tr(\hat{S}^{-1}\Sigma_\beta^{-1})\right\}$$

Then, the posterior distribution of ∑β is

$$\Sigma_\beta|\beta \sim IW(\hat{\mathrm{n}}, \hat{S})$$

Where $\hat{n} = n_0 + n - s - 1, \hat{S}^{-1} = \hat{S}_0^{-1} + \sum_{t=s+1}^{n-1}(\beta_{t+1}-\beta_t)(\beta_{t+1}-\beta_t)'$

5. Sample $\sum a$

The following prior is assumed for the i-th diagonals of $\sum a$

$$\omega_{ai}^2 \sim IG(\upsilon_{a_0}/2, V_{a_0}/2)$$

By using Bayes' theorem,

$$\pi(\omega_{ai}^2|a_i) \propto f(a_i|\omega_{ai}^2)\pi(\omega_{ai}^2)$$

$$= \left(\frac{1}{\sqrt{2\pi\omega_{ai}^2}}\right)^{n-s-1} \exp\left[\sum_{t=s+1}^{n-1}\left\{-\frac{(a_{i,t+1}-a_{i,t})^2}{2\omega_{ai}^2}\right\}\right] \times \left(\frac{1}{\omega_{ai}^2}\right)^{\frac{\upsilon_{a_0}}{2}-1} \exp\left\{-\frac{V_{a_0}}{2\omega_{ai}^2}\right\}$$

$$= \left(\frac{1}{\omega_{ai}^2}\right)^{\frac{\upsilon_{a_0}+n-s-1}{2}-1} \exp\left\{-\frac{V_{a_0} + \sum_{s+1}^{n-1}(a_{i,t+1}-a_{i,t})^2}{2\omega_{ai}^2}\right\}$$

Then, the posterior distribution is obtained

$$\omega_{ai}^2 | a_i \sim IG(\hat{\upsilon}_a / 2, \hat{V}_{a_i} / 2)$$

Where $\hat{\upsilon}_a = \upsilon_{a_0} + n - s - 1, \hat{V}_{a_i} = V_{a_0} + \sum_{s+1}^{n-1} \left(a_{i,t+1} - a_{i,t} \right)^2$

6. Sample ∑h

The following prior is assumed for the i-th diagonals of ∑h

$$\omega_{hi}^2 \sim IG(\upsilon_{h_0} / 2, V_{h_0} / 2)$$

The same as sampling ∑α , we can obtain the posterior distribution of ∑h

where $\omega_{hi}^2 | h_i \sim IG(\hat{\upsilon}_h / 2, \hat{V}_{h_i} / 2)$

$$\hat{\upsilon}_h = \upsilon_{h_0} + n - s - 1, \hat{V}_{h_i} = V_{h_0} + \sum_{s+1}^{n-1} \left(h_{i,t+1} - h_{i,t} \right)^2$$

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