Optimal Monetary Policy Rules in A Simple Stochastic Macro Model: China's Evidence

Shen Guo
Department of Economics, Concordia University

Shengzu Wang
Department of Economics, McGill University and CIREQ

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Abstract

In this paper we apply a simple macro model to explore and evaluate certain optimal monetary policy rules for China's economy. To be more consistent with the central bank (the People's Bank of China)'s behaviour, we use money supply as a monetary policy instrument rather than the commonly used interest rate. Policy rules are optimal in terms of minimizing the predetermined loss functions, and the parameters of these rules are determined by stochastic simulation. Different forms of policy rule and loss function are considered, especially for exchange rate volatility and money supply volatility. The optimality of monetary policy rules is evaluated by comparing the shifts of policy frontiers.

Key Words

Monetary Policy Rule, Loss Function, Stochastic Simulation, Policy Frontier, China

JEL classification **C15 E47 E52**

1. Introduction

The profession of monetary policy analysis in the past decade has extensively focused on modeling the central bank's behavior through monetary policy rules and their performance. Taylor (1993) proposed a simple interest rate rule to describe the behavior of the U.S. Federal Reserve between 1987 and 1992. Since Taylor's paper, there has been much interest in evaluating the optimality of these rules and the robustness of them to different macro models. The policy rule is optimal in terms of minimizing a predetermined loss function. Although the choice of the loss function is often subjective, most researchers define the loss function as a squared deviation of the target variable from its target level. If we target several macroeconomic variables instead of one, then different weight can be assigned to each target.

There are numerous studies that have considered the policy rules for different loss functions. Among these, Fair and Howrey (1996) examine monetary policy from an optimal control perspective. They assume that Federal Reserve Bank want to minimize a true loss function that targets both inflation and unemployment. Optimal values of the policy instruments (i.e. interest rate or monetary supply) are obtained by minimizing this true loss function in five different models. They also studied the effects of changing the loss function to target inflation alone, unemployment alone, nominal growth alone, and real growth alone. They mainly used the optimal control method to solve for the optimal instrument values, although they mentioned stochastic simulation method as an alternative to determine the optimal policy rules. Some recent influencing works include McCallum (1988, 1999), which suggest using multiple models to explore the robustness of policy rules, and Levin, Wieland and Williams (1999, 2003), which aim to find out the policy rules that work well across a wide range of structural models, that is, rules that are robust to model uncertainty. They find that simple policy rules that respond to the deviation of inflation from its target and the output gap perform nearly as well as more complicated rules in four models of the US. Economy. Their method is to compute the inflation-output volatility frontier of each model for alternative specification of interest rate rule, then evaluate robustness to model uncertainty by taking the rules that perform well in one model and measure their performance in each of the other three models. Among all the simple policy rules they investigated, the performance of the rules incorporating a high degree of interest rate smoothing dominate the others.

In constructing the monetary policy rules for an open economy, Ball (1999) uses a small open model to assess the role of the exchange rate in a monetary policy rule. Ball shows that adding the exchange rate to simple policy rules can improve macroeconomic performance in his model. However, it could be questioned whether this result is robust to other models. Taylor (1999), after simulating his multi-country model, finds that the rule proposed by Ball often creates more instability than the basic Taylor rule.

However, most studies on the monetary policy rules have involved models of developed countries like U.S. Few studies have been done to evaluate these types of rules in models of developing countries, such as China. This paper fills that gap by investigating the performance of several monetary policy rules in a simple model for China's economy.

Therefore, the purpose of this paper is to determine the optimal monetary policy rules for China. By conducting this analysis, we do not intend to assert that the central bank of China would have been or has been following certain monetary policy rules to minimize any loss function and stabilize the economy. In fact, even the US Fed has never admitted that its monetary policy followed any policy rules, even though its policy rules have been estimated and evaluated extensively. The point of our exercise – as of other such studies – is to see if the monetary policy actually pursued by the central bank can be captured and evaluated satisfactorily by certain policy rules and loss functions.

Before any attempt to evaluate the policy rules, the first question we need to solve is which policy instrument to use, monetary supply or interest rate? In some early studies, Poole (1970) considered the optimal choice of monetary policy instruments between interest rate and money supply in an IS-LM model. If the aim is to minimize the squared deviation of the real output from its target value, he showed that the choice of the optimal instruments depends on the variances of the error terms in the IS curve and LM curve, the covariance of the two error terms and the size of the parameters of the model. Fair (1988) used stochastic simulation and U.S. econometric model to examine the optimal choice of monetary policy instruments. His result is that U.S. Fed’s choice of using the interest rate as its instrument can be justified on the basis of Poole’s analysis.

When we try to answer this question concerning China's economy, we should consider the fact that China is still in the process of its transition from a planned economy to market economy. The central bank is learning how to stabilize the economy using market-oriented monetary policies instead of the old-fashioned direct instructions. We also should keep in mind that economic entities like individuals and firms are in the process of learning how to respond to the change of the interest rate by adjusting their consumption, saving and investment activities. Although it seems that most industrialized countries mainly use the interest rate as the policy instrument, it is still possible that an old-fashioned policy instrument like money supply (M2) could be more efficient than the popular instrument like interest rate in China, if there is a stronger relation between monetary supply and the ultimate objectives of the policy than the relation between interest rate and those objectives.

Our main objective is to find out the best policy reaction functions that minimize the loss functions of the central bank using the stochastic simulation method. We want to explore the difference between the simple form policy rules and more complicated policy rules. We also attempt to determine how the change of the central bank's loss function will affect the performance of different policy rules. Most researchers define the loss function as a weighted sum of the squared deviations of the target variables from theirs target levels. In our baseline case, we assume that central bank only targets the output gap and the inflation. Since export plays an important role in the economic growth of China, the central bank would prefer a stable exchange rate[1] and give some weight to the volatility of exchange rate in its loss function. We will examine how this extra consideration affect the performance of policy rules compared with the baseline case. Another extension of the loss function is to put the volatility of the monetary supply into consideration since we believe that a large fluctuation of money supply is not feasible and acceptable to the central bank.

Our second objective is to do a historical analysis of China central bank's monetary policy during the period of 1995 to 2003. We compare the performance of our optimal policy rule to the actual policy adopted by the central bank, and identify any difference between them.

[1] The exchange rate regime in China is considered fixed and pegging to U.S. dollar, even though it is called "Managed Float" by the monetary authority. On July 21 2005, the People's Bank of China announced a 2% appreciation of RMB with respect to U.S. dollar and promised to adjust exchange rate based on a broader basket of currencies.

Our main conclusion is that the optimal policy rule for the central bank of China is to adjust the growth rate of money supply to the lagged money supply and the deviations of the inflation, output gap, and exchange rate from their respective target levels.

The rest of the paper is organized as follows. Section 2 gives a brief introduction to the monetary policy conduct of the central bank of China. Section 3 describes the models on which our policy evaluation will be based. Also, it defines the general form of the policy rules and the loss functions of the central bank. Section 4 illustrates the procedures to find out the optimal policy by using the stochastic simulation method. Section 5 shows the estimated macro model and simulation results. Section 6 concludes with a discussion of the further extension.

2. Monetary Policy Conduct of Central Bank of China

China's reform on the transmission mechanism of monetary policy has made a dramatic progress during the last 20 years, with credit ceilings[2] eliminated, required reserves system reformed and open market operations strengthened, China's monetary policy basically finished the transition process from the direct control to the indirect market-orientated regulation.

An important symbol of the reform of the transmission mechanism is the evolution of the intermediate target of the monetary policy. During the period of planned economy, China did not define any explicit intermediate targets for monetary policy. Discretion played a significant role in the policy decision. Since 1994, the central bank of China began to adopt money supply as an intermediate target and promulgate M0 (currency in circulation), M1 (narrow money) and M2 (broad money) indicators. In the meanwhile, open market operation becomes the primary channel to control the monetary base and monetary supply. The main task of the central bank is to set an appropriate growth rate of the monetary supply so that the inflation rate is within the preferred level and the predetermined GDP growth rate can be achieved.

[2] Credit ceiling is a kind of direct instructions from the central bank that limit the loans that the commercial banks can granted to the firms.

From 1991 to 1995, China achieved an average annual GDP growth rate of 12 percent. Yet at the same time it also experienced serious inflation, with the consumer price index rising at an annual average rate of 12.9 percent, and even reaching a peak of 24.1 percent in 1994. To curb the inflation, the central bank adopted a tight monetary policy by reducing the growth rate of the money supply. The growth rate of M2 hit the peak in 1994 and dropped year by year after 1995. It fluctuated within the range of 10%-20% since 1997(see Figure 1). As the result of the tight monetary policy, the consumer price index plunged to 2.8 percent in 1997. In the meanwhile, China still maintained a 7-9 percent annual economic growth rate during the period 1997-2004. The tight monetary policy played a significant role in curtailing inflation.

Most of the developed countries used monetary supply as the policy instrument in the 1970's and 80's. Nowadays, interest rate has replaced the monetary supply and becomes the major policy instrument adopted by the central banks. However, interest rate currently has not been chosen to be the major intermediate target in China due to the fact that interest rate hardly accurately reflects the demand and supply of the funds since the interest rates are not determined by the market. Although an interest rate marketization is already on the schedule of the central bank, there is still a long way to go before we can treat the interest rate as a fully-fledged policy instrument. Nevertheless, this does not mean that the central bank totally ignore the interest rate. In 1998, in the face of the adverse impact of the Asian financial crisis, the central bank cut the interest rates for seven times to boost the domestic demand and ensure a sustainable economy growth, which indicates that the central bank of China is giving more weights to the interest rate instrument.

(Insert Figure 1 here.)

To formally justify our choice of monetary supply as the policy instrument, we perform a Granger causality test to show that the money supply growth rate has a greater impact on the GDP gap than the interest rate does. The results in table 1 evidently indicate that the money supply granger causes the GDP gap while the interest rate does not.

(Insert Table 1 here.)

Based on the history of monetary policy conduct of central bank of China and results we obtained from the causality test, we believe the money supply is still a more appropriate policy instrument for China's economy. We will use the money supply as the policy instrument in the following sections.

3. Model Description, Loss Functions and Policy Rules

3.1 The Simple Stochastic Macro Model

Since the study on the macroeconomic model of China is very limited, the model we used here to evaluate the monetary policy is highly stylized. There are only three equations in our models: the first one describes aggregate demand, the second describes aggregate supply and the third one determines the exchange rate.

(1) $y_t = \alpha m_{t\text{-}1} - \beta e_{t\text{-}1} + \varepsilon_t, \quad \varepsilon_t = \rho_1 \varepsilon_{t\text{-}1} + \mu_{1t}$

(2) $\pi_t = \delta y_{t\text{-}4} - \lambda e_{t\text{-}1} + \eta_t, \quad \eta_t = \rho_2 \eta_{t\text{-}1} + \mu_{2t}$

(3) $e_t = -\theta m_{t\text{-}1} + v_t, \quad v_t = \rho_3 v_{t\text{-}1} + \mu_{3t}$

where y_t is the output gap at time period t; $m_t = 100(M_t - M_{t\text{-}4})$, M_t is the log of the money supply, then m_t is four quarter growth rate of the money supply; e_t is the log of the real effective exchange rate(an increase of e_t means appreciation); π_t is the inflation rate at time t . We assume the error terms ε_t, η_t, v_t follow AR(1) process[3], and μ_1, μ_2, μ_3 are white noise shocks. All parameters are positive.

[3] If we estimate equation (1)-(3) using usual OLS without the consideration of AR (1) in the error terms, the DW statistics are 0.56, 0.45,0.42 respectively, which indicates a strong serial correlation in the error terms. OLS is no longer BLUE in the presence of serial correlation. Even more importantly, the usual OLS standard errors and test statistics are not valid. Hence, to solve this problem, we apply the same method as in Wooldridge (2003). A feasible GLS estimation with AR (1) errors is applied, where the DW statistics become 2.13, 1.48, 1.69,respectively. The GLS estimator turns out to be BLUE and the t statistics from the transformed equation are valid.

All these three equations can also be written in a partial difference form. For example, Equation (1) can be written as:

(1') $(y_t - \rho_1 y_{t-1}) = \alpha(m_{t-1} - \rho_1 m_{t-2}) - \beta(e_{t-1} - \rho_1 e_{t-2}) + \mu_{1t}$

Equation (1) describes the aggregate demand. The GDP gap at time t depends on the lagged growth rate of the money supply and lagged real effective exchange rate. Equation (2) is an open economy Phillips curve. The inflation rate at time t is determined by the four periods lagged GDP gap and the lagged real effective exchange rate. Equation (3) shows the link between the monetary supply and the exchange rate. The intuition here is that an increase in monetary supply will lead to depreciation.

The central bank can control the inflation through two channels: First, a monetary contraction at time period t reduces output gap at time period t+1 and thus inflation at time t+5. Second, a monetary contraction at time t also leads to an appreciation at time t+1, which helps to curb the inflation in two ways: on one hand, an appreciation reduces the cost of imported goods, thus reduces the inflation directly; on the other hand, an appreciation will lower the GDP gap, thus curbs the inflation indirectly through Phillips curve.

3.2 The Loss functions and the policy rules

"The objective of China's monetary policy is to maintain the stability of the currency value and the economic growth," quoted from 'China's Monetary Policy: Retrospect and Prospect' (2001), "Maintaining the stability of the RMB currency value means internally retaining the stability of the general price index and externally retaining the stability of RMB (Chinese Currency)'s real effective exchange rate."

This monetary policy report also indicates that the central bank of China believes a rise of less than 3 percent in the price level should be regarded as price stability. The stability of real effective exchange rate is considered as a prerequisite for a country to maintain an international balance of payments. The supply-demand relation on the foreign currency market could cause drastic fluctuations of the exchange rate. In particular, in China, a country whose foreign currency market is far from mature, permitting RMB exchange rates to fluctuate freely is detrimental to the real economy. The interference of the central bank on the foreign exchange market irons out the drastic fluctuations in the nominal exchange rates and maintains the stability of the long-term real exchange rates.

Like the central banks of most industrialized countries, the central bank of China also thinks of the stabilization of the currency value and the output as the major objectives of the monetary policy. In the meanwhile, the central bank explicitly expresses its concerns about the stabilization of the real effective exchange rate. If we define the central bank's loss function as a weighted sum of the squared deviations of the target variables from their target levels, then the loss function of central bank of China is as follows:

(4) $L = E[(y - y^*)^2] + aE[(\pi - \pi^*)^2] + bE[(e - e^*)^2] + c\mathrm{Var}(m)$

Where y is the output gap, the preferred output gap is set to be zero, that is, $y^* = 0$; π is the inflation rate, and the target level of the inflation rate $\pi^* = 3\%$; e is the yearly percentage change of the real effective exchange rate, we assume the central bank dislikes both the appreciation and the depreciation of the currency, so e^* is set to be zero. m is the growth rate of money supply. The weight on the output stabilization is normalized to 1, a, b and c are the weights the central bank gives to the stabilization of the inflation rate, the exchange rate and the policy instrument respectively. This is the most general form of the loss function. The other forms of the loss function are just special cases of this general form.

We assume the central bank's policy rule has the following form:

(5) $m_t = \gamma m_{t-1} + \delta(\pi_{t-1} - \pi^*) + \varphi y_{t-1} + \rho e_{t-1}$

The money supply m_t is determined as a linear function of the lagged money supply m_{t-1}, the deviation of the lagged four-quarter inflation rate π_{t-1} from its target level π^*, lagged output gap y_{t-1} and lagged real exchange rate e_{t-1}. The inflation target π^* is set to be 3%. Equation (5) is also called the policy reaction function. This is the most general and complicated function form. The simpler rules are just the special cases of this general form.

The optimal monetary policy rule is obtained by choosing the optimal parameters of policy reaction function so that the value of the loss function defined by equation (4) is minimized.

4. Procedures of Stochastic Simulation

Policy rules are designed to deal with the stochastic shocks to the economy. An optimal policy rule is the one that smoothes the fluctuations caused by the shocks. Within the framework of stochastic simulations, a variety of shocks are imposed on the model. These shocks are taken at random from a particular distribution and are repeatedly applied to the model. Hence the deviations of the target variables from their target levels can be calculated, which is the key step to measure the loss function of the central bank.

In our model, the error terms ε_t, η_t, v_t can be treated as the shocks which are generated via the AR(1) processes in the corresponding equations (1)-(3). The innovation terms μ_{1t}, μ_{2t}, μ_{3t} are taken from three i.i.d. normal distributions N(0, σ_i). The variance σ_i can be estimated using the residuals after the estimation of equation (1)-(3).[4]

We first give initial values to all the parameters in the policy reaction function (equation (5)) and we want to calculate the value of the loss function under this policy rule by running a stochastic simulation. At time period t, after drawing the random shocks ε_t, η_t, v_t, , the values of the y_t, π_t, e_t can be solved in the model[5], then the policy instrument m_t can be calculated if all the parameters in the equation (5) are already chosen. At time t+1, another three shocks are drawn and we can solve for all the endogenous variables and the instrument variable as we did in time period t. After repeating this procedure for all the time periods, we obtain y_t, π_t, e_t for all the t. This is merely a deterministic simulation for the given values of the error terms. We call this a 'trial'. Another trial can be made by drawing a new set of ε_t, η_t, v_t for all the time periods. Each trial will generate an estimate of the target variables for all the time period. We can do as much trials as desired. Since we runs a simulation on a 3 equations model over 36 time periods, we need to draw 3 error terms for 36 times for each trial.

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[4] The estimated variance of μ_{1t}, μ_{2t}, $\mu_{3t}$are 0.624, 1.608, 0.0004 respectively.
[5] When solving the model for the first four periods (1995:1-1995:4), we use the lagged information (1994:1-1994:4).

Let y_{it}, π_{it}, e_{it} denote respectively the value of y, π, e at time period t of ***i***th trial. Then the mean squared deviation of the target variable from their target levels can be calculated using the following formula:

$$(6) \quad \text{MSD}(y) = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{1}{T}\sum_{t=1}^{T}\left(y_{it} - y^{*}\right)^{2}\right]$$

where T denotes the number of the time periods we run the simulation, N denotes the number of the trials taken, y^* is the target level. This formula also applies to π_{it} and e_{it}.

The value of the loss function defined in equation (4) then can be measured by the weighted sum of the MSDs.

$$(7) \quad L = \text{MSD}(y) + a\,\text{MSD}(\pi) + b\,\text{MSD}(e) + c\,\text{Var}(m)$$

The above-mentioned procedures are used to calculate the value of the loss function for one set of the chosen parameters of the policy reaction function. To find out the optimal policy rule, we will keep changing the parameters of the policy rule until we reach the minimization of the loss function.[6]

5. Estimation and Simulation Results

In this section, we will apply the stochastic simulation to our estimated model to determine the optimal policy rules. Our target is to find out the parameters of the policy reaction function (equation 5) to minimize the value of the loss function of the central bank (equation 4).

Firstly, the estimation results of the simple macro model, using China's data for the sample period 1995:1-2003:4, are shown below. Parameters estimates are obtained by using a Prais-Winsten AR(1) regression. (Absolute values of t-statistics are given in parentheses.)

(1a) $y_t = 0.216m_{t-1} - 0.96e_{t-1} + \varepsilon_t$, $\varepsilon_t = 0.871\varepsilon_{t-1} + \mu_{1t}$
(2.51) (2.32)

(2a) $\pi_t = 234.036 + 1.036y_{t-4} - 50.218e_{t-1} + \eta_t$, $\eta_t = 0.703\eta_{t-1} + \mu_{2t}$
(5.05) (2.94) (4.93)

(3a) $e_t = 4.707 - 0.00756m_{t-1} + v_t$, $v_t = 0.78v_{t-1} + \mu_{3t}$
(108.77) (3.56)

As described in Section 4, after applying the stochastic simulation on our estimated model, we can calculate the variable volatilities and the loss function according to Eq. (6) and (7). Obviously, our results will depend on the choice of the *a, b* and *c*, the relative weights given to the inflation, exchange rate and the money supply volatilities[7]. Instead of listing all the results for different choices, we use a policy frontier that can trace out all the best obtainable combinations of the inflation and output volatilities in an inflation-output volatility space.

Before moving to the details, we observe huge differences between the volatilities of the output, inflation, exchange rate and money supply. Table 2 shows the historical volatilities of these four variables over the period 1995:1- 2003:4. The volatilities of the inflation and money supply dominate the value of the loss function. For example, a double of the volatility of the output only causes an increase of 4.11 in loss function while an 11.6% increase of the volatility of inflation is enough to cause the same increase in loss function. Even we give the same weight to output and inflation volatility in the loss function (i.e. a=b=1), the volatility of inflation still influences the loss function much more. In our calculation of the loss function, we use a relative volatility, which is defined as the percentage of the historical volatility. For instance, suppose the output and inflation volatilities we obtained via stochastic simulation are 3 and 30 respectively, the relative volatilities used to calculate the loss function are 0.73 (3/4.11) and 0.85(30/35.35) respectively.

(Insert Table 2 here.)

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[6] The minimization is reached by using a Broyden-Fletcher-Goldfarb-Shanno (BFGS) method. The details can be found in Greene,W.H.'s Econometric Analysis (4[th] editon), Chapter 5 .
[7] We use MSDs defined in section 4 to measure the volatilities.

5.1 Consider Only the volatility of the output and inflation in the loss function (b = 0, c = 0)

5.11 General reaction function form: $m_t = \gamma m_{t-1} + \delta(\pi_{t-1} - \pi^*) + \varphi y_{t-1} + \rho e_{t-1}$

We start by considering only the volatility of the output gap and the inflation in the loss function. Table 3 shows the parameters of the optimal policy rules and the relative volatilities of the output gap, inflation, exchange rate and money supply obtained under the optimal policy rules. The column 'loss' shows the value of the loss function under the optimal policy rules; the column 'actual loss' shows the value of the loss function calculated using the historical volatilities. If the value of 'loss' is less than the value of the 'actual loss', it indicates our optimal rule outperforms the actual policy adopted. Note that historical volatilities are normalized to one. So, a less than one value of the relative volatility indicates an improvement for that target variable, vice versa. For example, in the case of $a = 0$, MSD(y) = 0.32, MSD(π) = 1.76, which means the volatility of the output under the optimal policy rule only accounts for 32% of the historical volatility; meanwhile, the volatility of the inflation surge to 176% of the historical volatility. It is not a surprise to see this result, since we assume the central bank does not care about the inflation by assuming $a = 0$.

(Insert Table 3 here.)

When we increase the weight given to the inflation by increasing ***a***, the optimal policy tends to respond to the inflation more aggressively and react to the output gap more tenderly. The relative volatility of the inflation drops from 1.76 to 0.67; meanwhile, the relative volatility of the output increases from 0.32 to 2.03. Although all the policy rules outperform the actual policies adopted in terms of value of the loss function, however, the volatilities of the money supply exceed the historical volatilities in all cases, which indicates that the central bank actually adopted a more smooth policy with a less fluctuation of the money supply.

We also observe that a feasible range of the weight the central bank gives to the inflation is from 1 to 3. If the weight is less than 1, the inflation volatility exceeds the historical volatility; if the weight is more than 3, the output volatility surpasses the historical volatility.

5.12 Special reaction function form: not consider the exchange rate

$m_t = \gamma m_{t-1} + \delta(\pi_{t-1} - \pi^*) + \varphi y_{t-1} + \rho e_{t-1}$ ($\rho = 0$)

If the central bank does not consider the exchange rate in the policy rule, that is, ρ is set to be zero, the results are shown in table 4. We observed that the values of the loss function obtained are worse than those in the table 3. Both the volatility of output and the volatility of the inflation are larger than the corresponding values in table 3.

(Insert Table 4 here.)

Figure 2 clearly shows the impact of the consideration of the exchange rate on the performance of the policy rules. Obviously, a consideration of the exchange rate in the policy rules function improves the performance the policy rules since the policy frontier of considering the exchange rate is closer to the origin.

We also observe the policy frontiers are convex, which can be explained by the trade off between the volatility of the output and the volatility of the inflation when the central bank chooses different ***a***. When ***a*** is small, i.e., the central bank does not care about the volatility of inflation, a small sacrifice of the output can gain a large improvement in the volatility of inflation. The marginal benefit of increasing ***a*** is the reduction of the volatility of the inflation, which becomes smaller and smaller when ***a*** increases.

(Insert Figure 2 here.)

5.13 Special reaction function form: only consider the output and the inflation

$m_t = \gamma m_{t-1} + \delta(\pi_{t-1} - \pi^*) + \varphi y_{t-1} + \rho e_{t-1}$ ($\rho = 0, \gamma = 0$)

If the central bank does not consider the lagged money supply and the exchange rate in the policy rule, that is, ρ and γ are set to be zero, the results are shown in table 5. We observe that the values of the loss function obtained are much worse than those in the table 3 and table 4. None of the rules can outperform the actual rules adopted. We also observe that the omission of the lagged money supply from the reaction function affects the volatility of output more than the volatility of the inflation.

(Insert Table 5 here.)

Figure 3 clearly shows the impact of the omission of the lagged money supply on the performance of the policy rules (Compare table 5 and table 4, both of them do not consider the exchange rate so that we can see the impact of lagged money supply more clearly). Obviously, an omission of the lagged money supply from the reaction function worsen the performance of policy rules by a lot since the policy frontier of not considering the lagged money supply lies much farther away from the origin.

(Insert Figure 3 here.)

5.2 Add the volatility of the money supply into the loss function (c is not equal to 0)

$m_t = \gamma m_{t-1} + \delta(\pi_{t-1} - \pi^*) + \varphi y_{t-1} + \rho e_{t-1}$ ($c = 0.5$)

In section 5.1, we already find out several optimal policy rules which can beat the performance of the actual policy adopted in terms of both the volatility of output and volatility of inflation (see rows in bold). However, the volatilities of money supply exceed the historical volatility by a lot, which indicates that the central bank may hate the volatility of the money supply and prefer a more smooth policy.

To keep the volatility of money supply in the desirable range, we include the volatility of the money supply to the loss function. When we set the weight equal to 0.5, we observe that the volatilities of the money supply obtained are within the acceptable range, so c= 0.5 is an appropriate choice. If we give more weight (ex. c=1) to the money supply, the volatility of the money supply obtained only accounts for about half of the historical volatility.

(Insert Table 6 here.)

All the policy rules outperform the actual policies adopted in terms of value of the loss function; meanwhile, both the output volatility and the inflation volatility are less than the corresponding historical volatilities when ***a*** ranges from 1 to 2. In this range, the volatilities of the money supply are also close to the historical volatilities.

In Figure 4, we use the policy frontier shift to clearly show the impact of the constraint on the money supply on the volatility of the inflation and the output. Obviously, a constraint on the volatility of the money supply eases the fluctuation of the money supply at the cost of worsening the performance of the policy rules, but just a little.

(Insert Figure 4 here.)

5.3 Add the volatility of exchange rate into the loss function (b is not equal to zero)

$m_t = \gamma m_{t-1} + \delta(\pi_{t-1} - \pi^*) + \varphi y_{t-1} + \rho e_{t-1}$ ($b = 2$, $c = 0.5$)

In the following experiment, we assume the central bank give a large weight (c=2) to the volatility of the exchange rate in the loss function so that the volatility of the exchange rate can be reduced to approximately half of the historical level.

The results are shown in table 7. Notice that volatilities of the output are worse than the historical volatilities in all cases, which indicates a tradeoff between the volatility of the exchange rate and the volatility of the output.

(Insert Table 7 here)

In Figure 5, we use the policy frontier shift to clearly show the impact of the constraint on the exchange rate on the volatilities of the inflation and the output. Obviously, a constraint on the volatility of the exchange rate eases the fluctuation of the exchange rate at the cost of worsening the performance of the policy rules, especially to the output.

(Insert Figure 5 here.)

5.4 A Historical Analysis of China's monetary policy

Based on all the experiments we did in the previous section, the best candidates for the optimal policy rules are listed in table 8: (chosen from table 6, where both the volatilities of the money supply and exchange rate are less than the historical ones)

(Insert Table 8 here.)

Suppose the central bank gives an equal weight to the output gap and the inflation rate, i.e. $\boldsymbol{a}=1$. In figure 6,7 and 8, we plot the money supply, inflation and output gap determined by the optimal policy rule and their corresponding actual levels.

Note that the optimal yearly growth rate of money supply is between 15-20% during the period of 95.1[8]-96.4, while the actual growth rates of money supply lie between 20-30%. In the same period, the inflation rates with the optimal policy rule fall to the vicinity of target level (3%) in four quarters while the actual inflation rates drop to the vicinity of target level in 9 quarters. It seems that the optimal rule reacts to the inflation more drastically than the actual policy adopted. However, this quick restoration of the inflation to the target level comes at the cost of a 1%-2% of potential output loss.

We also observe that the optimal growth rates of the money supply return to 20-25% after the inflation rates drop to the neighborhood of the target level during the period of 97.1-2001.4, while the actual growth rates of money supply fluctuate along 15%. This relatively low money supply causes 2-3% loss of the potential output during this period. The inflation rates even drop below zero during 98.2-99.4 and 2001.4-2002.4.

Since the first quarter of 2002, the actual growth rate of the money supply increases to 18-20%, which brings the inflation back to the target level. In the meanwhile, the output gap jumps to the positive side. However, we already see the signs of overheat of the economy. The actual growth rate of money supply is higher than the optimal one by 3-4% in year

[8] The numbers after the years denote for quarters, i.e., 95.1 means the first quarter of 1995.

2003, which results in an inflation of above 3% in 2004. (The actual inflation rates in each quarter of year 2004 are 3.33, 5.22,4.1 and 2.73 respectively.)

(Insert Figure 6, 7 and 8 here.)

6 Conclusion

This paper has applied the stochastic simulation method to explore the optimal policy rules in a stylized economic model of China. We considered different forms of the policy reaction function and the loss functions. The results have been reported in the previous section. Our findings suggest that the best policy rule for the central bank of China is to adjust the growth rate of money supply to the lagged money supply and the deviations of the inflation, output gap, and exchange rate from their respective target levels.

The present results obviously highly depend on the model we used, and a model robust test can be done in the future study to see if similar results hold for other models.

We choose money supply as the policy instrument in this study because the growth rate of the money supply significantly causes the output change during the time period of 1995:1-2003:4, while the interest rate does not. However, as we mentioned in section 2, the central bank of China has already realized the importance of the interest rate as the policy instrument since 1998. We can build up a model using the interest rate as the policy instrument in the future study for the time period after 1998, but now we do not have enough samples.

Another extension is to study the asymmetric policy rules, which react to the positive deviation and the negative deviation of the target variables asymmetrically.

Appendix: Data Description

Real GDP

We choose year 1997 as the base year, i.e. the real GDP is just equal to the nominal GDP in 1997. For the other years, the quarterly real GDP is calculated using the real quarterly GDP growth rate. Then, an X-11 seasonal adjustment is applied on the real quarterly GDP data. The quarterly nominal GDP levels are obtained from IMF-IFS database 2004.

GDP gap

The GDP gap is defined as the percentage deviation of real GDP to the potential GDP.

GDP gap = [(Real GDP – Potential GDP) / Potential GDP] * 100%

The potential GDP is just the fitted value of the following regression:

$y_t = \alpha + \beta T + e$

Where y_t is the real GDP (seasonal adjusted), T is the time period, and e is the error term.

Real interest rate

We choose China Inter Bank Offered Rate (CIBOR) as a proxy of the nominal interest rate. For the period of 1993-1995, data is collected from *Report of Shanghai Inter Bank Offer Center*. For the period of 1996-2004, data is collected from *Quarterly Report of the People's Bank of China*. Both of them are annualized 7-day interest rate and a moving average is computed to obtain the quarterly data.

Real interest rate = Nominal interest rate – Inflation rate

Inflation rate

We choose the CPI as the measurement of the inflation rate. The quarterly CPIs are collected from IMF-IFS database 2004. The base of each quarter's CPI is the same quarter of last year. The inflation is then calculated as:

Inflation = [(CPI –100)/100] * 100%

Exchange rate and money supply

Real Effective Exchange Rate is collected from IMF-IFS database 2004. Note that an increase of the index indicates an appreciation of Chinese Currency RMB. M2 (M1+ quasi-money) is chosen to measure the money supply. The data is also collected from IMF-IFS database 2004.

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Table 1: Granger causality Wald tests

	chi2	df	Prob> chi2
Interest rate causes GDPgap	1.3038	2	0.5211
Money supply causes GDPgap	5.6368	2	0.0597

Note: Null hypothesis is interest rate or money supply does not granger cause GDP gap. We reject the null hypothesis that money supply does not granger cause GDP gap at 10% significance level.

Table 2: Historical volatilities

	Output	Inflation	Exchange rate	Money supply
Volatility	4.11	35.35	0.004	23.75

Table 3: $m_t = \gamma m_{t\text{-}1} + \delta(\pi_{t\text{-}1} - \pi^*) + \varphi y_{t\text{-}1} + \rho e_{t\text{-}1}$

	γ	δ	φ	ρ	MSD(y)	MSD(π)	MSD(e)	Var(m)	Loss	Actual Loss
a =0	0.91	0.14	-3.12	0.30	0.32	1.76	1.27	2.68	0.32	1
a =0.25	0.86	0.07	-2.86	0.45	0.35	1.46	1.08	2.21	0.72	1.25
a =0.5	0.83	0.02	-2.74	0.56	0.42	1.28	0.96	1.92	1.06	1.5
a =1	0.77	-0.07	-2.55	0.75	0.57	1.06	0.82	1.60	1.64	2
a =1.5	**0.72**	**-0.14**	**-2.43**	**0.90**	**0.72**	**0.95**	**0.74**	**1.46**	**2.14**	**2.5**
a =2	**0.68**	**-0.20**	**-2.35**	**1.02**	**0.84**	**0.88**	**0.70**	**1.39**	**2.59**	**3**
a =3	0.62	-0.29	-2.25	1.21	1.03	0.80	0.66	1.37	3.43	4
a =4	0.58	-0.35	-2.18	1.34	1.17	0.76	0.65	1.41	4.20	5
a =10	0.47	-0.55	-1.96	1.69	1.56	0.69	0.69	1.69	8.49	11
a =1000	0.36	-0.80	-1.70	2.00	2.03	0.67	0.84	2.34	673.9	1001

Table 4: $m_t = \gamma m_{t\text{-}1} + \delta(\pi_{t\text{-}1} - \pi^*) + \varphi y_{t\text{-}1} + \rho e_{t\text{-}1}$ (ρ = 0)

	γ	δ	φ	ρ	MSD(y)	MSD(π)	MSD(e)	Var(m)	Loss	Actual Loss
a =0	0.95	0.13	-3.10	0	0.34	1.84	1.42	3.09	0.34	1
a =0.25	0.93	0.07	-2.95	0	0.37	1.57	1.28	2.74	0.76	1.25
a =0.5	0.91	0.01	-2.83	0	0.43	1.39	1.19	2.52	1.13	1.5
a =1	0.89	-0.07	-2.64	0	0.57	1.20	1.08	2.29	1.77	2
a =1.5	0.87	-0.13	-2.53	0	0.70	1.09	1.03	2.20	2.34	2.5
a =2	0.86	-0.17	-2.47	0	0.81	1.03	1.00	2.17	2.87	3
a =3	**0.84**	**-0.23**	**-2.41**	**0**	**0.96**	**0.98**	**0.98**	**2.18**	**3.85**	**4**
a =4	0.82	-0.27	-2.40	0	1.11	0.92	0.99	2.24	4.79	5
a =10	0.76	-0.41	-2.48	0	1.52	0.85	1.08	2.67	10.05	11
a =1000	0.67	-0.62	-2.64	0	2.19	0.82	1.48	4.05	826.3	1001

Table 5: $m_t = \gamma m_{t-1} + \delta(\pi_{t-1} - \pi^*) + \varphi y_{t-1} + \rho e_{t-1}$ ($\rho = 0, \gamma = 0$)

	γ	δ	φ	ρ	MSD(y)	MSD(π)	MSD(e)	Var(m)	Loss	Actual Loss
a =0	0	0.55	-4.15	0	2.66	1.54	1.20	1.95	2.66	1
a =0.25	0	0.48	-4.11	0	2.67	1.50	1.17	1.91	3.04	1.25
a =0.5	0	0.42	-4.07	0	2.68	1.47	1.15	1.89	3.42	1.5
a =1	0	0.35	-3.99	0	2.70	1.44	1.13	1.87	4.14	2
a =1.5	0	0.29	-3.92	0	2.73	1.42	1.10	1.85	4.86	2.5
a =2	0	0.24	-3.86	0	2.76	1.40	1.09	1.84	5.56	3
a =3	0	0.16	-3.73	0	2.83	1.37	1.07	1.85	6.94	4
a =4	0	0.08	-3.61	0	2.89	1.35	1.06	1.87	8.31	5
a =10	0	-0.21	-3.17	0	3.19	1.31	1.08	2.17	16.25	11
a =1000	0	-0.60	-2.60	0	3.68	1.28	1.25	2.99	1288	1001

Table 6: Consider the volatility of the money supply in the loss function
$m_t = \gamma m_{t-1} + \delta(\pi_{t-1} - \pi^*) + \varphi y_{t-1} + \rho e_{t-1}$ ($c = 0.5$)

	γ	δ	φ	ρ	MSD(y)	MSD(π)	MSD(e)	Var(m)	Loss	Actual Loss
a =0	0.67	0.10	-2.16	1.43	0.63	1.23	0.68	1.03	1.14	1.5
a =0.25	0.65	0.07	-2.11	1.41	0.68	1.12	0.65	0.95	1.43	1.75
a =0.5	0.63	0.04	-2.07	1.40	0.74	1.05	0.62	0.89	1.70	2
a =1	**0.60**	**-0.01**	**-2.00**	**1.41**	**0.84**	**0.95**	**0.58**	**0.82**	**2.20**	**2.5**
a =1.5	**0.58**	**-0.05**	**-1.95**	**1.43**	**0.93**	**0.89**	**0.56**	**0.78**	**2.66**	**3**
a =2	**0.56**	**-0.09**	**-1.92**	**1.46**	**1.00**	**0.86**	**0.54**	**0.76**	**3.10**	**3.5**
a =3	0.53	-0.15	-1.87	1.52	1.12	0.81	0.52	0.77	3.93	4.5
a =4	0.51	-0.20	-1.84	1.57	1.21	0.78	0.51	0.80	4.72	5.5
a =10	0.44	-0.39	-1.76	1.76	1.49	0.71	0.53	1.05	9.15	11.5
a =1000	0.36	-0.80	-1.70	2.00	2.02	0.67	0.84	2.31	675.1	1001.5

Table 7: Consider the volatility of the money supply in the loss function
$m_t = \gamma m_{t-1} + \delta(\pi_{t-1} - \pi^*) + \varphi y_{t-1} + \rho e_{t-1}$ ($b = 2$, $c = 0.5$)

	γ	δ	φ	ρ	MSD(y)	MSD(π)	MSD(e)	Var(m)	Loss	Actual Loss
a =0	0.47	-0.08	-1.61	2.74	1.12	1.20	0.39	0.47	2.15	3.5
a =0.25	0.47	-0.09	-1.59	2.55	1.12	1.08	0.40	0.48	2.43	3.75
a =0.5	0.46	-0.10	-1.58	2.41	1.13	1.01	0.41	0.48	2.69	4
a =1	0.46	-0.12	-1.56	2.25	1.17	0.92	0.42	0.49	3.17	4.5
a =1.5	0.45	-0.14	-1.55	2.15	1.21	0.87	0.42	0.51	3.62	5
a =2	0.45	-0.15	-1.55	2.09	1.25	0.84	0.43	0.52	4.05	5.5
a =3	0.44	-0.19	-1.55	2.02	1.32	0.80	0.43	0.56	4.87	6.5
a =4	0.43	-0.22	-1.55	1.99	1.36	0.78	0.44	0.60	5.66	7.5
a =10	0.40	-0.35	-1.57	1.95	1.53	0.73	0.47	0.82	10.15	13.5
a =1000	0.36	-0.79	-1.69	2.01	2.02	0.67	0.83	2.28	676.8	1003.5

Table 8 Candidates for optimal policy rules

	γ	δ	φ	ρ	MSD(y)	MSD(π)	MSD(e)	Var(m)	Loss	Actual Loss
a =1	**0.60**	**-0.01**	**-2.00**	**1.41**	**0.84**	**0.95**	**0.58**	**0.82**	**2.20**	**2.5**
a =1.5	**0.58**	**-0.05**	**-1.95**	**1.43**	**0.93**	**0.89**	**0.56**	**0.78**	**2.66**	**3**
a =2	**0.56**	**-0.09**	**-1.92**	**1.46**	**1.00**	**0.86**	**0.54**	**0.76**	**3.10**	**3.5**

Figure 1.Growth rate of M2 and inflation rate for China: 1994-2004

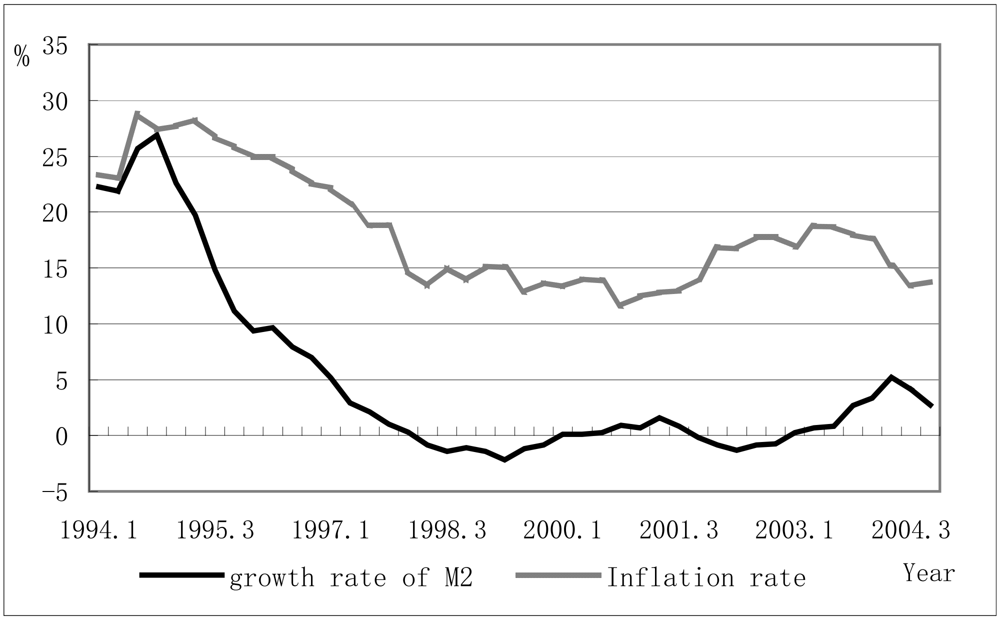

Figure 2 Policy frontier shift (consider exchange rate vs. not consider exchange rate)

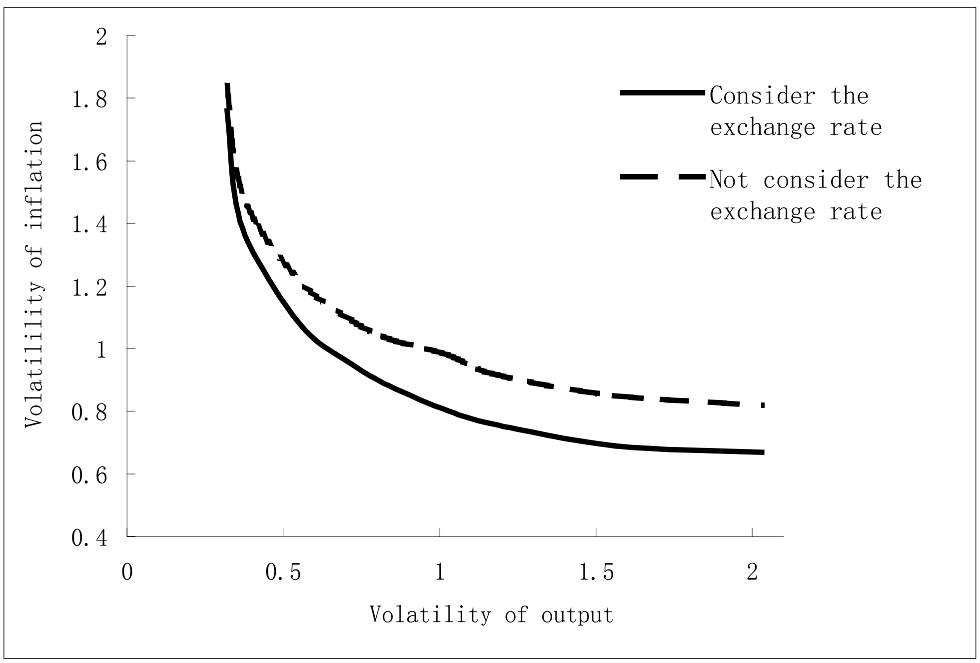

Figure 3 Policy frontier shift (consider lagged money supply vs. not consider lagged money supply)

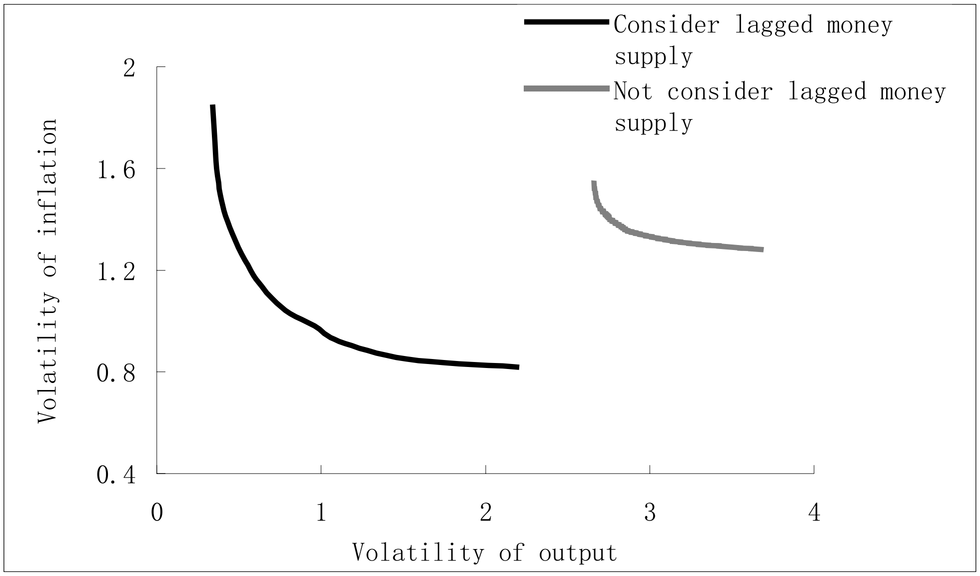

Figure 4 Policy frontier shift: with the money supply constraint vs. without the money supply constraint

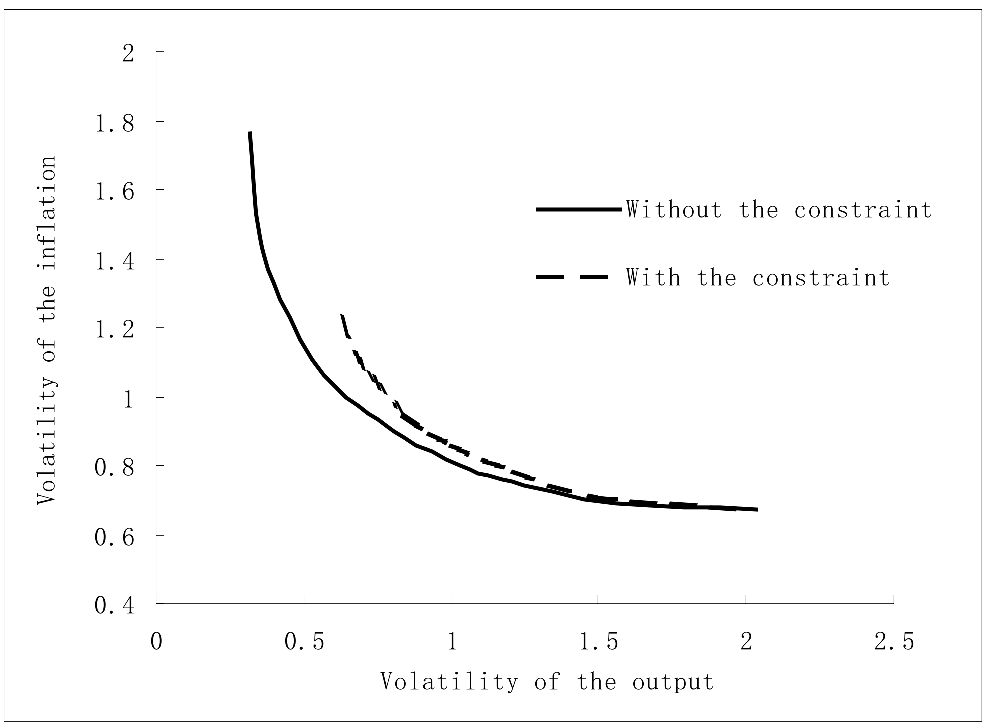

Figure 5 Policy frontier shift: with the exchange rate constraint vs. without the exchange rate constraint

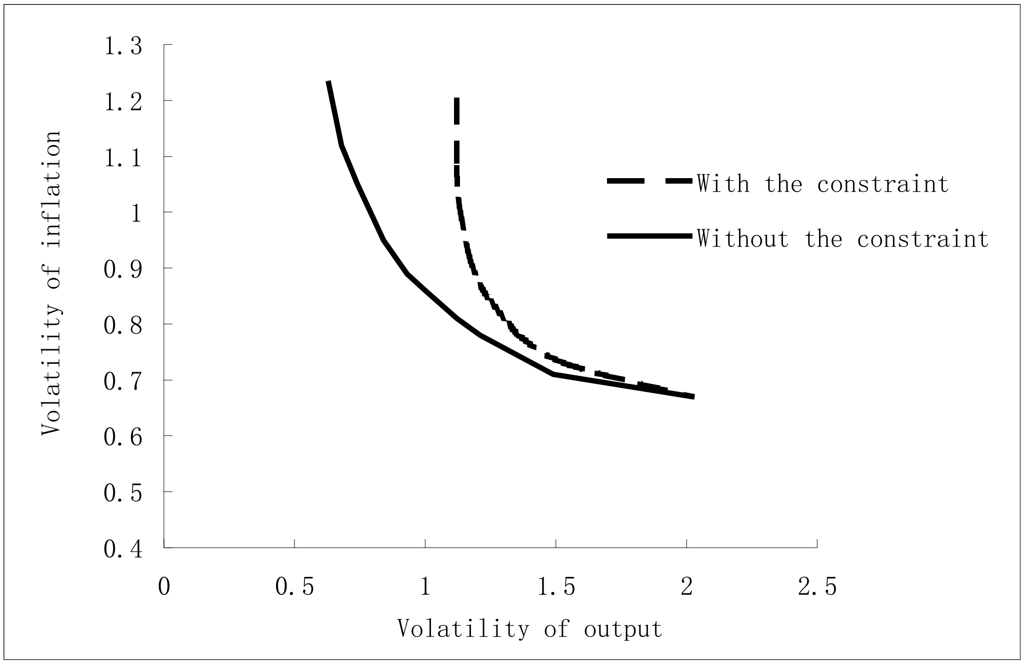

Figure 6 Optimal and actual growth rate of money supply

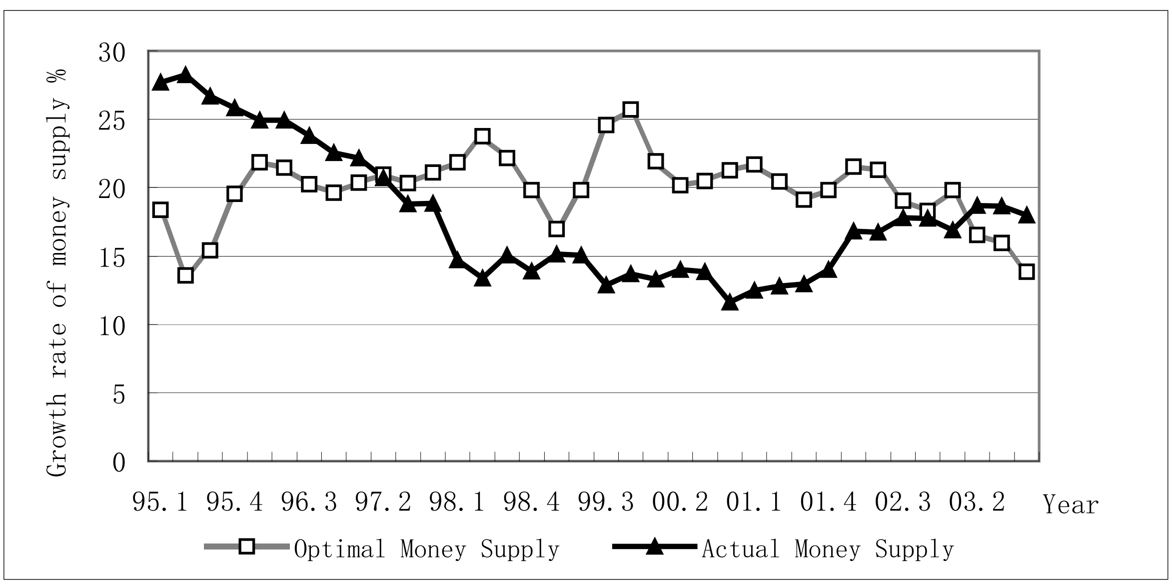

Figure 7 Optimal and actual inflation

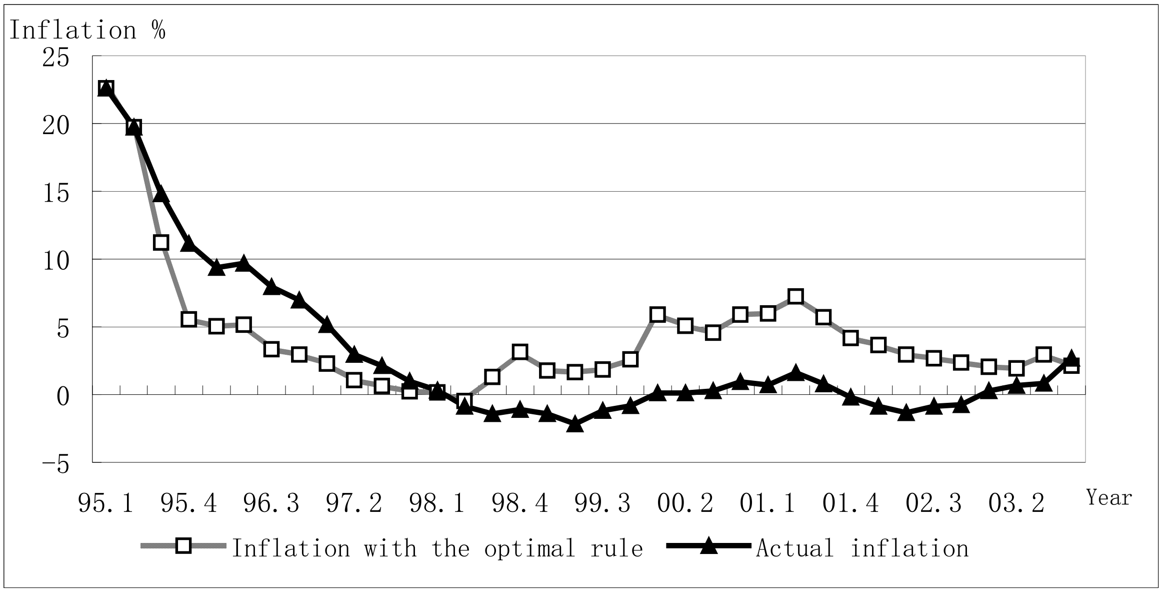

Figure 8 Optimal and actual output gap