Optimal Monetary Policy Rules in an Open Economy: Theory and Evidence

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Optimal Monetary Policy Rules in an Open Economy: Theory and Evidence

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Abstract

The main objective of this paper is to provide a theoretical and empirical framework for monetary policy rule in an open economy. Our model is an optimal but simple forward looking model. Our estimate shows that at least, the trinity of inflation gaps, the structure of the economy and the fiscal policy intervention should be used in each optimal and simple monetary policy reaction function. In this model the gap between domestic inflation and the world inflation make the reaction function appropriate for open economy. Our result especially the value of domestic inflation gap coefficient support the finding of Taylor (1993) and Calarida, Gali and Gertler (2000). Another important finding of this paper is the ability to estimate time-varying long-term interest rate. The fluctuation of the short-term interest rate around the long-term can be used as another important criterion to analyze the conduct of monetary policy.

Keywords: Monetary Policy Rule, Open Economy, Loss Function, Okun’s Law, Purchasing Power Parity.
1. Introduction

Macroeconomic equilibrium depends on both current and expected future behavior of monetary policy. Nowadays, we can see an agreement about the major goals of economic policies. These goals are: low unemployment, low inflation and high and stable growth. But as we know, there is less agreement about the compatibility of these goals especially when the authority wants to make a monetary policy decision. According to mainstream economics the most important role of monetary policy is to reduce and stabilize inflation. On the other hand, a good monetary policy is one that produces low average of inflation and keeps output and inflation as stable as possible. Inflation targeting regime which most of the central banks recently establish as a goal for monetary policy is a proof for the above mention.

However, as Sargent and Wallace (1976) argued, monetary policy should obey a rule and nowadays this prescription is widely accepted. We can divide rule in two main categories: without and with feedback. Rule without feedback is a rule like the prescription that Freidman (1948, 1968) suggested. Friedman (1968) argued: “My own prescription is still that the monetary authority go[es] all the way in avoiding such swings by adopting publicly the policy of achieving a steady rate of growth in a specified monetary total.” Rule with a feedback is a rule that have feedback from current and past variables to the money supply. Taylor (1993) argued: “the rules are responsive, calling for changes in the monetary instrument, the monetary base, or short-term interest rate in response to changes of the price level or real income”. This shows the idea about rule with feedback. Sargent and Wallace (1976) believed this feedback is the central issue that separating monetarists from Keynesians of the appropriate monetary policy. On the other hand, the discretionary conduct of policy meaning that the monetary authority is free at any time to alter its instrument.

The purpose of this study is to suggest an optimal rule in an open economy. Theoretical explanation of our model shows that the monetary rule should respond to the structure of the economy, fiscal policy intervention, the gap between current inflation and inflation goal, current inflation and the world inflation and of course three kinds of shock: demand, supply and foreign. In this study we define a monetary policy rule as a prescribed guide for conduct of monetary policy.

The rest of this study organized as follows. Next part describes the academic background. Part three present a model with two different parts. At first we describe a closed economy model. Then we develop that model for an open economy. After that and with respect to method of optimization, we also present the optimal reaction function for conduct of monetary policy as a modified Taylor’s rule. Next section describes the econometric methodology. Estimating, evaluating of monetary policy rule and calculation the long-run time-varying interest rate presented in part six. And finally, we express the conclusion remarks.

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2. This rule has been known as Friedman’s constant growth rate rule.
3. The open economy assumption impose some constraint on the effectiveness on conduct of monetary policy, which will be useful to design a monetary rule (Frenkel; 1983).
2. Academic Background:

The issue of “rule versus discretion” has also been studied in the academic theoretical literature, particularly using the techniques of optimization and game theory. But most of the researches in this area of study are theoretical, so more empirical research needed to determine the importance of rule in different kind of countries.

One of the earliest studies in this area is probably Henry Simons (1936). Simons in his classic paper “Rule versus Authorities in Monetary Policy” concluded that the monetary policy should obey definite, stable and legislative rule.

After this semantic issue, Milton Friedman advocated a long debate that monetary authority has to adapt a simple money supply rule without any feedback from current or past variables. Friedman (1948) recommended a monetary framework that should operate under the “rule of law” rather than the discretionary authority of administrators. He argued that government must provide this stable framework to eliminate the uncertainty and undesirable political implications of discretionary action. He expressed that because of the lag in policy, any discretionary action can make a large disturbance.

Friedman (1968) counts the different roles of monetary policy as a policy instrument. His belief for instance monetary policy cannot peg interest rate or unemployment rate. In this paper he introduced the concept of “natural rate of unemployment” and argued that the use of this term is to separate the real forces from monetary forces. He introduced money as an extraordinary efficient machine that historically was a major source of economic disturbance. And finally he argued that the monetary authority should avoid sharp swings in this policy, and restate rule as a best monetary action. He restated the constant growth rate rule as his own prescription for monetary policy of achieving a steady rate of growth.

In the late of 1970s the United States and most of European economies experienced high and volatile inflation. The most important puzzle of this decade was the answer to this question that why the monetary authority allowed such a high inflation? However, given the rational expectation and if we accept the long-term vertical Phillips curve, then the authorities cannot reduce the unemployment rate beyond the NAIRU in the long-term without imposing the higher inflation. So from the late of 1970s to the early of 1980s most of the academic economists tried to explain the discrepancy between the optimal and actual rate of inflation. This problem solved first by Kydland and Prescott (1977) and then by two brilliant papers by Barro and Gordon (1983a&b).

The early research on rule versus discretion focused on the intentions, capability and independence of the monetary authority, but this viewpoint was totally changed by Kydland and Prescott (1977), who pursued the rule as a commitment. On the other hand, Barro and Gordon models provide a simple but rich game theoretic framework for studying monetary policy outcomes. The equilibrium concept in the basic Barro and Gordon model is non-cooperative Nash.
After these works many studies investigate the behavior of the monetary authority especially in developed countries using simple and optimal rules with respect to inflation targeting, output gap or unemployment gap, using money supply and short run interest rate as a monetary instrument. The motivation of these studies can be fined in the seminal papers of McCallum (1988) and Taylor (1993). The most important property of these rules is that they do not require a specific economic model.

MacCallum (1988) suggested a monetarist’s rule for the conduct of monetary policy. He argued that the rule should be kept the nominal GNP close to a smooth target growth path, and examined his suggested rules in the United States for the period 1954-1985. In the other hand, a policy rule should specify of an instrument variable that the monetary authority can control directly and/or accurately. He started with this proposition that the theory and evidence both point to validity of the natural rate hypothesis, this means that money in long-term would be neutral. He proposed the following simple quarterly rule:

\[
\Delta b_t = 0.00739 - \left( \frac{1}{16} \right) \left[ (X_{t-1} - X_{t-17}) - (b_{t-1} - b_{t-17}) \right] + \lambda (X_{t-1}^* - X_{t-1})
\] (1)

where \( b \) is log of the monetary base and \( X \) and \( X^* \) are log of the nominal and target value of nominal GNP respectively. In this equation, the constant term is simply shows a 3% annual growth rate expressed in quarterly logarithmic units, the second part shows the average growth rate of base velocity and the third part is the feedback adjustment in response to deviation from GNP to its target path. \( \lambda \) shows the speed of this adjustment too. After some different specification, McCallum suggested that the policy rule such as (1) can be used as a specific rule for the conduct of monetary policy. His result expressed that monetary policy rule such that (58) would have be yielded zero inflation in the United State during the period of study.

Taylor (1993) argued that a good policy rules calling for changes in the money supply, monetary base, or short-term interest rate in response to changes in the price level or changes in real income. Rule has empirically significant advantages for policy makers because the time inconsistency demonstration that policy rules are superior to discretion. The advantage of rule over discretion is like the advantage of a cooperative over non-cooperative solution in game theory. Taylor designs the following policy rule:

\[
r = p + 0.5y + 0.5(p - 2) + 2
\] (2)

where \( r \) shows the federal fund rate (short term interest rate), and \( p \) and \( y \) are the rate of inflation and the percentage deviation of real GDP from its target, respectively. Equation (2) shows that the federal fund rate as a monetary policy instrument depend on the deviations of inflation from its optimal rate and the deviation of output from its target level. As Taylor argued if both inflation and output would be on target then the federal fund rate would equal 4 percent or 2 percent in real term.
By comparing the McCallum rule with the Taylor rule we can find that McCallum’s rule is a rule for setting the monetary base, but Taylor’s rule is a rule for setting the short-term interest rate.

However, McCallum (1993) in his comment on Taylor’s paper argue that this paper has two problems but nowadays, Taylor’s rule widely used in the most of the empirical estimation of alternative rule for monetary policy.

In recent years a series of papers published that empirically have examined the performance of the simple monetary policy rules.

Clarida, Gali and Gertler (1998), empirically characterizes the way in which the European central banks conducted monetary policy since 1979. They argue that its policy rule essentially is a forward looking version of the backward looking of the Taylor (1993). They started with this observation that the evidences show that many of the central banks used short term interest rate as the main operating instrument of monetary policy. They assume that the central banks have a target for the nominal short term interest rate based on the structure of the economy. After eliminate the unobservable forecast variables, the policy rule in terms of realized variables would be as follow:

$$r_t = (1 - \rho) (\overline{r} - \beta \pi^*) + (1 - \rho) \beta \pi_{t+n} + (1 - \rho) \gamma (y_t - y^*_t) + \rho \pi_{t-1} + \epsilon_t$$  \hspace{1cm} (3)$$

where $r$ is the policy instrument, $\overline{r}$ is the long-run equilibrium of nominal interest rate, $\pi^*$ and $y^*$ are represent the bliss points for inflation ($\pi$) and output ($y$). $\pi_{t+n}$ also shows the inflation rate between periods $t$ and $t+n$. The error term $\epsilon_t$ is a linear combination of the forecast errors of inflation and output and the exogenous disturbance of random shock to the interest rate.

In equation (3) the magnitude of the parameter $\beta$ is the key. On the other hand, the estimated magnitude of the parameter $\beta$ provides an important role for evaluating a central bank’s policy rule. If $\beta > 1$ then the target real interest rate adjusts to stabilize inflation, as well as output.

Taylor (1999) argued that the degree of inflation rate fluctuations around its target level is the key variables for evaluating the interest rate rule, but it is not the only performance measurement. Real output gap, unemployment gap and unanticipated inflation also can have a weight in the loss function. But historical analysis of rule shows the importance of interest rate response to inflation gap. Taylor in his first table gathered the recent articles that used the interest rate as the instrument in policy rule. He employed the following simple model:

$$y_t = -\beta (\pi_t - \pi^*) + u_t ; \hspace{1cm} \beta > 0$$  \hspace{1cm} (4)$$
\[ \pi_t = \pi_{t-1} + \alpha y_{t-1} + e_t; \quad \alpha > 0 \]  \hspace{1cm} (5)

\[ i_t = g_{\pi} \pi_t + g_y y_t + g_0; \]  \hspace{1cm} (6)

where \( y_t \) is the percentage deviation of real GDP from potential GDP, \( i_t \) is short-term interest rate, \( \pi_t \) is the inflation rate, and \( r \) is the long term interest rate. \( \epsilon_t \) and \( e_t \) are serially uncorrelated stochastic shocks. In equation (6) the coefficients \( g_{\pi} \), \( g_y \) and \( g_0 \) are the policy parameters. Taylor argued the long term steady inflation rate occurs where \( y = 0 \) and equal to:

\[ \pi = \frac{(g_0 - r)}{1 - g_{\pi}} \]  \hspace{1cm} (7)

This can be used as a target value for inflation, but as we can see for determine equation (7) the central bank needs to have an estimation of long term interest rate. To examine the effect of this policy rule in EMU, he added the exchange rate in his multi-country model and found:

\[ i = 1.5\pi_{EMU} + 0.5y_{EMU} - 0.25e + 0.15e(-1) \]  \hspace{1cm} (8)

As we can see in the equation (8) the response coefficient on the inflation rate is greater than one, and Taylor believes that this is the first step to have a good performance for monetary policy rule.

Clardia, Gali and Gertler (2000) analyze the conduct of monetary policy pre and post-1970 in the United States, and explore how monetary policy differed before and after Volcker. They believe that this difference is the most important source of changes in the Macroeconomic behavior. Then they present a theoretical model that shows the changes in policy rule could changes the macro performance. They employed a version of Clardia, Gali and Gertler (1998) and found the existence of a symmetric relationship between the fund rate and forecast of future inflation and output. Based on estimated monetary policy rule, they identify differences in conduct of monetary policy pre and post 1970. The most important difference can be shown in the coefficient associated with expected inflation, which is below unity (0.83) in the period of pre-Volcker and really greater than one (2.15) for the Volcker-Greenspan period. As we know interest rate rules characterized by \( \beta > 1 \) will tend to be stabilizing. With \( \beta < 1 \), a rise in anticipated inflation leads to a decline in the real interest rate. The decline in the real interest rate then stimulates aggregate demand, thus induced a rise in inflation. So the initial rise in expected inflation thus becomes self-confirmed.
Orphanides (2001) compared the real–time monetary accommodation with those obtained by \textit{ex post} revised data. He employed Taylor rule as an example. As a result of this difference, the result shows that estimation the reaction function based on the \textit{ex post} revised data instead of the data available in real time could easily overshadow the fact that forward-looking policy reaction functions appear to provide a more accurate description of policy than Taylor type contemporaneous specification. Kuttner and Posen (2004) analyzed the difficulty of using Taylor rule in zero interest rate such as Japan. Esanov, Merkl and de Souza (2005) estimate the monetary policy rule for Russia and review the recent conduct of monetary policy in this country. Gerberding, Seitz and Worms (2005) estimate the reaction function of Bundesbank and analyze the way that this bank conducts the monetary policy. Ishak-Kasim and Ahmed (2010) estimated the reaction function for short run interest rate to understand how Bank Indonesia conducts its monetary policy as part of the implication of inflation targeting.

3. Structure of the Model:

In this section we will discuss the structure of the model that we want to use in the study. In this study we present two different models. At first we mention the model in a closed economy. Then an open economy would be analyzed. In this study two classes of rules for closed and open economy will be suggested. The main assumption in these optimal rules is that the central banks have a target for short run nominal interest rate based on the structure of the economy.

3.1. Closed Economy:

The closed economy is described by three equations. Suppose that the policy maker has a single period loss function quadratic in the deviation of inflation and unemployment around a target level:

\[
L = \frac{1}{2} \lambda_i (u_i - k_i u_i^n)^2 + \frac{1}{2} \lambda_i (\pi_i - k_i \pi_i^*)^2; \quad 0 \leq k_i \leq 1 \quad \forall i \quad (9)
\]

where $\pi_i^*$ and $u_i^n$ show the long-term inflation rate and the natural rate of unemployment, respectively. The assumption is that the central bank desires to stabilize both unemployment and inflation around $k_i u_i^n$ and $k_i \pi_i^*$ respectively. This means the central bank wants to achieve to the level of inflation and unemployment goals below its long-term inflation and natural rate of unemployment. Policymakers never observe $u_i^n$ and $\pi_i^*$ directly but must infer it from observations of $u_i$ and $\pi_i$, respectively. In this loss function the monetary authority, target inflation rate defers from zero. The parameters $\lambda_i; \forall i$ show the weight that the central bank place on unemployment and inflation. The basic assumption behind this loss function is that the central bank desire to stabilize both inflation and unemployment around its goal. On the other hand because the expected value of \((9)\) involves the variance, this function will generate a special role for stabilization policy (Walsh; 2003). This function shows that the central bank has target inflation rate $k_i \pi_i^*$. It is assumed that $\pi_i$ is the choice variable for policymaker.
The second equation shows the aggregate demand in a closed economy:

\[ y_t = \alpha_1 r_t + \alpha_2 g_t + \varepsilon^D_t \quad ; \quad \alpha_1 < 0, \alpha_2 > 0 \]  \hspace{1cm} (10)

In this equation real output \( y_t \) is a function of real interest rate (monetary policy instrument), i.e. \( r_t \), and the fiscal instrument \( g_t \). \( \varepsilon^D_t \) is the white noise demand shocks.

Our model will be completed with the Okun’s law:

\[ (u_t - u^n_t) = \theta(y_t - y^p_t) + \varepsilon^S_t \quad ; \quad \theta < 0 \]  \hspace{1cm} (11)

This equation shows that the difference between the rate of unemployment and the natural rate is negatively related to the output gap.

### 3.2. Open Economy:

Because in the second part of our model we focus on an open economy, thus the forth equation that appear is the purchasing power parity. This equation helps to analysis the effect of foreign variables:

\[ e_t = \gamma_0 + \gamma_1 (\pi_t - \pi^f_t) + \varepsilon^f_t \quad ; \quad \gamma_0, \gamma_1 > 0 \]  \hspace{1cm} (12)

In this equation \( e_t \) shows the real exchange rate, \( \pi^f_t \) is the foreign inflation rate and \( \varepsilon^f_t \) is the white noise external shocks. This shock tends to be large and persistent especially in emerging countries which can be creating a policy dilemma in these countries. As Ho and McCauley (2003) argued in the emerging economies that miss their inflation target are generally the ones experiencing sharp exchange rate volatility. So exchange rate and the external shock would so important in our model. Also, in the open economy the aggregate demand equation would be changed as follow:

\[ y_t = \alpha_1 r_t + \alpha_2 g_t + \alpha_3 e_t + \varepsilon^D_t \quad ; \quad \alpha_1 < 0, \alpha_2 > 0, \alpha_3 < 0 \]  \hspace{1cm} (13)

The evidences show that many of the central banks used short term interest rate as the main operating instrument of monetary policy. So in our model, a policy rule is a rule for setting the short-term interest rate. This study wants to show such a rule leads to setting the interest rate as a relation of inflation gaps, natural rate of unemployment and the government policy behavior.

In the open economy model, we envisaged the Taylor’s monetary policy trinity for the emerging market economies, i.e. flexible exchange rate, inflation target and monetary rule.
4. Theoretical Explanation:

In this part we want to explain the theoretical interpretation of the above models. There are three noticeable key points: First, in our model the optimal policy rule can be expressed as a rule for setting short run interest rate as a function of the inflation gaps, the fiscal policy instrument and the structure of the economy. Second, monetary policy only has a short run effects on real variables. Third, in this model the supply shocks have direct effects on our policy rule.

4.1. Closed Economy:

In order to analyze how well an optimal rule performs in our closed model, at first we should obtain the interest rate policy rule. By substitute equation (10) into (11) we have:

\[ u_t = u^n_t + \theta \left[ \alpha_1 r_t + \alpha_2 g_t + \varepsilon^d_t - y_t^p \right] + \varepsilon^S_i \]

Or:

\[ u_t = u^n_t + \alpha_1 \theta r_t + \alpha_2 \theta g_t - \theta y_t^p + \left( \theta \varepsilon^d_i + \varepsilon^S_i \right) \quad (14) \]

Now for finding the reaction function of the central bank, we use the loss function i.e. equation (9). We substitute the above equation on it, thus:

\[ L = \frac{1}{2} \lambda_1 \left( u^n_t + \alpha_1 \theta r_t + \alpha_2 \theta g_t + \theta \varepsilon^d_i + \varepsilon^S_i - \theta y_t^p - k_i u^n_t \right)^2 + \frac{1}{2} \lambda_2 \left( \pi_t - k_2 \pi_t^* \right)^2 \quad (15) \]

---

4 Taylor (2000) argued that “for those emerging market economies that do not choose a policy of permanently fixing the exchange rate—perhaps through a currency board or dollarization, the only sound monetary policy is one based on the trinity of a flexible exchange, an inflation target, and a monetary rule.”

5 Taylor (2000) mentioned velocity uncertainty as ruling in favor of the interest rate instrument.

6 There are two different inflation gaps in this paper: First \( \pi_t - \pi_t^f \), and Second \( \pi_t - k_2 \pi_t^* \).

7 We can measure this as the ratio of government deficit (or Expenditure) to GDP.

8 Natural rate of unemployment and potential output are the measures.

The above equation involves two variables \( \pi \) and \( r \), i.e. \( L = L(\pi, r) \). Taking partial derivatives and setting equal to zero \( \frac{\partial L}{\partial r} = 0 \) gives:

---
\[ \lambda_1 \left[ (1-k_1)u_t^n + \alpha_1 \theta \pi_t + \alpha_2 \theta g_t - \theta y_t^p + \theta \epsilon_t^d + \epsilon_t^S \right] + \alpha_1 \theta + \lambda_2 \left( \pi_t - k_2 \pi_t^* \right) \alpha_1 \beta \theta = 0 \quad (16) \]

By rewriting the above equation for \( \tilde{r}_t \), we would have:

\[ \tilde{r}_t = \frac{1}{\alpha_1} y_t^p + \frac{(k_1-1)}{\alpha_1 \theta} u_t^n - \frac{\alpha_2}{\alpha_1} g_t - \frac{\lambda_2}{\lambda_1} \frac{\beta}{\alpha_1 \theta} \left( \pi_t - k_2 \pi_t^* \right) \left( \frac{1}{\alpha_1} \epsilon_t^d + \frac{1}{\theta} \epsilon_t^S \right) \quad (17) \]

In the above equation, \( \frac{\lambda_2}{\lambda_1} \) ratio shows the social trade-off between inflation and unemployment rate. For simplicity we can write:

\[ \tilde{r}_t = \Phi_1 y_t^p + \Phi_2 u_t^n + \Phi_3 g_t + \Phi_4 \left( \pi_t - k_2 \pi_t^* \right) + \zeta_t^r \quad (18) \]

where:

\[ \Phi_1 = \frac{1}{\alpha_1} \]

\[ \Phi_2 = \frac{(k_1-1)}{\alpha_1 \theta} \]

\[ \Phi_3 = -\frac{\alpha_2}{\alpha_1} \]

\[ \Phi_4 = -\frac{\lambda_2}{\lambda_1} \frac{\beta}{\theta \alpha_1 (1 + \alpha_3 \beta \gamma_1)} \]

and \( \zeta_t = \left( \frac{1}{\alpha_1} \epsilon_t^d + \frac{1}{\theta} \epsilon_t^S \right) \). Equation (18) shows that the monetary policy rule (reaction function) depends on the structure of the economy, fiscal policy instrument, and the inflation gap. Equation (18) is the modify version of the Taylor’s rule that obtained from social objective function optimization. The sign of the coefficients are as follow:

\[ ^9 \text{For solving } \frac{\partial L}{\partial r_t} = 0, \text{ we need to have } \frac{\partial \pi_t}{\partial r_t}. \text{ So we use the expected-augmented Phillips curve as follow:} \]

\[ \pi_t = \sigma \pi_t^e + \beta \left( u_t - u_t^n \right) \quad \beta < 0 \]

\[ \Phi_1 < 0 \quad \Phi_2 < 0 \]

\[ \Phi_3 > 0 \quad \Phi_4 > 0 \]

By rewriting the above equation for \( \tilde{r}_t \), we would have:

\[ \tilde{r}_t = \frac{1}{\alpha_1} y_t^p + \frac{(k_1-1)}{\alpha_1 \theta} u_t^n - \frac{\alpha_2}{\alpha_1} g_t - \frac{\lambda_2}{\lambda_1} \frac{\beta}{\alpha_1 \theta} \left( \pi_t - k_2 \pi_t^* \right) \left( \frac{1}{\alpha_1} \epsilon_t^d + \frac{1}{\theta} \epsilon_t^S \right) \quad (17) \]
Now we obtain the optimal inflation from equation (15):

$$\frac{\partial L}{\partial \pi_i} = \lambda_2 (\pi_i^\sigma - k_2 \pi_i^\sigma) = 0$$

Thus the optimal inflation rate would be:

$$\pi_i^\sigma = k_2 \pi_i^\sigma$$  \hspace{1cm} (19)

This means in the closed economy the optimal inflation rate would be equal to the target of the central bank. On the other hand, the expected inflation \(E_{t-1}(\pi_i) = \pi_i^e\) is:

$$\pi_i^e = k_2 \pi_i^\sigma$$  \hspace{1cm} (20)

This equation expressed, if the central bank’s target would be different from the long-run inflation then \(\pi_i^e \neq \pi_i^\sigma\). On the other hand the public expectation of inflation is equal the target of the central bank, not to the long run inflation rate\(^1\).

4.2. Open Economy:

Like the closed economy, in this part we want to have a theoretical explanation of optimal monetary policy rule for an open economy. Due to this fact that the short term interest rate is the main instrument for monetary authority, we obtain the reaction function in open economy model. So at first by substituting equation (12) into (13) we have:

\[
y_i = \alpha_i r_t + \alpha_2 g_t + \alpha_3 \left[ y_0 + y_1 (\pi_t - \pi_t^f) + \epsilon_i^f \right] + \epsilon_i^d\]

Or:

\[
y_i = \alpha_i r_t + \alpha_2 g_t + \alpha_3 y_0 + \alpha_3 y_1 (\pi_t - \pi_t^f) + \alpha_3 \epsilon_i^f + \epsilon_i^d\]

\hspace{1cm} (21)

\(^1\) We should mention that \(\pi_i^e = \pi_i^\sigma\) indicates that the inflation shocks are zero in the equilibrium. So if the inflation target’s monetary authority would be different from the long run inflation, then the inflation shock will be happened in the equilibrium.

Now if we rewrite equation (11) as \(u_i = u_i^n + \theta (y_i - y_i^p) + \epsilon_i^S\) and substitute on equation (21), it we can be obtained:

\[
u_i = u_i^n + \theta \left[ \alpha_i r_t + \alpha_2 g_t + \alpha_3 y_0 + \alpha_3 y_1 (\pi_t - \pi_t^f) + \alpha_3 \epsilon_i^f + \epsilon_i^d - y_i^p \right] + \epsilon_i^S\]
Or:

$$u_i = u_i'' + \alpha_1 \theta_i + \alpha_2 \theta_s + \alpha_3 \theta_0 + \alpha_3 \theta_1 (\pi_i - \pi_i^f) + \alpha_3 \theta e_i^f + \theta e_i^d - \theta y_i^p + \varepsilon_i$$  \hspace{1cm} (22)$$

Now for finding the reaction function of the central bank, we use the loss function i.e. equation (9). We substitute the above equation on it, thus:

$$L = \frac{1}{2} \lambda_1 [(1 - k_1)u_i'' + \alpha_1 \theta_i + \alpha_2 \theta_s + \alpha_3 \theta_0 + \alpha_3 \theta_1 (\pi_i - \pi_i^f) + (\alpha_3 \theta e_i^f + \theta e_i^d + \varepsilon_i^s) - \theta y_i^p]$$

$$+ \frac{1}{2} \lambda_2 (\pi_i - k_2 \pi_i^*)^2 \hspace{1cm} (23)$$

The above equation involves two variables \(\pi\) and \(r\). Taking partial derivatives and setting to zero gives:

$$\frac{\partial L}{\partial r_i} = \lambda_1 [(1 - k_1)u_i'' + \alpha_1 \theta_i + \alpha_2 \theta_s + \alpha_3 \theta_0 + \alpha_3 \theta_1 (\pi_i - \pi_i^f) + (\alpha_3 \theta e_i^f + \theta e_i^d + \varepsilon_i^s) - \theta y_i^p]$$

$$+ \lambda_2 (\pi_i - k_2 \pi_i^*) \frac{\partial \pi_i}{\partial r_i} = 0 \hspace{1cm} (24)$$

$$\frac{\partial L}{\partial \pi_i} = \lambda_1 [(1 - k_1)u_i'' + \alpha_1 \theta_i + \alpha_2 \theta_s + \alpha_3 \theta_0 + \alpha_3 \theta_1 (\pi_i - \pi_i^f) + \alpha_3 \theta e_i^f + \theta e_i^d + \varepsilon_i^s - \theta y_i^p]$$

$$\alpha_3 \theta_1 + \lambda_2 (\pi_i - k_2 \pi_i^*) = 0 \hspace{1cm} (25)$$

At first we solve equation (24) to find \(\tilde{r}_i\), we need to find \(\frac{\partial \pi_i}{\partial r_i}\). For calculating this derivative we know that:

$$\frac{\partial \pi_i}{\partial r_i} = \alpha_1 \beta \theta < 0 \hspace{1cm} (26)$$

So:
\[
\lambda_1 \left[ (1-k_1)u_t^n + \alpha_1 \theta \gamma_t + \alpha_2 g_t + \alpha_3 \theta \gamma_t + \alpha_3 \theta \gamma_t (\pi_t - \pi_t') - \theta \gamma_t p + (\alpha_3 \theta e_t^f + \theta e_t^d + \epsilon_t^s) \right] \\
(\alpha_1 \theta + \alpha_2 \beta \theta^2 \gamma_t^2) + \lambda_2 \alpha_1 \beta \theta (\pi_t - k_2 \pi_t^*) = 0
\]

By rewriting the above equation for \( \tilde{r}_t \), we would have:

\[
\tilde{r}_t = -\frac{\alpha_3}{\alpha_1} \gamma_0 \frac{1}{\alpha_1} y_t^p + \frac{(k_1-1)}{\alpha_1} u_t^n - \frac{\alpha_2}{\alpha_1} g_t - \frac{\alpha_3}{\alpha_1} \gamma_1 (\pi_t - \pi_t') - \left( \frac{\alpha_3}{\alpha_1} e_t^f + \frac{1}{\alpha_1} e_t^d + \frac{1}{\alpha_1} \theta e_t^s \right) \\
- \frac{\lambda_2}{\lambda_1} \frac{\beta}{\alpha_1 \theta (1 + \alpha_3 \beta \theta \gamma_t^1)} (\pi_t - k_2 \pi_t^*)
\]

(27)

As we mentioned in the above equation, \( \frac{\lambda_2}{\lambda_1} \) ratio shows the social trade-off between inflation and unemployment too. For simplicity we can write:

\[
\tilde{r}_t = \Gamma_0 + \Gamma_1 y_t^p + \Gamma_2 u_t^n + \Gamma_3 g_t + \Gamma_4 (\pi_t - \pi_t') + \Gamma_5 (\pi_t - k_2 \pi_t^*) + \xi_t^r
\]

where:

\[
\Gamma_0 = -\frac{\alpha_3}{\alpha_1} \gamma_0 \\
\Gamma_1 = \frac{1}{\alpha_1} \\
\Gamma_2 = \frac{(k_1-1)}{\alpha_1 \theta} \\
\Gamma_3 = -\frac{\alpha_2}{\alpha_1} \\
\Gamma_4 = -\frac{\alpha_3}{\alpha_1} \gamma_1 \\
\Gamma_5 = -\frac{\lambda_2}{\lambda_1} \frac{\beta}{\alpha_1 \theta (1 + \alpha_3 \beta \theta \gamma_t^1)}
\]

and \( \xi_t^r = -\frac{1}{\alpha_1} \left( \frac{\alpha_3}{\alpha_1} e_t^f + e_t^d + \frac{1}{\theta} e_t^s \right) \). Equation (28) specifies that the policy rule should respond on the structure of the economy, fiscal policy instrument, and the inflation gaps. This equation is a modify version of Taylor’s rule that obtained from social objective function optimization. Noteworthy, in the simple monetary policy rule, i.e. non-optimal rule, it should response directly to the ultimate goal variables, namely inflation and output stability. The sign of the coefficients are as follow:
As we can see the only conditional sign is belong to $\Gamma_5$. We mentioned in previous chapter that interest rate rules characterized by $\Gamma_5 > 1$ and this will tend to be stabilizing. This condition would be happened if $1 + \alpha_3 \beta \gamma_1 > 0$ and of course $\frac{\lambda_2}{\lambda_1} > -\frac{\alpha_1 \theta (1 + \alpha_3 \beta \gamma_1)}{\beta}$. However, if $\alpha_1 \theta (1 + \alpha_3 \beta \gamma_1) > |\beta|$ then $\frac{\lambda_2}{\lambda_1} > 1$, this means that the central bank should put more attention on inflation rather than other variables ($\lambda_2 > \lambda_1$). On the other hand, more attention on unemployment or other goals induces the economy in inflation and the economic fluctuation would be worse.

Now we solve equation (25) to find the optimal inflation rate. By rewriting this equation for $\tilde{\pi}_t$, we would have:

$$
\tilde{\pi}_t = \frac{\lambda_1^2 \alpha_3 \theta^2 (k_1 - 1)}{\lambda_2 + \lambda_1 (\alpha_3 \theta)^2} u_n^t - \frac{\alpha_1 \alpha_3 (\lambda_1 \theta)^2 \gamma_1}{\lambda_2 + \lambda_1 (\alpha_3 \theta)^2} r_i^t - \frac{\alpha_2 \alpha_3 (\lambda_1 \theta)^2 \gamma_1}{\lambda_2 + \lambda_1 (\alpha_3 \theta)^2} g_t^v
$$

$$
- \frac{\gamma_0 (\alpha_1 \theta \lambda_1)^2 \gamma_1}{\lambda_2 + \lambda_1 (\alpha_3 \theta)^2} \gamma_1^f + \frac{(\alpha_3 \theta \lambda_1)^2 \gamma_1}{\lambda_2 + \lambda_1 (\alpha_3 \theta)^2} \pi_i^f + \frac{\lambda_2 k_2}{\lambda_2 + \lambda_1 (\alpha_3 \theta)^2} \pi_i^s
$$

$$
+ \frac{\lambda_1^2 \alpha_3 \theta^2}{\lambda_2 + \lambda_1 (\alpha_3 \theta)^2} \gamma_1^p - \frac{\lambda_1 \gamma_1 \alpha_3 \theta}{\lambda_2 + \lambda_1 (\alpha_3 \theta)^2} \left( \alpha_3 \theta e_i^f + \theta e_i^d + e_i^s \right)
$$

For simplicity we can write:

$$
\tilde{\pi}_t = \Psi_0 + \Psi_1 u_n^t + \Psi_2 r_i^t + \Psi_3 g_t^v + \Psi_4 \pi_i^f + \Psi_5 \pi_i^s + \Psi_6 \gamma_i^p + \zeta_i^\pi
$$

where:

* Explanation of the optimization is in the appendix.
\[\Psi_0 = -\frac{\gamma_0^2 \alpha_3 \theta \lambda_1}{\lambda_2 + \lambda_1 (\alpha_3 \theta \gamma_1)^2}\]
\[\Psi_1 = \frac{\lambda_2^2 \alpha_3 \theta \gamma_1 (k_1 - 1)}{\lambda_2 + \lambda_1 (\alpha_3 \theta \gamma_1)^2}\]
\[\Psi_2 = -\frac{\alpha_2 \alpha_3 \lambda_1^2 \gamma_1}{\lambda_2 + \lambda_1 (\alpha_3 \theta \gamma_1)^2}\]
\[\Psi_3 = -\frac{\alpha_2 \alpha_3 \lambda_1^2 \gamma_1}{\lambda_2 + \lambda_1 (\alpha_3 \theta \gamma_1)^2}\]
\[\Psi_4 = \frac{\lambda_1 (\alpha_3 \theta \lambda_1^2 \gamma_1)}{\lambda_2 + \lambda_1 (\alpha_3 \theta \gamma_1)^2}\]
\[\Psi_5 = \frac{\lambda_2 k_2}{\lambda_2 + \lambda_1 (\alpha_3 \theta \gamma_1)^2}\]
\[\Psi_6 = \frac{\lambda_1 (\alpha_3 \theta \gamma_1)^2}{\lambda_2 + \lambda_1 (\alpha_3 \theta \gamma_1)^2}\]

\[\zeta_t^r = -\frac{\lambda_1 \gamma_1 \alpha_3 \theta}{\lambda_2 + \lambda_1 (\alpha_3 \theta \gamma_1)^2} (\alpha_3 \theta e_t^f + \theta e_t^o + \epsilon_t^s)\]

The sign of the coefficient in equation (92) are as follow:

\[\Psi_0 < 0\]
\[\Psi_2 < 0\]
\[\Psi_4 > 0\]
\[\Psi_6 > 0\]
\[\Psi_1 < 0\]
\[\Psi_3 > 0\]
\[\Psi_5 > 0\]

As we know, \(\pi_t^e = E_{t-1}(\pi_t)\), which shows the private sector’s expected inflation rate. Now we can use equation (30) to calculate the expected inflation rate, thus:

\[\pi_t^e = \Psi_0 + \Psi_1 E_{t-1}(u_t^u) + \Psi_2 E_{t-1}(r_t) + \Psi_3 E_{t-1}(g_t) + \Psi_4 E_{t-1}(\pi_t^f) + \Psi_5^* (k_2 \pi_t^*) + \Psi_6^* (y_t^p)\]

(31)

where \(\Psi_5^* = k_2 \Psi_5^*\) and as we know \(k_2 \pi_t^*\) is the inflation target of the central bank.
Obviously, $u^n_t$ and $y^p_t$ are both the stochastic variables and they show the structure of the economy. These two variables are on its probability density function, respectively. $E_{t-1}(\pi^f_t)$ shows the expected value of the world inflation rate. On the other hand, it shows the private sectors’ expected world inflation. $E_{t-1}(g_t)$ and $E_{t-1}(r_t)$ indicates the future fiscal and monetary policies that expected the government and the central bank will set.

It is clear that the expected inflation depend on the expected world inflation, the prediction of changes in the structure of the economy, and the fiscal and monetary policies that the private sector predicts to be happened.

5. Empirical Results:

In this part we want to estimate and report the optimal monetary policy reaction function defined by equations (18) and (28). In this part we accomplish two main objectives. First, we identify the conduct of monetary policy in the period of our study. We did it by estimating the monetary policy rule in both closed and open model. Second, we estimate the time varying long run interest rate in both open and closed model and compare our result to each other.

The data that we used are quarterly time series, and the period is 1990:1-2009:4. We used the KPSS for checking the unit root and the GMM estimator for estimating the monetary policy rule. In this study the short run interest rate used as the policy instrument. The instrument set includes lags of short run interest rate, potential output, inflation gaps, as well as the same amount of lags of velocity of money, GDP price inflation, growth rate, real exchange rate, growth of M2, and the spread between the long term and short term interest rate. We used the HP filter to find the potential output and long-run inflation rate. Four lags of instrument were used.

5.1. The US Monetary Policy Rule Estimations:

As we discuss the procedure that is used to test the existence of a unit root is KPSS test for null of stationary. Table 1 shows this test statistic.
Table 1: KPSS Stationary Test

<table>
<thead>
<tr>
<th>Series in level</th>
<th>HPGDP</th>
<th>BDY</th>
<th>INFDGAP</th>
<th>INFFGAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPSS test statistics</td>
<td>1.241383</td>
<td>0.340672</td>
<td>0.045353</td>
<td>0.669609</td>
</tr>
<tr>
<td>Series in differences</td>
<td>HPGDP</td>
<td>ΔINFFGAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KPSS test statistics</td>
<td>0.392746</td>
<td>0.072480</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The critical value at 5% significance level is 0.463. So we can see that the variables BDY (the ratio of budget deficit to GDP) and INFDGAP (domestic inflation gap) are stationary at level and the variables HPGDP (potential GDP) and INFFGAP (Foreign inflation gap) are stationary at first difference.

Table 2 and 3 report the closed and open GMM estimates of the monetary policy rules in the United States of America, respectively. As Clarida et al (2000), our estimation are based on the specification of short run interest rate with two lags in closed economy model and three lags in open economy model, which seemed to be sufficient to eliminate any serial correlation in the error term. All of the coefficient have expected sign and statistically significant.

Table2: Estimate of the closed economy model

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Coefficient</th>
<th>t-statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.9422 93</td>
<td>2.66</td>
<td>0.0096</td>
</tr>
<tr>
<td>$\Phi_1$</td>
<td>-0.000195</td>
<td>-1.73</td>
<td>0.0880</td>
</tr>
<tr>
<td>$\Phi_3$</td>
<td>29.45778</td>
<td>1.83</td>
<td>0.0710</td>
</tr>
<tr>
<td>$\Phi_4$</td>
<td>1.524515</td>
<td>2.04</td>
<td>0.0442</td>
</tr>
<tr>
<td></td>
<td>0.546822</td>
<td>4.48</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

As we can see all coefficients have the expected sign. The most important estimated coefficient is the coefficient associated with the inflation gap (coefficient $\beta$ in the Taylor’s rule model). The amount of this coefficient is 1.52 that is really near the amount that Taylor proposed. This means the interest rate
rules in this period of study would be stabilized. The positive relation between the coefficient of government intervention and policy rule shows the positive intervention of fiscal policy should affect the policy rule and the increase the interest rate. The relation between potential output and the policy rate is negative as we expected in our model.

The coefficient of the foreign inflation gap shows a negative relationship between interest rate and this gap. The amount of this coefficient is less than one.

**Table 3: Estimate of the closed economy model**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Coefficient</th>
<th>t-statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma_0$</td>
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<td>8.742</td>
<td>0.0000</td>
</tr>
<tr>
<td>$\Gamma_1$</td>
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<td>-2.936</td>
<td>0.0045</td>
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<td>$\Gamma_3$</td>
<td>44.16922</td>
<td>7.313</td>
<td>0.0000</td>
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<tr>
<td>$\Gamma_4$</td>
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<td>0.2521</td>
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<td>$\Gamma_5$</td>
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<td>3.590</td>
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</tr>
<tr>
<td></td>
<td>0.383857</td>
<td>5.183</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

As a primary result, this paper strongly suggested that the trinity of inflation gaps, the structure of the economy, and the fiscal policy intervention should be used in each optimum and simple rule for monetary policy.

As Taylor (1993) argued if both inflation and output would be on target then the federal fund rate would equal 4 percent or 2 percent in real term. This means the long run interest rate in Taylor’s rule is always constant. But in this paper the second important finding is the ability of estimating time varying long-run interest rate.

Figure 1 and table 3 reports the estimated long run interest rate in both closed and open economy, and compare the interest rate in these two models to each other. As we can see in the both models the long run interest rate decreasing over the time, and are in the least amount in the 2009:Q4.
The fluctuation of short run interest rate around the long run can be shown the conduct of monetary policy in the United State of America during this period of time. Besides, the third part of the figure 1 shows that, the estimated long run interest rate of the open model in the most of the time is greater than the closed model and the gap increase after the recent world crisis.

Fig. 1: Estimated long run interest rate in the open and closed model in the USA

i. Comparing short run and long run interest rate in the closed model

![Graph comparing short run and long run interest rate in the closed model](image)

ii. Comparing short run and long run interest rate in the open model

![Graph comparing short run and long run interest rate in the open model](image)

iii. Comparing long run interest rate in the open and closed model

![Graph comparing long run interest rate in the open and closed model](image)
Table 4: Estimated long-run interest rates in the open versus closed economy

<table>
<thead>
<tr>
<th>Year / Quarter</th>
<th>Closed Economy Model</th>
<th>Open Economy Model</th>
</tr>
</thead>
<tbody>
<tr>
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<td>r.Short</td>
<td>r.Long</td>
</tr>
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<tr>
<td>1990Q2</td>
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<td>1990Q3</td>
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<td>Open Economy Model</td>
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<td>---------------</td>
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</table>

Table 4: Estimated long-run interest rates in the open versus closed economy
1. Summary and Conclusion Remarks:

Recent years we have seen an important convergence among academic and central bankers general framework around conducting of monetary policy. In this paper we have provided a theoretical and empirical characterization of the systematic of monetary policy rule. We tested our model for the United State of America. Our model is an optimal but simple forward looking monetary policy reaction function.

Our estimate precise that at least the trinity of inflation gaps, the structure of the economy (concluded in the natural rate hypothesis), and the fiscal policy intervention are the variables that the central bank should be used in each optimum and simple rules for monetary policy. The results also show that the proposed model can be used as a benchmark for analyzing the monetary policy. The results also

<table>
<thead>
<tr>
<th>Year</th>
<th>Inflation Gap 1</th>
<th>Inflation Gap 2</th>
<th>Inflation Gap 3</th>
<th>Interest Rate 1</th>
<th>Interest Rate 2</th>
<th>Interest Rate 3</th>
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show that, short run interest rate, especially in the period of study, can be a very good policy tools for conducting the monetary policy.

Openness complicates the monetary policy rule to extend the central bank must take into account the impact of the rest of the word on real activity and inflation. The results suggested the gap between domestic inflation and the world inflation can be a very good variable in the reaction function for monetary policy in an open economy. Comparative the results of the United States of America—as a closed economy— and the East Asian economies—as open economies— show that the degree of openness is a very important index to determine how aggressively the central bank should adjust the policy rate i.e. short run interest rate, in response to inflation gaps.

In this model the government intervention, measure by the ratio of budget deficit to GDP, has an important role to determine the short run interest rate.

Our results, especially the value of the domestic inflation gap, support the finding of Taylor (1993) and Calarida, Gali and Gertler (2000). The result also shows that in the period of the study the United State of America has a stable monetary policy rule, due to the value of the coefficient of the domestic inflation gap.

The quantitative evidence suggesting the time varying long run interest rate, as we can find it when all of the gaps in the model are equal to zero the interest rate is in the long run period. The fluctuation of the short run interest rate around the long run can be another important sign for checking the operation of monetary policy.

Obviously, it is more realistic to assume that policy makers gradually learn about the natural rate of unemployment over time, and should update its rule in each period as the number of observations increase.

Reference:


Barro, Robert J. (1985), Recent Developments in the Theory of Rules versus Discretion, the Economic Journal,