ACADEMIA ECONOMIC PAPERS
40 : 4 (December 2012), 447–482

Optimal Monetary Policy for Taiwan: A Dynamic Stochastic General Equilibrium Framework

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Keywords: Dynamic stochastic general equilibrium (DSGE), Monetary policy, Credit channel
JEL classification: F31, F41, F51

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ABSTRACT

The objective of this paper is to investigate the monetary policy of Taiwan by using a micro-based dynamic stochastic general equilibrium (DSGE) model with a banking sector. Because Taiwan's central bank has claimed to use the M2 aggregate growth rate as the monetary target since 1992, this study essentially centers on the welfare assessments of the optimized money growth rate rule and the alternative Taylor-type interest rate rule. We find that the money growth rate rule plays a better job in stabilization and is welfare dominating over the interest rate rule for all types of real shocks. Due to the liquidity effects that the monetary aggregate supplies for consumption, controlling the growth rate of the monetary aggregate can successfully reduce both the inflation and output volatilities. The welfare superiority of the monetary aggregate rule holds for alternative specifications of the model, including the frictionless credit market, the lower international capital mobility and lower nominal rigidity. The current monetary policy, estimated by Teo (2009), follows in a similar fashion to the optimized monetary policy that this study suggests, but has smaller effects in stabilizing the CPI inflation and exchange rates. Reinforcing its endeavors in inflation and exchange rate stabilization can be welfare improving.

1. INTRODUCTION

The objective of this paper is to investigate the welfare implications of Taiwan's monetary policy using a micro-based dynamic stochastic general equilibrium (DSGE) model. In contrast to the interest rate rule that has prevailed internationally since the 1990s, Taiwan's central bank declared that its monetary policy has been implemented based on the monetary aggregate rule using the growth rate of M2 as the intermediate target since 1992 (see the Central Bank of the Republic of China (Taiwan), 2006, p. 31). Over the course of the period that has followed, the macroeconomy has remained fairly stable.

However, whether Taiwan's central bank actually follows the money growth rate rule or uses the interest rate rule which is prevalent worldwide remains an open question. The empirical findings may imply that Taiwan's central bank has implemented a mixed strategy in the formulation of its monetary policy. For example, Hsu (1999), Hou (2005), Chen and Wu (2010) and others find that the monetary aggregate may not be the only target in policy-making. The estimation results in Chen and Wu (2010) show that the monetary policy can be better described by the monetary aggregate rule for the period 1981–1997, while the interest rate rule may be more appropriate in 1998–2008. Differing from these studies, Teo (2009), however, finds that the central bank implements the money supply growth rate rule rather than a Taylor-style interest rate rule by using Bayesian estimation based on a DSGE model.

Given that Taiwan's central bank has announced the money growth rate rule as its monetary policy while the interest rate rule remains the possible alternative rule that the central bank may apply, it is important to conduct policy analyses by examining the macroeconomic effects of these two policy rules on Taiwan. This issue matters for two reasons. First, in recent years, many studies based on the micro-founded DSGE models have found that the interest rate rule, particularly the inflation targeting rule, is optimal for the US and European countries, for instance, Kollmann (2002), Sutherland (2006), Schmitt-Grohé and Uribe (2007), Bergin et al. (2007), and many others. Whether or not the interest rate rule is welfare superior, compared to the monetary aggregate rule for Taiwan, is an important issue.

Secondly, although some attempts have been made to study Taiwan's monetary policy as described above, theoretical examinations of Taiwan's monetary policy are scarce in the literature. The lack of a micro-foundation leaves the study of optimal monetary policy deficient. In the past decade, significant progress has been made with the micro-based DSGE frameworks, and this approach has been widely used in monetary policy studies all over the world. It would therefore be critical to conduct a welfare examination of Taiwan's monetary policy, which could provide objective suggestions for the central bank's policy making.[1]

Therefore, instead of characterizing the monetary policy rule that the central bank actually implements, the goal of this paper is to investigate more carefully the macroeconomic and welfare implications of these two specifications of policy rules for Taiwan. We use a small-open-economy DSGE model with a banking sector as in Hwang and Yang (2010) to calibrate the data for Taiwan. The small-open-economy DSGE framework is fairly standard, which essentially follows the specification of Kollmann (2002). The frictional banking sector that calls for collateral and for monitoring labor for loan making, the primary service of the banking system, is specified according to Goodfriend and McCallum (2007).[2] We include the costly banking sector for three reasons. Firstly, the shocks to the collateral and the monitoring efforts resemble one of the primary causes of the financial crises in the 1990s and the recent subprime crisis. We are thus able to investigate the optimal policy reactions to the shocks that may cause the financial deficiency. Secondly, there are a great number of studies that have shown that the banking sector, as the credit channel of monetary policy, may play an essential role in the transmission of monetary policy.[3] Empirical studies, such as that of Wang and Li (2004), Wu and Chen (2004) and Wu (2004), have demonstrated that the credit channel is crucial in the transmission mechanism of Taiwan's monetary policy. Wang and Li (2004) further find that the credit channel of monetary policy performs better under the monetary aggregate regime than under an interest rate rule. Furthermore, ac-

[1] In a working paper presented at a meeting of the 2010 Taipei Conference on DSGE Modeling and Monetary Policy in Taipei, Teo examines the welfare implications of three simple policy rules for Taiwan by using a small open economy DSGE model with inventory investment. However, the focus of his paper is on the effects of inventory investment on the welfare ranking of alternative simple rules, but not the general investigations of the monetary policies.

[2] Goodfriend and McCallum (2007) use a DSGE model with the banking sector to evaluate the role of money and banking in the monetary policy analyses, with an emphasis on the movement of the EFP. Hwang and Yang (2010) extend the specification of Goodfriend and McCallum (2007) to a small open economy to discuss the role of exchange rate flexibility for the macroeconomic implications of financial crises which originate from the domestic credit market.

[3] The credit channel of monetary policy has been well recognized in the literature, having been initiated by Bernanke and Blinder (1988), followed by many other studies such as Bernanke and Gertler (1989, 1995), Kiyotaki and Moore (1997), Edwards and Végh (1997), Iacoviello (2005) and Goodfriend and McCallum (2007).

cording to Bernanke and Gertler (1995), costly banking can be translated into nonzero external finance premium (EFP). The EFP from Taiwan's data, which is obtained from the difference between the deposit and prime loan rates, is approximately 2% on average during the sample period 1996–2006. Therefore, it is of particular interest to examine Taiwan's monetary policy in a model with a frictional credit market.

The policy assessments are conducted quantitatively by calibrations. We examine the welfare and macroeconomic implications of alternative monetary policies, the money growth rate rule that Taiwan's central bank claims and the alternative interest rate rule that the central banks all over the world implement by calibrating Taiwan's data from 1996Q1 through 2006Q4. Both types of policy rules are specified according to the Taylor type. The money growth rate rule is implemented by manipulating the growth rate of high-powered money in response to the CPI inflation, output gap and the exchange rate depreciation. The specification of the interest rate rule follows the same form.

Our analyses include two parts: deterministic steady state analyses and welfare investigations of policies under various shocks and specifications. The steady state results demonstrate that the EFP can be significantly larger than zero in this model when the banking system is less efficient, which is consistent with the data. When the banking system becomes more efficient, the EFP will be close to zero. The efficient financial system which does not incur the additional external financing cost resembles the conventional setting and thus can serve as a basis for policy analyses. This allows us to investigate optimized monetary policies in response to shocks under different degrees of financial efficiency.

The welfare-optimizing policy rules are obtained by finding the policy rule that generates the highest welfare level through the grid search of the policy parameters, following Bergin et al. (2007).[4] The examinations regarding welfare demonstrate that the monetary aggregate policy performs a better job in stabilizing the economy under real shocks to productivity, foreign interest rates and prices by reducing the output and inflation volatilities thus generates higher welfare than the interest rate rule. The main factor that accounts for the welfare superiority of the money growth rate rule is the liquidity effect that the monetary aggregate policy supplies. The monetary aggregate, which supports consumption, is closely related to the real economy. Thus, controlling

[4] We compare the welfare levels under the policies with the policy parameters lying within the search range. Therefore, the welfare-optimizing rules obtained in this study are essentially the "constrained optimized" rules.

the growth rate of the monetary aggregate not only reduces inflation and exchange rate volatilities, but also helps dampen output fluctuations. The welfare ranking of these two policy rules also holds for alternative specifications such as the frictionless credit market, the reduced international capital market mobility and the lower price rigidity. In particular, the welfare-optimizing monetary aggregate rule in the benchmark case remains optimal for most of the cases.

In addition to real shocks, we also investigate optimized policy responses to financial shocks which occur to the efficiencies of the collateral and monitoring efforts in the loan-making process. The calibration results show that the interest rate rule may be welfare-dominating instead. However, this occurs because the interest rate rule causes a sharper decline in the employment during times of financial distress which results in reductions in output and consumption. This thus reduces the disutility from the labor supplied. Although the welfare level is higher, this may not be the desirable outcome under the financial crises.

Furthermore, we use this approach to investigate the welfare and macroeconomic implications of the current monetary policy in Taiwan. According to the estimate by Teo (2009), using Bayesian estimation, the current monetary aggregate rule in a similar fashion essentially follows the optimized monetary policy that this study suggests, but appears more persistent and has weaker responses to the CPI inflation and exchange rate depreciations. This policy thus leads to greater fluctuations in output, inflation and exchange rates, and generates a lower welfare gain than the optimized rule.

The remainder of this paper is organized as follows. In Section 2, we outline the model's specification, as well as the monetary policies and interest rate relationships. The steady state calibration and a discussion of the banking sector are presented in Section 3. The welfare examinations of monetary policies are conducted in Section 4 and the sensitivity analyses under alternative specifications are provided in Section 5. Section 6 concludes.

2. THE MODEL

2.1 Goods Market

In this paper, we construct a small open economy with a banking sector. There are two types of consumption goods in the domestic market: the home tradable and imported goods, each of which is monopolistically competitive. The representative household consumes the composite goods, which are composed of domestic goods C_t^d and imported goods C_t^m:

$$C_t = \left[(\alpha^d)^{1-\theta}(C_t^d)^{\frac{\theta-1}{\theta}} + (\alpha^m)^{1-\theta}(C_t^m)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}, \tag{1}$$

where $\alpha^m, \alpha^d > 0$ represents the ratios of imported and domestic goods in the aggregate consumption, C_t, respectively. Each type of goods consists of various heterogeneous goods, following the CES form:

$$C_t^i = \left[\int_0^1 C_t^i(s)^{\frac{(\nu-1)}{\nu}} ds\right]^{\frac{\nu}{(\nu-1)}}, \quad i = d, m. \tag{2}$$

where ν is the elasticity of substitution among different goods. θ is the intratemporal elasticity of substitution between domestic and imported goods. The associated demand functions for domestic and imported goods are described below:

$$C_t^i(s) = \left(\frac{P_t^i(s)}{P_t^i}\right)^{-\nu} C_t^i, \quad C_t^i = \alpha^i \left(\frac{P_t^i}{P_t}\right)^{-\theta} C_t, \quad i = d, m, \tag{3}$$

where $C_t^d(s)$ and $C_t^m(s)$ stand for the domestic goods and imported goods of variety s. The corresponding prices are shown as follows:

$$P_t^i = \left[\int_0^1 P_t^i(s)^{1-\nu} ds\right]^{\frac{1}{1-\nu}}, \quad i = d, m, \tag{4}$$

$$P_t = [\alpha^d (P_t^d)^{1-\theta} + (\alpha^m)(e_t P_t^m)^{1-\theta}]^{\frac{1}{1-\theta}}, \tag{5}$$

where $P_t^d(s)$ and P_t^d are the home-currency prices of individual and aggregate domestic goods, respectively, $P_t^m(s)$ and P_t^m are the foreign-currency prices for the imported goods and P_t is the aggregate price index. e_t is the nominal exchange rate, expressed in units of the domestic currency per one unit of foreign currency.

The home firm produces goods sold in both the domestic and foreign markets. The export demand function $C_t^x(s)$ of variety s is assumed to resemble the domestic demand function, Eq. (2):

$$C_t^x(s) = \left(\frac{P_t^x(s)}{P_t^x}\right)^{-\nu} C_t^x \text{ and } C_t^x = S_t^{ex}\left(\frac{P_t^x}{P_t^*}\right)^{-\mu}, \quad \mu > 0, \tag{6}$$

where $P_t^x(s)$ is the firm's export price in the foreign currency, P_t^x is the aggregate price index of exported goods denominated in the foreign currency, and P_t^* is the foreign price index. μ is the price elasticity of the aggregate exports. Furthermore, as a small open economy, Taiwan has been highly concerned about foreign demand for exports. Therefore, we assume a shock S_t^{ex} that may occur to the export demand, following an AR(1) process as specified below.

2.2 Household Problem

In this model, a representative household does not only consume composite goods, save and supply labor, but also owns a monopolistically competitive firm and operates a competitive bank.

We assume that the infinitely-lived household maximizes an expected lifetime utility based upon a consumption bundle and leisure:

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t [\phi \log(C_t) + (1-\phi)\log(1 - n_t^s - m_t^s)], \tag{7}$$

where $\beta \in (0,1)$ is the household's subjective discount factor, ϕ stands for the share of consumption in the utility, and n_t^s and m_t^s are supplies of labor in the production and banking sectors, respectively.

The budget constraint of the households can be described as follows. The representative household's income includes the net sale of capital goods, the receipt of financial assets, the wages for working in both sectors, as well as the revenue from the sales of products:

$$\begin{aligned} &q_t(1-\delta)K_t + \frac{B_t}{P_t} + \frac{e_t B_t^*}{P_t} + \frac{H_{t-1}}{P_t} + w_t(n_t^s + m_t^s) + \alpha^d \left(\frac{P_t^d(s)}{P_t^d}\right)^{1-\nu}\left(\frac{P_t^d}{P_t}\right)^{1-\theta} C_t^A \\ &\quad + \left(\frac{e_t P_t^x(s)}{P_t}\right)\left(\frac{P_t^x(s)}{P_t^x}\right)^{-\nu}\left(\frac{P_t^x}{P_t^*}\right)^{-\mu} - w_t(n_t^d + m_t^d) - \frac{H_t}{P_t^A} - \mathrm{tax}_t - q_t K_{t+1} \\ &\quad - \frac{e_t B_{t+1}^*}{P_t(1+R_t^{B^*})} - \frac{B_{t+1}}{P_t(1+R_t^B)} - C_t = 0. \end{aligned} \tag{8}$$

Here, w_t is the real wage, which is assumed to be identical in both sectors. n_t^d and m_t^d are the labor demanded in the production and banking sectors, respectively. B_{t+1} is the domestic bond and B_{t+1}^* is the foreign bond, denominated in foreign currency. The nominal interest rates which B_{t+1} and B_{t+1}^* pay are denoted by R_t^B and $R_t^{B^*}$, respectively. tax_t is the lump-sum tax, and H_t stands for the nominal holdings of base money at the end of t.

Following Kollmann (2002), we assume that the foreign bond rate, $R_t^{B^*}$, is equal to the world interest rate, R_t^*, plus a factor of $\sigma(B_{t+1}^*/P_t^*)/\chi$, which characterizes friction in the international financial market:

$$(1 + R_t^{B^*}) = (1 + R_t^*) - \frac{\sigma\left(\dfrac{B_{t+1}^*}{P_t^*}\right)}{\chi}, \tag{9}$$

where σ is the parameter which captures the degree of capital mobility. A lower σ stands for higher capital mobility and χ is the steady-state value of exports $(P_t^x/P_t^*)^{1-\mu}$.

2.3 Production

The goods market is subject to the market clearing condition:

$$K_t^\eta (A_t^P n_t^d)^{1-\eta} - \alpha^d \left(\frac{P_t^d(s)}{P_t^d}\right)^{-\nu} \left(\frac{P_t^d}{P_t}\right)^{-\theta} C_t^A - \left(\frac{P_t^x(s)}{P_t^x}\right)^{-\nu} \left(\frac{P_t^x}{P_t^*}\right)^{-\mu} = 0, \tag{10}$$

where $C_t^A = C_t + q_t(K_{t+1} - (1-\delta)K_t)$. Under monopolistic competition, the firm produces goods to satisfy the demand from both the domestic and foreign markets. The first term is the production function of the goods. The firm uses capital goods K_t and labor n_t^d as the input (where η is the capital share) with the stochastic productivity A_t^P. To simplify the model, we assume that K_t is equal to its steady-state value in each period. The second term is the domestic demand for a typical good s. C_t^A stands for the home aggregate consumption, including consumption and capital investment, where q_t is the real price of capital and δ is the depreciation rate. The third term is the foreign demand for a typical good s.

We assume that firms adopt the Calvo (1983) staggered pricing strategy. In each period, the probability of firms changing price is $1 - \xi_d$. Therefore, the mean interval of price change is $1/(1-\xi_d)$. At period t, the profit maximization problem of a typical firm s who can change the price is to choose $P_t^d(s)$ to maximize the profit within the period t and $t+z$ when the price remains valid. The optimal price that a typical firm sets is:

$$P_{t,t}^{d,flex} = \frac{\nu}{\nu-1} \frac{\left\{ \sum_{z=0}^{\infty} (\xi_d)^z \mathrm{E}_t \Lambda_{t,t+z}^d \mathrm{mc}_{t+z} \right\}}{\left\{ \sum_{z=0}^{\infty} (\xi_d)^z \mathrm{E}_t \Lambda_{t,t+z}^d \right\}}, \tag{11}$$

where $\Lambda_{t,t+z} = (\beta^z C_t / C_{t+z})(P_t/P_{t+z})(C_t^d + C_t^x)(P_{t+z}^d)^{\nu}$ and mc_t is the marginal production cost which can be stated as $w_t(1-\eta)A_t^{1-\eta}(K_t/n_t)^{\eta}$.

The price index for the domestic price will evolve following:

$$(P_t^d)^{1-\nu} = \xi_d (P_{t-1}^d)^{1-\nu} + (1-\xi_d)(P_{t,t}^{d,flex})^{1-\nu}, \tag{12}$$

We assume that the producers take the producer-currency pricing for exports and thus the law of one price (LOOP) holds such that $P_t^d = e_t P_t^x$. However, the purchasing power parity (PPP) does not necessarily hold.

2.4 Bank

The household's consumption is subject to a "deposit-in-advance" constraint, based on holding the deposit before the consumption transaction. The transaction constraint of a typical household is

$$C_t = \frac{VD_t}{P_t}, \tag{13}$$

where D_t is the deposit and V is a constant, representing the velocity of the aggregate deposit.

The bank operates by receiving the deposits of and extending loans to households. Each bank's balance sheet can be written as:

$$H_t + L_t = D_t, \tag{14}$$

where L_t and H_t represent the loans and reserve money, respectively. Let rr be the reserve ratio, and then the funds available for loan making amount to $(1-\text{rr})D_t$.

Due to the asymmetric information problem with the credit market, the bank makes loans by hiring labor for monitoring and utilizing collateral. We assume that the loan production function follows a Cobb-Douglas form as follows: [5]

$$\frac{L_t}{P_t} = F(b_{t+1} + A_t^K kq_t K_{t+1})^{\alpha}(A_t^m m_t)^{1-\alpha}, \tag{15}$$

where m_t is the labor input for monitoring, and $b_{t+1}+kq_tK_{t+1}$ are the collateral, which consists of home government bonds and capital goods, with $b_{t+1} = B_{t+1}/P_t^A(1+R_t^B)$. We assume that the foreign bond cannot be used for collateral. α is the share of collateral in the loan production. Here, $0 < k < 1$ characterizes the inferiority of capital relative to bonds for collateral purposes, because capital goods need more monitoring effort than bonds to confirm the market value. F is a constant, which stands for the efficiency of the loan-making process. A lower F represents a highly frictional credit market.

Following Goodfriend and McCallum (2007), we also assume that there are shocks to the value of capital as the collateral and to the effectiveness of credit check efforts, characterized by A_t^K and A_t^m respectively.

2.5 Government

The government budget constraint is as follows:

$$G_t - \text{tax}_t = \frac{H_t}{P_t} - \frac{H_{t-1}}{P_t} + \frac{B_{t+1}}{P_t(1+R_t^B)} - \frac{B_t}{P_t}. \tag{16}$$

The government finances its expenditure, G_t, through levying a lump-sum tax, tax_t, issuing base money and bonds. For simplification, we set G_t to zero.

[5] From the deposit-in-advance constraint, we know that the loans are made essentially to finance consumption expenditure. Although this specification is different from the loans financing the capital investments of firms, which may account for the majority of loans in the real world, it is consistent with the estimation results in Wu (2004) in that the consumption expenditures of the private sector in Taiwan are more sensitive to the shocks to loans than investments.

2.6 Monetary Policy

In line with the monetary aggregate rule that Taiwan's central bank is currently conducting, the monetary policy is assumed to be the growth rate of the high-powered money. The growth rate of base money is specified according to the following process:

$$\Delta h_t = (1 - \alpha_H)[\Delta h + \alpha_p^H \Delta p_t + \alpha_{mc}^H \mathrm{mc}_t + \alpha_e^H \Delta e_t] + \alpha_H \Delta h_{t-1} + \varepsilon_t^H, \quad (17)$$

where $\Delta h_t = \log(H_t) - \log(H_{t-1})$ is the growth rate of the stock of base money. Here, $\Delta p_t = \log(P_t) - \log(P_{t-1})$ is the CPI inflation rate. mc_t is the real marginal cost of goods production, which serves as the measure of the output gap. $\Delta e_t = \log(e_t) - \log(e_{t-1})$ denotes the rate of exchange rate depreciation. $\alpha_p^H, \alpha_{mc}^H, \alpha_e^H < 0$ are the money growth rate rule's responses to the associated variables respectively. In contrast to the general Taylor rule, the negative policy parameters for the money growth rate are specified to characterize the lean-against-the-wind policy of the central bank.[6] ε_t^H is the shock to the growth rate of high-powered money.

We also examine an alternative interest rate rule, following the general form of the Taylor rule (Taylor, 1993) with a lagged value of R_t^{IB} to reflect the interest rate smoothing and policy responses to the inflation rates, output gap and exchange rate depreciation. The interest rate rule can be written as:[7]

$$R_t^{IB} = (1 - \alpha_R)[R^{IB} + \alpha_p^R \Delta p_t + \alpha_{mc}^R \mathrm{mc}_t + \alpha_e^R \Delta e_t] + \alpha_R R_{t-1}^{IB} + \varepsilon_t^R, \quad (18)$$

where R^{IB} is the steady-state interbank rate and $\alpha_p, \alpha_{mc}, \alpha_e > 0$ are policy parameters, which control the degree of policy's responses to the CPI inflation, output gap and exchange rate, respectively. $0 \leq \alpha_R < 1$, and ε_t^R is the shock to the interest rate rule.

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[6] Teo (2009) also specifies a similar form for estimation. He finds that Taiwan's central bank puts higher weight on the CPI stabilization than the exchange rate stabilization, and the policy with the response to the output gap is rejected.

[7] We refer to a similar form in Devereux et al. (2006).

2.7 Exogenous Variables

The exogenous processes of shocks in the model are all assumed to follow first-order autoregressive processes:

$$a_t = (1-\rho_A)a + \rho_P a_{t-1} + \varepsilon_t^A, \quad 0 \le \rho_A < 1, \tag{19}$$

$$a_t^K = (1-\rho_K)a^K + \rho_K a_{t-1}^K + \varepsilon_t^K, \quad 0 \le \rho_K < 1, \tag{20}$$

$$a_t^m = (1-\rho_m)a^m + \rho_m a_{t-1}^m + \varepsilon_t^m, \quad 0 \le \rho_m < 1, \tag{21}$$

where $a_t^i = \log(A_t^i)$, $\forall i = P, K, m$, which characterize the shocks to the production and financial sectors respectively.

Since the small open economy cannot influence the foreign prices and interest rate, we assume that these foreign variables are exogenous and move with the following AR(1) processes:

$$P_t^* = (1-\rho^{P^*})P^* + \rho^{P^*} P_{t-1}^* + \varepsilon_t^{P^*}, \quad 0 \le \rho^{P^*} < 1, \tag{22}$$

$$R_t^* = (1-\rho^{R^*})R^* + \rho_{R^*} R_{t-1}^* + \varepsilon_t^{R^*}, \quad 0 \le \rho_{R^*} < 1, \tag{23}$$

where R^* and P^* are the steady state level respectively. The import price P_t^m is assumed to be a constant, remaining at the steady state level.

Export shocks are also assumed to follow an AR(1) process:

$$s_t^{ex} = (1-\rho^s)s^{ex} + \rho_{ex} s_{t-1}^{ex} + \varepsilon_t^{ex}, \quad 0 \le \rho_{ex} < 1, \tag{24}$$

Here, $s_t^{ex} = \log(S_t^{ex})$. $\varepsilon_t^P, \varepsilon_t^K, \varepsilon_t^m, \varepsilon_t^{P^*}, \varepsilon_t^{R^*}$ and ε_t^{ex} are independent, white noises.

2.8 Optimization

The household chooses 8 variables $\{m_t^s, m_t^d, n_t^s, n_t^d, K_{t+1}, B_{t+1}, B_{t+1}^*, P_t^d(s)\}$ to maximize Eq. (7), subject to the budget constraint Eq. (8) and market clearing condition Eq. (10), with ζ_t and λ_t as the Lagrangian multipliers associated with Eqs. (8) and (10) respectively. In addition, we define

$$\Omega_t = \frac{\alpha C_t}{b_{t+1} + A_t^K k q_t K_{t+1}}. \tag{25}$$

We assume that all the households are identical and symmetrical. The budget constraint and goods clearing condition, the balance sheet and loan making process of the bank, the deposit-in-advance constraint, 8 first-order conditions, the real home and foreign bonds, the law of one price, the liquidity yield of the various collateral, the price adjustment process, and the government budget constraint determine the equilibrium characterized by twenty endogenous variables, $C, l, n, w, \lambda, \Phi, L, D, q, B, B^*, b^*, e, P, P^d, C^A, \zeta, R^B, R^{B^*}$, tax given the processes of exogenous variables and government policy M and b.

2.9 Interest Rates and the External Finance Premium

With the frictional credit market, the interest rates associated with the various assets such as bonds, deposits and loans should diverge to reflect the different roles these assets play in the market and the yields that they generate. Let R_t^T represent the interest rate in a conventional model without the banking sector; this can be obtained by using the conventional Euler equation:

$$1 + R_t^T = \mathrm{E}_t \frac{\lambda_t P_{t+1}}{\beta \lambda_{t+1} P_t}. \tag{26}$$

This is also the interest rate for borrowing and lending without using the collateral. All the interest rates under credit friction, particularly due to costly loan making process, are listed as follows: [8]

$$\frac{1 + R_t^B}{1 + R_t^T} = 1 - \left(\frac{\phi}{C_t \lambda_t} - 1 \right) \Omega_t, \tag{27}$$

$$(1 + R_t^T) = (1 + R_t^{IB}) \left[1 + \frac{V w_t m_t}{(1-\alpha)(1-\mathrm{rr}) C_t} \right], \tag{28}$$

$$(1 + R_t^L) = (1 + R_t^{IB}) \left[1 + \frac{V w_t m_t}{(1-\mathrm{rr}) C_t} \right]. \tag{29}$$

[8] Because the credit market exists in the domestic economy, and we assume that only the capital and home bond can serve as the collateral, the interest rate relationships are essentially the same as those in Goodfriend and McCallum (2007).

The difference between the bond rate and the uncollateralized rate reflects the efficiency of the loan making process precipitated by bonds as the collateral. Furthermore, a typical bank obtains funds in the reserve market at the interbank rate denoted by R_t^{IB} and extends loans to households at the benchmark rate R_t^T without collateral or at the loan rate R_t^L with collateral. The spread between the uncollateralized or collateralized loan rates and the interbank rate covers the marginal cost that the loan making process incurs.

The EFP should reflect the marginal cost of making loans and can be endogenously obtained by taking the difference between the external and internal funding costs of the firm, the spread between R_t^L and R_t^{IB}. Consequently, the EFP can be written as: [9]

$$\mathrm{EFP}_t = R_t^L - R_t^{IB} \approx \frac{V w_t m_t}{(1-\mathrm{rr})C_t}. \tag{30}$$

As Bernanke and Gertler (1995) mention, the EFP, just as the spread between the external and internal financing costs, essentially describes the cost of the asymmetric information problem that the costly banking incurs and thus can characterize the friction in the credit market.

3. STEADY STATE ANALYSIS

3.1 Parameterization

Following Goodfriend and McCallum (2007), by letting boc be a constant steady-state ratio of government bonds to consumption, first-order conditions, goods market clearing condition, and a loan production function can be degenerated into nine equations for nine endogenous steady-state variables $C, m, n, \Omega, \lambda, w, K, b^*, R^B$.[10] All the parameters are summarized in Table 1. The steady state is assumed to be current account balanced. Therefore, given the assumption that the price indices of the country

[9] The EFP reflects the marginal cost of loan making, which is closely related to the value of collateral. When the value of collateral is higher, the loan making process requires fewer workers for credit check for the same amount of loans. This will lower the cost of loan making as well as the EFP. Therefore, given C_t and w_t in Eq. (30), higher value of collateral lowers the need for m_t and thereby the EFP. As a result, higher value of capital implying greater value for collateral will help reduce the cost for the loan making and the EFP.

[10] Please refer to Hwang and Yang (2010) for the derivation of the steady state.

Table 1 Parameter Values (on Quarterly Basis)

Parameter	Description	Value
ϕ	The importance of consumption in the utility function	0.42
η	Capital share in goods production	0.36
β	Discount rate	0.99
δ	Depreciation rate of capital	0.025
q	Capital value	1
boc	Real government bond/consumption bundle	1.194
V	Velocity of aggregate bank deposits	0.134
rr	Reserve rate	0.054
α	Collateral share in loan production	0.68
F	Efficiency parameter of banking sector	8
k	Inferiority of capital to bonds for collateral purposes	0.55
α^m	Ratio of import goods to aggregate consumption in the steady state	0.43
α^d	Ratio of domestic goods to aggregate consumption in the steady state	0.57
υ	Elasticity of substitution among different variety of goods	6
θ	Elasticity of substitution between domestic goods and imported goods	5
μ	Price elasticity of demand for export	5
ξ_d	The degree of price rigidity	0.75
σ	The degree of capital mobility	0.0019

$P = P^d = P^m = P^x = 1$, and the foreign price index $P^* = 0.86$ to assure the zero foreign bonds in the steady state.[11] The market price of capital goods is assumed to be $q = 1$, and the nominal exchange rate is specified as $e = 1$. Following Kollmann (2002), both the steady-state foreign bond rate R^{B^*} and the world interest rate R^* are equal to 0.01 under perfect capital mobility.

We set the discount rate $\beta = 0.99$ and $\eta = 0.36$ to reflect the relative shares of capital in goods production as conventional settings. The steady-state price-marginal cost markup factor for goods is set at $\upsilon/(\upsilon-1) = 1.2$ (i.e., $\upsilon = 6$) and the depreciation rate of capital is 0.025. The elasticity of substitution between domestic and imported goods, θ, is set to 5, and the price elasticity of demand for exports $\mu = 5$. ϕ is chosen

[11] However, the home bond rate R^B is lower than the foreign bond rate R^{B^*} due to the liquidity service that the home bond can serve.

to be 0.42 to generate the labor employment to be roughly $1/3$ of the total available labor force. The degree of price stickiness ξ_d is specified according to the conventional value of 0.75, implying the average price stickiness lasting for 4 quarters.

We calibrate the model to the quarterly data for Taiwan for the time period 1996Q1 to 2006Q4.[12] α^m is set to 0.43 for the steady-state import share in the GDP, which is close to 0.49, the average of the Taiwanese import share during the sample period. The financial parameters are calibrated based on the average of Taiwanese data during the sample period. First, we set the velocity of aggregate bank deposits at $V = 0.134$, which is measured by the average ratio of Taiwan's nominal GDP to M2. Second, the reserve ratio is set at rr $= 0.054$ and is obtained from the average ratio of reserves to M2. Third, the fiscal policy parameter, boc $= 1.194$, is obtained by taking the average share of the outstanding government bonds to consumption.

Furthermore, following Goodfriend and McCallum (2007), three primary parameters in the loan production function, which characterize the credit market friction, are calibrated to match the financial situation in Taiwan. First, the average ratio of labor employed in the banking sector to the total labor employment in Taiwan is 3.98%.[13] Second, the average ratio of annual real capital to output is 2.13 during the sample period. Third, the average EFP within the sample period is 2.6%. Fourth, the typical short run interest rates are 1%. Thus the financial parameters are chosen as $\alpha = 0.68$, $k = 0.55$ and $F = 8$.

3.2 Steady State Results

Table 2 lists the steady-state results of the benchmark model. First of all, the total available working time $m + n = 32.8\%$ is close to $1/3$, and is consistent with the Taiwanese data. Moreover, the share of banking employment in the total labor effort is $m/(m + n) = 2.2\%$, and is lower than the average banking employment share of 3.98% in Taiwan. The ratio of capital to output on an annual basis is $K/4y = 2.29$, which is close to the ratio 2.13 in the Taiwanese data.

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[12] We wish to capture the macroeconomic fundamentals, particularly of the banking sector, for Taiwan before the outbreak of the subprime crisis in 2007.

[13] The data is obtained by taking the average ratio of the number of workers employed in the financial sector to the total labor force between 1996 and 2006. However, the financial sector includes both the banking and insurance industries, and therefore 3.98% will overstate the real bank employment share. If we use working hours instead of the number of the workers, the average share of banking employment will be 7.8%.

Table 2 Steady-State Values of the Benchmark Model $(F = 8)$

w	C	C^A	m	n
1.8573	0.8601	1.1167	0.0075	0.3207
b	K	λ	R^T	R^{IB}
1.0274	10.2638	0.4648	0.0101	0.0029
R^L	R^B	R^K	EFP	
0.0052	0.0056	0.0076	0.0023	

The interest rates in this model diverge due to the credit friction. The calibrated short-term rates, the interbank rate R^{IB} and the government bond rate R^B, are 1.26% and 2.24% per annum, respectively.[14] The interbank rate is close to the 1% per annum average short-term riskless real rate in the finance literature, while the bond rate is higher.[15] However, the calibrated bond rate is close to the average 3-month T-bill rate in Taiwan in 2006 which is 1.48%. Furthermore, since the collateral helps reduce the default risk in the frictional credit market, with the liquidity service yields, the government bond rates R^B and R^K are lower than R^T by 1.78% p.a. and 0.98% p.a., respectively.[16]

Frictional credit market results in a nonzero steady-state EFP, which is 0.92% per annum. Although it is lower than the average EFP of 2.6% in Taiwan, it still reflects significant credit friction in Taiwan. As indicated in the literature on the credit view, the nonzero EFP can play an important role in monetary policy transmission. The results of the steady state highlight the importance of the banking sector in the Taiwanese economy.

To demonstrate the importance of costly banking in Taiwan which Wang and Li (2004) point out, we also calibrate the steady state under a highly efficient banking sector by setting a higher banking efficiency parameter $F = 50$. The results are summarized in Table 3. With the efficient banking sector, all the interest rates converge to R^T and the EFP is driven down to a level close to zero.[17] The labor effort in a bank

[14] Since there is no inflation in the steady state, steady-state interest rates are obtained as real rates.

[15] For example, see Campbell (1998). However, the average interbank rate in Taiwan during the sample period is 1.58%.

[16] Since capital is less effective as collateral than bonds, the capital rate is higher than the bond rate by 0.8% per annum.

[17] The bond and loan rates rise under efficient banking. The reason that accounts for the rise in interest

Table 3 Steady-State Values under Highly Efficient Banking $(F = 50)$

w	C	C^A	m	n
1.7832	0.8658	1.1012	0.00003	0.3293
b	K	λ	R^T	R^{IB}
1.0342	9.4141	0.4850	0.0101	0.0107
R^L	R^B	R^K	EFP	
0.01008	0.01008	0.01009	8×10^{-6}	

m also declines to a very low level. Because of the efficiency of the loan production, lower banking employment as well as collateral, particularly capital, are required for the loan making.[18] The absence of credit friction under a highly efficient banking sector essentially degenerates to a conventional model without the banking sector.

4. WELFARE ANALYSIS OF OPTIMAL MONETARY POLICY

In this section, we conduct welfare examinations of two policies, namely, the monetary growth rate rule and the alternative interest rate rule, both of which optimize welfare. The monetary policy rules are specified as shown above in Eq. (17) and Eq. (18). The optimized monetary policy rules are obtained for various shocks: real and financial shocks. The real shocks include a productivity shock to the production sector ε_t^A, foreign interest rate shock $\varepsilon_t^{R^*}$, foreign demand shock to exports ε_t^{ex} and international price shock $\varepsilon_t^{P^*}$. We use the US 3-month CD rate and CPI during the sample period

rates can be the uncollateralized interest rate, R^T, which is essentially the representative interest rate in the conventional model without banking, is determined exogenously from the standard Euler equation, $R^T = 1/\beta - 1$. In a small open economy, the foreign bond rate, R^{B^*}, is also set as $1/\beta - 1$. Therefore, other interest rates are determined by their spreads from R^T or R^{B^*}. When the spread is lowered by the banking efficiency, interest rates are moving close to each other. This is why the EFP can be lowered, but also why other interest rates are raised up, moving closer to R^T and R^{B^*}. Higher interest rates under a highly efficient banking sector may contrast with empirical findings. However, recent studies emphasize the movement of the EFP, but not the loan rate. In line with these studies, we will focus on the behavior of the EFP, but not the loan rate itself.

[18] Since $L/P = (1 - \text{rr})D/P = (1 - \text{rr})c/V$, the loans under the highly efficient banking is higher due to greater consumption. Therefore, the banking sector expands when it becomes more efficient. The welfare under efficient banking is also higher.

as the measure of the foreign price and interest rate to estimate the AR(1) process. The persistence of the foreign interest rate and price are set according to the estimated AR(1) coefficients, $\rho_{R^*} = 0.97$ and $\rho_{P^*} = 0.15$, respectively. The estimated standard deviations of the interest rate and price are 0.46% and 0.45%, respectively, and thus we set $\sigma_{R^*} = \sigma_{P^*} = 0.5\%$. The persistence and volatility of the export shocks are obtained from the estimate derived by Teo (2009) wherein we set $\rho_{ex} = 0.5$ and $\sigma_{ex} = 0.2\%$. Since we do not have the data for the Solow residual for Taiwan, we simply assume that the productivity shock evolves following the standard specification $\rho_a = 0.9$ and $\sigma_a = 1\%$. Financial shocks are specified as negative shocks to the effectiveness of capital as the collateral and efficiency of monitoring efforts in the banking sector in the loan production function, ε_t^K and ε_t^m, respectively, to characterize adverse financial distress from the credit market. Following Goodfriend and McCallum (2007), they are assumed to evolve according to $\rho_K = 0.9$, $\rho_m = 0.99$ for persistent financial deficiencies and $\sigma_K = \sigma_m = 3\%$. International asset market friction is set as $\sigma = 0.0019$, following Kollmann (2002). In the analyses on optimal monetary policy, we specify that shocks to the monetary aggregate and interest rate rules, ε_t^H and ε_t^R, are specified to zero.

4.1 Welfare Criterion

We use the expected lifetime utility of the representative household, discounted back to the period zero, as the welfare measure:

$$\mathrm{CV}_0 = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t [\phi \log(C_t) + (1-\phi)\log(1 - n_t - m_t)]. \tag{31}$$

Following Schmitt-Grohé and Uribe (2007), we evaluate the monetary policy by computing the welfare level under each policy a:

$$\mathrm{CV}_0^a = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \phi \log\left[\left(1 + \frac{\gamma^a}{100}\right)\overline{C}\right] + (1-\phi)\log(1 - \overline{n} - \overline{m}) \right\}, \tag{32}$$

where $\overline{C}, \overline{n}$ and $\overline{m}$ are the steady-state values of consumption and labor in the goods production and banking sectors, respectively. γ^a is the welfare gain and is measured by the fraction of the steady-state consumption that would increase under the regime a for the household to be as well off as in the steady state.

4.2 Welfare Analyses

The welfare examinations are conducted by applying a second-order approximation to the system, and are computed with the software package, Dynare. The optimized policies are obtained by choosing the policy parameters $\alpha_H, \alpha_p^H, \alpha_{mc}^H$ and α_e^H for the monetary growth rate rule and $\alpha_R, \alpha_p^R, \alpha_{mc}^R$ and α_e^R for the interest rate rule which lead to the highest level of γ^a.[19]

4.2.1 The benchmark model: optimized money growth rate rule

In this section, we first examine the benchmark optimal money growth rate rule under the four types of real shocks which occur all together. The results are listed in Table 4. The optimized monetary aggregate policy can be characterized by $\Delta h_t^{OPT} = 0.9[-2\Delta p_t - 0.2\text{mc}_t - 2\Delta e_t] + 0.1\Delta h_{t-1} + \varepsilon_t^H$. This policy suggests that much attention is directed at stabilizing the inflation and exchange rate depreciation rates, but with not much effort being made to stabilize the output gap. This policy generates volatilities for the macroeconomic variables such as those for the GDP and the inflation rate of 7.3% and 0.1%, while leading to greater fluctuations in exports and the terms of trade with standard deviations of 15.4% and 4.4%, respectively. As shown, this policy will incur a welfare gain of 0.57% of the steady state consumption.

Table 4 also reports the macroeconomic performance under each individual shock aided by the implementation of the optimized money growth rate rule. The results show that the shock to the foreign interest rate is the main factor that drives significant fluctuations in the exports and terms of trade, accounting for 98% of the fluctuation in output, 100% of the fluctuation in the price inflation and 95% of the fluctuation in the exchange rate. However, if home productivity, export or international price shocks occur, this policy can successfully assist in the stabilization of the economy.

[19] We conduct grid search to obtain the optimized policy parameters. For stabilization purposes, the policy parameters of the monetary aggregate rule should be negative, while those of the interest rate rule should be positive. The search ranges for the monetary growth rate rule under real shocks are from 0 to 0.9 for α_H with step size 0.1, and from -2 to 0 for $\alpha_p^H, \alpha_{mc}^H$ and α_e^H with step size 0.2. The search ranges for the interest rate rule are from 0 to 0.9 for α_R, from 0 to 2 for $\alpha_p^R, \alpha_{mc}^R$, and α_e^R with the step sizes same as above. These ranges are chosen arbitrarily, but the welfare gains under the parameters outside the range are lower, or can be negligible if there are any. This method can also be seen in Bergin et al. (2007).

Table 4 Optimal Monetary Growth Rate Rule: Benchmark Model (under Real Shocks)

Optimized monetary growth rate rule: $\Delta h_t^{OPT} = 0.9[-2\Delta p_t - 0.2\text{mc}_t - 2\Delta e_t] + 0.1\Delta h_{t-1} + \varepsilon_t^H$.

	Money growth rate rule: Δh_t^{OPT}				
Shock	$\varepsilon^A, \varepsilon^{R^*}, \varepsilon^{ex}, \varepsilon^{P^*}$	ε^A	ε^{R^*}	ε^{ex}	ε^{P^*}
Welfare (as the percentage of the steady state consumption)					
γ^a	0.5702	−0.0028	0.0058	0.0000	−0.0047
Standard deviations (in the percentage deviation from the steady state)					
Y	7.30	1.45	7.19	0.06	0.73
C	8.90	1.01	8.86	0.03	0.10
n	11.30	0.64	11.23	0.09	1.14
EX	15.40	1.50	15.23	0.16	2.00
IM	8.40	1.03	8.38	0.02	0.09
Δp	0.10	0.05	0.51	0.00	0.02
Δp^d	0.37	0.06	0.36	0.00	0.05
Δe	1.20	0.04	1.14	0.01	0.06
TOT	4.40	0.27	4.36	0.02	0.19
q	8.30	1.12	8.20	0.03	0.09
R^{IB}	0.89	0.06	0.89	0.01	0.02
R^L	0.89	0.06	0.88	0.00	0.02
R^T	0.88	0.05	0.88	0.00	0.02
EFP	0.03	0.00	0.03	0.00	0.00
Means (in the percentage deviation from the steady state)					
Y	−0.7314	−0.0014	−0.7314	−0.0014	−0.0014
C	0.4453	−0.0047	0.4453	−0.0047	−0.0047
n	−1.1473	0.0027	−1.1473	0.0027	−0.0073
EX	−0.9245	−0.0045	−0.9045	−0.0045	−0.0145
IM	0.4856	−0.0044	0.4856	−0.0044	0.0056

Note: TOT denotes the terms of trade, measured by eP^d/P^m, EX denotes the export and IM denotes the import.

4.2.2 The alternative interest rate rule under real shocks

If the central bank implements the interest rate rule instead, the welfare-maximizing rule is $R_t^{IB,OPT} = 0.1[0.0029 + 1.4\Delta p_t + 2\text{mc}_t + 0.0\Delta e_t] + 0.9R_{t-1}^{IB,OPT} + \varepsilon_t^R$. The associated moments of the endogenous variables are listed in Table 5. In contrast to

Table 5 Optimal Interest Rate Rule: Benchmark Model (under Real Shocks)

Optimized interest rate rule: $R_t^{IB,OPT} = 0.1[0.0029 + 1.4\Delta p_t + 2\text{mc}_t + 0.0\Delta e_t] + 0.9R_{t-1}^{IB,OPT} + \varepsilon_t^R$.

	Interest rate rule: $R^{IB,OPT}$				
Shock	$\varepsilon^A, \varepsilon^{R^*}, \varepsilon^{ex}, \varepsilon^{P^*}$	ε^A	ε^{R^*}	ε^{ex}	ε^{P^*}
Welfare (as the percentage of the steady state consumption)					
γ^a	0.5142	−0.0021	0.0052	0.0000	0.0000
Standard deviations (in the percentage deviation from the steady state)					
Y	7.93	1.73	7.73	0.02	0.38
C	8.89	1.07	8.83	0.01	0.10
n	12.11	0.58	12.08	0.03	0.59
EX	15.02	1.59	15.04	0.13	1.57
IM	8.36	1.05	8.29	0.01	0.09
Δp	0.56	0.05	0.55	0.00	0.05
Δp^d	0.36	0.05	0.35	0.01	0.07
Δe	1.18	0.12	1.16	0.01	0.16
TOT	4.90	0.45	4.87	0.03	0.27
q	8.19	1.00	8.12	0.01	0.10
R^{IB}	0.89	0.07	0.88	0.00	0.08
R^L	0.89	0.07	0.88	0.00	0.08
R^T	0.88	0.06	0.88	0.01	0.08
EFP	0.03	0.00	0.03	0.00	0.00
Means (in the percentage deviation from the steady state)					
Y	−0.7614	−0.0014	−0.7614	−0.0014	−0.0014
C	0.4553	−0.0047	0.4553	−0.0047	0.0053
n	−1.1973	0.0027	−1.1873	0.0027	−0.0073
EX	−0.7845	0.0055	−0.7845	−0.0045	−0.0045
IM	0.5256	−0.0044	0.5256	−0.0044	0.0056

Note: Refer to Table 4.

the optimized monetary aggregate rule, the optimized interest rate rule is characterized by attaching higher weights to the lagged interest rate and output gap than to the CPI inflation or exchange rate depreciation. The welfare under the interest rate rule can be

0.056% lower each quarter than under the monetary aggregate rule.[20] This shows that it will not improve welfare to switch from the monetary aggregate rule to the interest rate rule.

The reason for the welfare superiority of the monetary aggregate rule is that the monetary aggregate rule does a better job of stabilizing the economy. Without explicit effort in removing the output fluctuations, the optimized monetary aggregate rule can generate lower volatilities in output and the CPI inflation which are 7.30% and 0.1%, respectively, under the monetary aggregate rule, relative to 7.93% and 0.56% under the interest rate rule. It is because of the liquidity effect that the monetary aggregate generates. The high-powered money, which is the reserve money of the banking system, is directly relevant to the deposit which supports the consumption and thereby the output in the economy. The implementation of the money growth rate rule with the inflation targeting requires good control of the growth rate of the high-powered money which in turn reduces not only the fluctuations in the inflation rate, but also the output. With the direct liquidity services that the monetary aggregate can supply, the control of the monetary growth rate moderates both real and nominal fluctuations. This is consistent with the monetarists' view on the monetary policy which advocates controlling the monetary aggregate to stabilize the economy while leaving the interest rate to fluctuate more widely.[21]

4.2.3 Financial shocks

The inclusion of a frictional banking sector allows us to examine optimal policy responses to shocks that originate from the credit market. These shocks resemble the causes of the subprime crisis which were mainly the domestic credit market disruption. The credit market failure is also one of the factors that exacerbated the economic downturns during the East Asian financial crisis in 1997. The financial shocks that impacted the effectiveness of collateral and efficiency of monitoring efforts for credit checks can well characterize the shocks that are normally factors causing the credit market to deteriorate. In this section we thus emphasize the optimal policy reaction to the credit market failure of these types.

We calibrate welfare-maximizing monetary policies under financial shocks which

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[20] Lucas (1987) estimates that the costs of business cycle fluctuations are 0.04% of annual consumption, which is concluded to be trivial. With a two-country DSGE model, Bergin et al. (2007) find that the welfare gain from the optimized interest rate rule is 0.04% relative to the fixed exchange rate, which is considered to be small.

[21] See King and Lin (2005).

Table 6 Optimal Policy Rules under Financial Shocks $(\varepsilon^K, \varepsilon^m)$

Optimized monetary growth rate rule: $\Delta h_t^{FIN} = [-2\Delta p_t - 2\text{mc}_t - 2\Delta e_t] + 0.0\Delta h_{t-1}^{FIN} + \varepsilon_t^H$.
Optimized interest rate rule: $R_t^{IB,FIN} = [0.0029 + 1.4\Delta p_t + 0.2\text{mc}_t + 2\Delta e_t] + 0.0R_{t-1}^{IB,FIN} + \varepsilon_t^R$.

	(A)	(B)	(C)	(D)
	Δh^{FIN}	$R^{IB,FIN}$	Δh^{OPT}	$R^{IB,OPT}$
Welfare (as the percentage of the steady state consumption)				
γ^a	−0.0642	0.0000	−0.0654	−0.0592
Standard deviations (in the percentage deviation from the steady state)				
Y	0.41	0.97	0.41	0.47
C	0.75	0.83	0.76	0.79
n	0.64	1.52	0.64	0.74
EX	0.23	1.00	0.34	0.15
IM	0.39	0.66	0.41	0.44
Δp	0.01	0.03	0.03	0.02
Δp^d	0.00	0.02	0.01	0.01
Δe	0.01	0.02	0.04	0.02
TOT	0.08	0.87	0.13	0.15
q	0.85	0.13	0.82	0.76
R^{IB}	0.17	0.18	0.18	0.16
R^L	0.12	0.13	0.13	0.11
R^T	0.02	0.02	0.03	0.01
EFP	0.05	0.05	0.05	0.05
Means (in the percentage deviation from the steady state)				
M	−0.0314	−0.1214	−0.0314	−0.0414
C	−0.0747	−0.0747	−0.0747	−0.0747
n	−0.0573	−0.1873	−0.0573	−0.0673
EX	−0.0145	−0.1255	−0.0145	−0.0045
IM	−0.0344	−0.0644	−0.0344	−0.0344

Note: Column (A) and (B) list the results with the implementation the welfare-optimizing policy reactions to the financial shocks. Column (C) and (D) list the results under the financial shocks with the implementation of the optimized policies for real shocks.

are $\rho_K = 0.9, \rho_m = 0.99$ and $\sigma_K = \sigma_m = 3\%$. The results are listed in columns (A) and (B) in Table 6. Under adverse financial distress, all macroeconomic variables such as the output, consumption and employment decline. Due to shocks to the financial system, it is required that more collateral be accumulated, which results in greater amounts of bonds and leads to larger fluctuations in the home bond rate. This will in turn give rise to the exchange rate volatility which will translate into the volatility of exports.

Therefore, the required optimal policy responses to the financial shocks are different from those to the real shocks, particularly the interest rate rule. The optimized money growth rate rule $\Delta h_t^{FIN} = [-2\Delta p_t - 2\text{mc}_t - 2\Delta e_t] + 0.0\Delta h_{t-1}^{FIN} + \varepsilon_t^H$ is slightly less persistent, but places greater emphasis on output fluctuations than the desirable policy under real shocks. This policy shows that, while there is an adverse financial shock, the central bank which uses the money growth rate rule should raise the money growth rate in accordance with the GDP recession resulting from a shock. The expansionary monetary policy will help dampen the decline as well as stabilize the economy. On the other hand, the optimized interest rate rule can be stated as: $R_t^{IB,FIN} = [0.0029 + 1.4\Delta p_t + 0.2\text{mc}_t + 2\Delta e_t] + 0.0R_{t-1}^{IB,FIN} + \varepsilon_t^R$. By reinforcing its role in the stabilization of the inflation and exchange rates, the interest rate rule can also assist in economic stabilization, but less well than the monetary aggregate rule.

In contrast to the real shocks, however, the interest rate rule generates a higher welfare level than the money growth rate rule. The interest rate rule leads to greater economic contraction than the monetary aggregate rule and thus causes a sharper decline in employment. The welfare gain from the decline in the labor supplied dominates the welfare loss from the reduction in consumption and thus makes the interest rate welfare dominating. This policy, however, may not be desirable.

We also conduct experiments where the central bank retains optimized rules proposed above in the benchmark case with real shocks, without recognizing a deteriorating credit environment. The results reported in column (C) show that the preceding optimized monetary aggregate rule can cause greater economic fluctuations and result in a large welfare loss. The results in column (D), however, show that the preceding optimized interest rate rule can perform a better job in stabilization, but leads to a higher welfare loss by exacerbating the economic downturn.

4.2.4 The current monetary aggregate rule of the central bank

Based on the optimized monetary policies obtained above, it would be helpful and interesting to use this framework to assess the welfare implications of current monetary policy, estimated from the small open economy DSGE model of Teo (2009). The

Table 7 The Estimated Monetary Aggregate Rule (under Real Shocks)

$$\Delta h_t^{Est} = 0.319[-1.116\Delta p_t - 0.0\text{mc}_t - 0.403\Delta e_t] + 0.681\Delta h_{t-1}^{Est} + \varepsilon_t^H.$$

	Estimated MA policy: Δh_t^{Est}					
Shock	$\varepsilon^A, \varepsilon^{R^*}, \varepsilon^{ex}, \varepsilon^{P^*}$	ε^A	ε^{R^*}	ε^{ex}	ε^{P^*}	$\varepsilon^K, \varepsilon^m$
Welfare (in the percentage deviation from the steady state)						
γ^a	−1.3193	−0.0186	−1.2916	0.0000	−0.0095	−0.0714
Standard deviations (in the percentage deviation from the steady state)						
Y	14.27	1.17	14.19	0.06	0.89	0.61
C	8.52	0.90	8.47	0.01	0.10	0.71
n	22.26	1.41	22.18	0.10	1.40	0.96
EX	20.44	1.75	20.24	0.17	2.19	0.94
IM	8.05	0.88	8.00	0.01	0.09	0.32
Δp	1.89	0.14	1.88	0.00	0.04	0.10
Δp^d	0.68	0.09	0.67	0.00	0.05	0.04
Δe	3.13	0.11	3.12	0.00	0.03	0.14
TOT	7.57	0.22	7.57	0.02	0.13	0.31
q	8.77	0.81	8.73	0.01	0.07	1.09
R^{IB}	0.86	0.07	0.85	0.00	0.03	0.21
R^L	0.85	0.07	0.85	0.00	0.03	0.16
R^T	0.84	0.07	0.84	0.00	0.03	0.08
EFP	0.03	0.00	0.03	0.00	0.00	0.05
Means (in the percentage deviation from the steady state)						
Y	−1.0513	−0.0014	−1.0514	−0.0014	−0.0014	−0.0314
C	−0.0847	−0.0047	−0.0747	−0.0047	−0.0047	−0.0747
n	−1.6373	0.0027	−1.6373	0.0027	−0.0073	−0.0473
EX	−2.9645	−0.0245	−2.9145	−0.0045	−0.0245	−0.0245
IM	0.7656	−0.0044	0.7656	−0.0044	0.0056	−0.0245

estimated monetary policy can be stated as $\Delta h_t^{Est} = 0.319[-1.116\Delta p_t + 0.0\text{mc}_t - 0.403\Delta e_t] + 0.681\Delta h_{t-1}^{Est} + \varepsilon_t^H$, which is more persistent than the optimized policy, but follows by stabilizing the CPI inflation and exchange rates in a similar fashion.

Table 7 reports the results. As shown, this policy leads to higher macroeconomic fluctuations in most of the variables such as output, CPI inflation and exchange rate.

This policy also lowers the mean levels of output, consumption and employment which consequently results in a significant welfare loss of 1.89% of the steady state consumption, relative to the implementation of the optimized policy. Under financial shocks, this policy leads to higher variations in output, inflation as well as exchange rates, and results in lower welfare than that under the optimized rule.

This study may suggest that, while the monetary aggregate policy rule that Taiwan's central bank conducts is in line with the welfare-optimizing monetary policy rule, it may be welfare improving by alleviating some of the need to smooth the monetary growth rate and by strengthening its efforts in stabilizing the inflation and exchange rate fluctuations.

5. SENSITIVITY ANALYSES

In this paper, we consider some variations of the benchmark model to check for the robustness of the results obtained above in which the monetary aggregate rule is optimal.

5.1 Highly Efficient Banks

In line with the steady state analyses, it would be helpful for us to examine the model under a highly efficient banking sector by raising the banking productivity F to 50. As shown in its steady state results, the EFP and the banking employees are lowered to a level close to zero, which resembles the conventional model with the frictionless financial intermediary. The results are shown in Table 8. The optimized money growth rate rule under the frictional credit market remains optimal when the financial friction is absent. The welfare-maximizing interest rate rules in both cases are also almost identical, but require slightly greater effort in inflation stabilization under efficient banking. As shown, the monetary aggregate rule still outperforms the interest rate rule.

Furthermore, the comparison of Tables 4 and 8 demonstrates that an efficient financial system leads to lower output volatility under both rules, and helps boost the mean level of output, consumption and employment. This in turn raises the welfare level by 0.44% regardless of whether the monetary aggregate rule or interest rate rule is implemented.

Table 8 Highly Efficient Financial Intermediary $(F = 50)$

Optimized monetary growth rate rule: $\Delta h_t^{Eff} = 0.9[-2\Delta p_t - 0.2\text{mc}_t - 2\Delta e_t] + 0.1\Delta h_{t-1}^{Eff} + \varepsilon_t^H$.
Optimized interest rate rule: $R_t^{IB,Eff} = 0.1[0.0029 + 1.8\Delta p_t + 2\text{mc}_t + 0.0\Delta e_t] + 0.9R_{t-1}^{IB,Eff} + \varepsilon_t^R$.

	Δh_t^{Eff}	$R_t^{IB,Eff}$
	$\varepsilon^A, \varepsilon^{R^*}, \varepsilon^{ex}, \varepsilon^{P^*}$	
Welfare (as the percentage of the steady state consumption)		
γ^a	1.0099	0.9452
Standard deviations (in the percentage deviation from the steady state)		
Y	7.18	7.63
C	9.30	9.28
n	11.00	11.62
EX	15.35	15.08
IM	8.70	8.60
Δp	0.52	0.55
Δp^d	0.37	0.35
Δe	1.16	1.16
TOT	4.38	4.83
q	8.69	8.52
Means (in the percentage deviation from the steady state)		
Y	−0.6873	0.7073
C	0.4782	0.4678
n	−1.0844	−1.1044
EX	35.1199	35.2399
IM	36.4999	36.5299

5.2 Lower Degree of International Capital Mobility

In the benchmark model, we assume that the degree of capital mobility $\sigma = 0.0019$, which is an estimate based on 21 developed countries derived by Lane and Milesi-Ferretti (2001). However, the capital market in Taiwan would be less open than in these countries. Thus, we run the calibrations under the international capital market with greater friction by assuming that $\sigma = 0.019$. The results are reported in column

Table 9 Alternative Specifications

(A) Higher international asset market friction: $\sigma = 0.019$

Optimized monetary growth rate rule: $\Delta h_t^{FRI} = [-2\Delta p_t - 2\text{mc}_t - 2\Delta e_t] + 0.0\Delta h_{t-1}^{FRI} + \varepsilon_t^H$.

Optimized interest rate rule: $R_t^{IB,FRI} = [0.0029 + 2\Delta p_t + 2\text{mc}_t + 0.0\Delta e_t] + 0.0 R_{t-1}^{IB,FRI} + \varepsilon_t^R$.

(B) Lower price stickiness: $\xi_d = 0.635$

Optimized monetary growth rate rule: $\Delta h_t^{STI} = 0.8[-2\Delta p_t - 0.2\text{mc}_t - 2\Delta e_t] + 0.2\Delta h_{t-1}^{STI} + \varepsilon_t^H$.

Optimized interest rate rule: $R_t^{IB,STI} = 0.1[0.0029 + 0.0\Delta p_t + 2\text{mc}_t + 0.0\Delta e_t] + 0.9 R_{t-1}^{IB,STI} + \varepsilon_t^R$.

	(A) High capital market friction: $\sigma = 0.019$		(B) Low price stickiness: $\xi_d = 0.635$	
	Δh_t^{FRI}	$R_t^{IB,FRI}$	Δh_t^{STI}	$R_t^{IB,STI}$
	$\varepsilon^A, \varepsilon^{R^*}, \varepsilon^{ex}, \varepsilon^{P^*}$		$\varepsilon^A, \varepsilon^{R^*}, \varepsilon^{ex}, \varepsilon^{P^*}$	
Welfare (as the percentage of the steady state consumption)				
γ^a	0.1697	0.1430	0.5851	0.5324
Standard deviations (in the percentage deviation from the steady state)				
Y	3.78	3.89	7.48	8.10
C	4.46	4.38	8.94	9.01
n	5.40	5.60	11.48	12.37
EX	8.09	7.96	15.44	14.92
IM	4.41	4.29	8.46	8.49
Δp	0.36	0.39	0.70	0.73
Δp^d	0.31	0.31	0.33	0.29
Δe	0.89	0.90	1.34	1.29
TOT	2.23	2.36	4.45	5.17
q	4.49	4.29	8.30	8.36
Means (in the percentage deviation from the steady state)				
Y	−0.1814	−0.1714	−0.7514	−0.7914
C	0.1253	0.1253	0.4553	0.4653
n	−0.2873	−0.2673	−1.1773	−1.2373
EX	−0.2445	−0.2345	−0.9545	−0.7345
IM	0.1256	0.1356	0.4956	0.5456

(A) in Table 9. The optimized money growth rate can be characterized by $\Delta h_t^{FRI} = [-2\Delta p_t - 2\text{mc}_t - 2\Delta e_t] + 0.0\Delta h_{t-1}^{Est} + \varepsilon_t^H$ which is less persistent than the optimized rule in the benchmark case, but emphasizes the stabilization of output gap. On the other hand, the welfare-maximizing interest rate rule is $R_t^{IB,FRI} = [0.0029 + 2\Delta p_t + 2\text{mc}_t + 0.0\Delta e_t] + 0.0R_{t-1}^{IB,FRI} + \varepsilon_t^R$ which placesgreater emphasis on output stabilization, but not on interest rate smoothing. Since the asset market is less open, it is less necessary to smooth the interest rate to reduce the exchange rate volatility while the foreign interest rate fluctuates. Overall, with a lower degree of international risk sharing when the capital is less mobile, the domestic macro economy exhibits greater stability, but the higher asset market friction lowers the welfare gain of both policies. The monetary aggregate rule remains welfare dominating compared to the interest rate rule.

5.3 Lower Degree of Price Stickiness

In the benchmark model, we assume the degree of price stickiness ξ_d to be 0.75, which implies an average price-change duration of 4 quarters following the conventional setting based on the estimates for European countries. However, the estimation of price stickiness based on the Taiwanese data provided by Teo (2009) shows that prices in Taiwan may be less sticky than in Europe, being only 0.635 when associated with 2.74 quarters of price rigidity. The results under lower price stickiness are reported in column (B) in Table 9. These results show that the optimized monetary aggregate rule is slightly more persistent than that under higher price rigidity, while the optimized interest rate rule tends to attach less effort to stabilizing the CPI inflation. With higher price flexibility, the fluctuations in the economy become greater, but the welfare levels are raised up. Implementing the monetary aggregate rule is still welfare improving.[22]

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[22] The factor that determines the welfare dominance of the monetary aggregate rule remains an interesting issue for future study. As discussed above, the factors considered in the sensitivity analyses, including the financial friction, are not the determinants. It is natural to conjecture that trade openness can be the key factor in the monetary policy for a small open economy which can be strongly affected by external shocks and exchange rate variations. To examine this issue more carefully, we calibrate the model under alternative degrees of trade openness where $\alpha^m = 0.6, \alpha^m = 0.1$, and under a closed economy according to the specification in Goodfriend and McCallum (2007). The monetary aggregate rule remains welfare superior to the interest rate rule in all cases, but the welfare under each of these two policies become closer to each other when α^m decreases. Thus, trade openness can be the factor that influences the welfare level of monetary policy, but not the determinant of welfare superiority of the monetary aggregate rule. In a more open economy, the foreign shocks and exchange rate fluctuations have greater impacts on the economic variations. As a result, the optimized monetary aggregate rule, which is characterized by strong exchange rate stabilization, can be more effective in reducing the inflation rate fluctuations. When $\alpha^m = 0.6$, the standard deviation of the inflation rate is 0.8% under the optimized interest rate rule and is 0.76% under the optimized monetary aggregate rule. Since we have not found the condition under which the interest rate rule can strictly dominate the monetary aggregate rule, more efforts may be required to check whether the alternative specifications of the model can make the interest rate rule welfare superior to the monetary aggregate policy.

6. CONCLUSION

In this paper, we investigate the optimal monetary policy for Taiwan by using a micro-based DSGE model with a frictional banking sector. The focus of this study is the welfare examination of monetary policies in response to various shocks. We investigate the welfare implications of the money growth rate rule which is the announced monetary policy rule of Taiwan's central bank at present, and the alternative Taylor-type interest rate rule. The welfare assessment shows that the money growth rate rule can be welfare superior to the interest rate rule. Without specific inflation or exchange rate targeting, the calibration results show that the optimized money growth rate rule can stabilize the economy better than the optimized interest rate rule. The volatilities of the output, inflation and exchange rates under the money growth rate rule are lower than those under the interest rate rule. With the direct relevance of the monetary aggregate lying with consumption and output, the control of the money growth rate rule can help stabilize both the nominal and real variables. This result supports the monetarists' view.

The welfare ranking of these two policy rules also holds for alternative specifications of the model: a highly efficient credit market, greater international capital friction, and lower nominal rigidity, the latter two of which may better characterize the Taiwanese economy while the benchmark case uses the parameter values obtained from the mainstream literature, are the estimates from the US and European countries.

Two of the analyses are also worth noting here. First, the inclusion of the banking sector allows us to examine the optimal policy responses to the adverse shocks to the credit market. We show that the interest rate rule can be welfare dominating vis-à-vis the money growth rate rule, but generates a less desirable outcome in causing a sharper decline in employment during the recession. Secondly, the estimated monetary policy of Teo (2009) follows the optimized monetary aggregate rule in this study in a similar fashion, but with lower weights for the inflation and exchange rate stabilization. This policy therefore generates greater macroeconomic volatilities and results in a larger welfare loss.

We conclude this paper by mentioning some interesting issues for future research. First of all, we may instead consider the welfare ranking of several simple monetary rules for Taiwan, such as inflation targeting and exchange rate peg policies as in Sutherland (2006), under this framework. This may provide the better insight for welfare consideration of exchange rate variations which remain the main concern for Taiwan. Secondly, and finally, it would be interesting to examine whether the monetary policy should react to the asset price. This has been an important issue recently and the stability of the asset market has been the primary concern for Taiwan.

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動態隨機一般均衡 (DSGE) 架構下之台灣最適貨幣政策分析

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摘　要

本文藉由比較在一具有銀行部門的動態隨機一般均衡(DSGE)模型中,採行貨幣成長率法則與泰勒法則下之福利水準來評估台灣的最適貨幣政策。研究結果顯示,對台灣而言,貨幣成長率法則較泰勒法則更能有效地促進經濟穩定而達到較高的福利水準。主要原因在於貨幣總量具有與消費直接相關的流動性效果,透過控制貨幣總量的成長率將可有效地降低通膨與產出的波動性。此結果在不同的模型設定下皆成立,且與 Teo(2009)在一 DSGE 模型下估計所得之台灣當前的貨幣政策大致上一致,但最適貨幣政策在穩定通貨膨脹率與匯率上的效果較佳。