Monetary policy responses amid credit and asset booms and busts

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Optimal Monetary Policy Responses amid Credit and Asset Booms and Busts

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Abstract

This paper examines the conduct of monetary policy in the presence of credit and asset booms and busts. Conventional wisdom is for the central bank to respond to asset prices and other financial indicators insofar as these factors affect the forecasts of inflation. This paper finds that such strategy is far from being optimal. This paper derives optimal policy under commitment in a standard financial accelerator model and finds that in the optimal equilibrium, the central bank responds to a rise in productivity growth by making a credible commitment to keep the rate of return on capital below the trend. This causes net worth to be countercyclical, which is the key mechanism that allows the central bank to successfully stabilize the economy. The countercyclicality of net worth is consistent with what can be found in the data on the periods following the Volcker chairmanship of the FOMC.

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Keywords: Financial accelerator, optimal policy under commitment, asset prices, credit market frictions, countercyclicality of net worth

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1 Introduction

Over the past few decades, one interesting economic trend has emerged. It appears that global financial markets are increasingly subject to credit, investment and asset-price booms and busts.[1] Such a phenomenon is associated with a sharp surge in credit and investment in the upturn of the cycle, due to among other things an excessive rise in productivity growth. This in turn leads to a boom in equity prices and real-estate markets. Then, some disruptive incidents trigger the bust phase of the cycle, resulting in a sudden drying-up of liquidity and a sharp fall in asset prices, which for many cases culminating into a banking or a currency crisis.

A case in point is the sharp surge in credit to the real estate sector, that led to the US savings and loan crisis in the 1980s. A similar chain of events occurred in Japan in the late 1980s, that resulted in the "lost decades," the periods of economic stagnation characterized by strings of recession and deflation. A boom in credit and an excessive rise in asset prices were also observed prior to the Asian Financial Crisis in 1997-98. Most recently, the world witnessed equity-price bubbles in the NASDAQ, which were associated with heavy investment in information technology and telecommunications, only to end up with the stock market collapse in 2002.

This raises a question on how central banks should conduct monetary policy amid credit and asset booms and busts. One prominent approach, dubbed by Bordo and Jeanne (2002b) as 'Benign Neglect' is for central banks to respond to asset prices and other financial factors insofar as these factors affect the forecasts of inflation. Under this notion, several authors suggest that an appropriate monetary-policy strategy is to set short-term interest rates to respond strongly to inflation [See Bernanke and Gertler (1999, 2001), Gilchrist and Leahy (2002) and Gilchrist and Saito (2006)].[2]

The question is whether such a strategy is desirable from the standpoint of an inflation-targeting central bank whose objective is to maintain price stability and full employment. The earlier literature did not give a definite answer to this. It should be noted that to evaluate the monetary policy strategy of responding strongly to inflation, the earlier literature compares the performance of such strategy with those of a narrowly-defined set of Taylor-type interest rate rules. In particular, the earlier literature finds that the policy strategy to respond strongly to inflation leads to a better macroeconomic outcome than, for instance, a rule that responds *weakly* to inflation and a rule that responds to asset prices. But this does not necessarily mean that the policy strategy to respond strongly to inflation is *optimal.*

The present paper attempts to examine whether it is optimal for central banks to follow the policy strategy of responding strongly to inflation. As a contribution, the present paper is the first paper that derives optimal policy

[1] See for instance Bordo and Jeanne (2002a) and White (2006).

[2] To respond *strongly* to inflation means that the extent to which the central bank raises the nominal interest rate is much larger than the increase in inflation. See section 3 for a more precise definition and how to model this strategy analytically.

under commitment in a standard financial accelerator model with endogenous capital accumulation and credit-market frictions.[3] The paper evaluates the performance of the policy strategy of responding strongly to inflation and compares it with macroeconomic outcomes under optimal policy.

The paper finds that the monetary policy strategy of responding strongly to inflation is far from being optimal. Under such a strategy, the economy is subject to credit and asset boom-bust cycles, in which following a rise in productivity growth, there is a run-up in credit. This leads to a sharp increase in investment and asset prices, which causes firms to take on more credit. The excessive growth rate of capital accumulation causes the economy to overheat, thereby resulting in inflationary pressures.

On the other hand, following optimal policy under commitment, the central bank is able to successfully stabilize inflation and the output gap while avoiding the vicious cycle of credit and asset booms and busts. The paper finds that under optimal policy the central bank responds to an unexpected rise in productivity growth by making a credible commitment to maintain the tightening bias and thus to keep the return on capital below the trend. This causes net worth to be countercyclical, which is the reason why the central bank can successfully sever the link between the distortions in the financial markets and those in the real sector. The countercyclicality of net worth under optimal policy is also consistent with the empirical evidence in the periods following the Volcker chairmanship of the FOMC, in which the economy has become much less volatile.

The remainder of the paper proceeds in the following manner. Section 2 sets up the model used for the analysis. Section 3 presents the policy problem of a central bank who can commit, and provides an algorithm for computing optimal policy under commitment. The stabilization performance of optimal policy under commitment and macroeconomic outcomes under the policy strategy of responding strongly to inflation are examined in section 4. Section 5 investigates some alternative monetary policy rules that are often used in the literature. Section 6 provides empirical evidence that the countercyclicality of net worth in the optimal equilibrium is consistent with what can be found in the data. Section 7 explains an intuition on why net worth is countercyclical in the optimal equilibrium. Section 8 concludes.

2 The model economy

The model used in the analysis is the one presented in Gilchrist and Saito (2006) [henceforth, GS]. The GS model is essentially a standard New Keynesian model augmented to include credit-market frictions through the financial accelerator mechanism described in Bernanke, Gertler and Gilchrist (1999) [henceforth, BGG]. The model consists of six sectors: households, entrepreneurs, retailers,

[3] Faia and Monacelli (2006) use social welfare evaluation but, in their analysis, the central bank is restricted to set the nominal interest rate according to a class of Taylor-type instrument rules.

capital producers, the government and the central bank. Households consume, hold money, save in one-period riskless bonds and supply labor to entrepreneurs. Entrepreneurs manage the production of wholesale goods, which requires capital constructed by capital producers and labor supplied by both households and entrepreneurs. Entrepreneurs purchase capital and finance the expenditures of capital with their net worth and debt. Entrepreneurs sell wholesale goods to monopolistically competitive retailers who differentiate the product slightly at zero resource cost. Each retailer then sets price and sells its differentiated product to households, capital producers, entrepreneurs and the government.

Rather than work through the details of the derivation, which are readily available in GS, I instead directly introduce the log-linearized version of the aggregate relationships of the model.

Table 1 provides a summary of the variables in the model. Throughout, steady-state levels of the variables are in lower case without time subscripts while log-deviations from the steady-state are in lower case with time subscripts. The corresponding hypothetical levels of the variables in the frictionless economy are denoted by a star. Greek letters and lower case Roman letters without subscripts denote fixed parameters. Table 2 provides a summary of the parameters as well as their baseline calibration.

The first equation is the log-linearized version of the national income identity:

$$y_t = \frac{c}{y} c_t + \frac{\mathrm{inv}}{y} \mathrm{inv}_t \tag{1}$$

Note that in the baseline calibration of the GS model, entrepreneurs' consumption and government spending are normalized to zero. Model simulations conducted under the original BGG framework imply that these simplifications are reasonable.

Households' consumption is determined by a standard Euler equation summarizing households' optimal consumption-savings allocation:

$$-c_t = -\mathrm{E}_t c_{t+1} - \mathrm{E}_t z_{t+1} + i_t - \mathrm{E}_t \pi_{t+1} \tag{2}$$

z_t, the growth of productivity, enters the Euler equation, as well as other several equations in the model, because the levels of consumption, investment, output, capital stock and net worth are normalized by the level of technology, in order to make these real quantities stationary.

Households also make a decision on labor supply. Labor demand, on the other hand, is derived from entrepreneurs' profit maximization problem. In an equilibrium, labor supply equals labor demand. Using the labor demand condition to eliminate wages from the labor supply equation yields the following labor-market equilibrium condition:

$$y_t + \mathrm{mc}_t - c_t = (1+\gamma) h_t \tag{3}$$

mc_t enters (3) because we use the definition of mc_t, $\mathrm{mc}_t = p_{w,t} - p_t$, to

eliminate $p_{w,t} - p_t$, where $p_{w,t}$ is the wholesale price and p_t is the price level of the economy. (3) thus is the equation that defines mc_t in the system.

On the production side, entrepreneurs have access to a Cobb-Douglas technology:

$$y_t = \alpha h_t + (1-\alpha) k_t - (1-\alpha) z_t \tag{4}$$

Capital k_t is purchased by the entrepreneurs at the end of period $t-1$. The expected real rate of return on capital, $\mathrm{E}_t r^k_{t+1}$, is given by:

$$\begin{aligned} \mathrm{E}_t r^k_{t+1} \quad &= \quad \frac{\mathrm{mc}(1-\alpha)\frac{y}{k}Z}{\mathrm{mc}(1-\alpha)\frac{y}{k}Z + (1-\delta)} \left(\mathrm{E}_t y_{t+1} - k_{t+1} + \mathrm{E}_t z_{t+1} + \mathrm{E}_t \mathrm{mc}_{t+1}\right) \\ &+ \frac{1-\delta}{\mathrm{mc}(1-\alpha)\frac{y}{k}Z + (1-\delta)} \mathrm{E}_t q_{t+1} - q_t \end{aligned} \tag{5}$$

Intuitively, the expected real rate of return on capital depends on the marginal profit from the production of wholesale goods, which (in log-linearized) is given by:

$$\frac{\mathrm{mc}(1-\alpha)\frac{y}{k}Z}{\mathrm{mc}(1-\alpha)\frac{y}{k}Z + (1-\delta)} \left(\mathrm{E}_t p_{w,t+1} - \mathrm{E}_t p_{t+1} + \mathrm{E}_t y_{t+1} - k_{t+1}\right)$$

$\mathrm{E}_t y_{t+1} - k_{t+1}$ is derived from log-linearizing the marginal product of capital. Substituting the real marginal cost (for the retailers), $\mathrm{mc}_t = p_{w,t} - p_t$, we derive the first part of the right-hand side of (5). The second part, $\frac{1-\delta}{\mathrm{mc}(1-\alpha)\frac{y}{k}Z+(1-\delta)} \mathrm{E}_t q_{t+1} - q_t$, is the capital gain. Summing the marginal profit and the capital gain, we derive at the real rate of return on capital.

To finance their capital expenditures, the entrepreneurs employ internal funds, net worth, but also need to acquire loans from financial intermediaries. In the presence of credit-market frictions, the financial intermediaries can verify the return on the entrepreneurial investment only through the payment of a monitoring cost. The financial intermediaries and the entrepreneurs design loan contracts to minimize the expected agency cost. The nature of the contracts is that the entrepreneurs need to pay a premium above the riskless rate, which in this model is the opportunity cost for the financial intermediaries. The external finance premium in turn depends on the financial position of the entrepreneurs. In particular, the external finance premium increases when a smaller fraction of the capital expenditures are financed by the entrepreneurs' net worth:

$$s_t = \chi \left(q_t + k_{t+1} - n_{t+1}\right) \tag{6}$$

In a competitive financial market, the expected cost of borrowing is equated to the expected return on capital:

$$\mathrm{E}_t r^k_{t+1} = i_t - \mathrm{E}_t \pi_{t+1} + s_t \tag{7}$$

where $i_t - \mathrm{E}_t \pi_{t+1}$ is the (real) riskless rate.

The rest of the capital expenditures are financed by entrepreneurial net worth, which is determined by,

$$n_{t+1} = \frac{k}{n} r^k_t - \left(\frac{k}{n} - 1\right) \mathrm{E}_{t-1} r^k_t + n_t - z_t$$

That is, the aggregate net worth of the entrepreneurs at the end of period t is the sum of the net worth from the previous period, n_t, and $\frac{k}{n} r_t^k - \left(\frac{k}{n} - 1\right) \mathrm{E}_{t-1} r_t^k$, the operating profit of the entrepreneurs earned during period t. $\frac{k}{n} r_t^k$ is the (log-linearized) realized return on investment. $\left(\frac{k}{n} - 1\right) \mathrm{E}_{t-1} r_t^k$ is the (log-linearized) entrepreneurs' marginal cost of external funds that is predetermined in period t by the financial intermediaries. Using the definition of the external finance premium, $\mathrm{E}_{t-1} r_t^k = s_{t-1} + i_t - \mathrm{E}_{t-1} \pi_t$, we have:

$$n_{t+1} = \frac{k}{n} r_t^k - \left(\frac{k}{n} - 1\right) (s_{t-1} + i_t - \mathrm{E}_{t-1} \pi_t) + n_t - z_t \tag{8}$$

The entrepreneurs purchase capital from capital-producers who combine investment and depreciated capital stock. This activity entails physical adjustment costs, with the corresponding CRS production. The aggregate capital accumulation equation is thus given by:

$$k_{t+1} = \frac{(1-\delta)}{Z} (k_t - z_t) + \left(1 - \frac{1-\delta}{Z}\right) \mathrm{inv}_t \tag{9}$$

Capital producers maximize profit subject to the adjustment cost, yielding the following first-order condition:

$$q_t = \eta_k (\mathrm{inv}_t - k_t + z_t) \tag{10}$$

(10) can be interpreted as an equilibrium condition for the investment-good market. That is, the demand for investment from entrepreneurs equals the investment goods supplied by capital producers. This determines the price of capital, which in this model, interpretable as asset prices. (10) implies that investment increases as asset prices rise.

The retailers set price in a staggered fashion, as in Calvo (1983). This gives rise to a standard Phillip curve:

$$\pi_t = \kappa \mathrm{mc}_t + \beta \mathrm{E}_t \pi_{t+1} \tag{11}$$

It is practical to use (11) to write the dynamics of net worth as:

$$n_{t+1} = \frac{k}{n} r_t^k - \left(\frac{k}{n} - 1\right) \left(s_{t-1} + i_t - \frac{\pi_{t-1}}{\beta} + \frac{\kappa}{\beta} \mathrm{mc}_{t-1}\right) + n_t - z_t \tag{12}$$

The growth of productivity has both transitory and persistent components:

$$z_t = d_t + \varepsilon_t \tag{13}$$

The persistent component follows an AR(1) process:

$$d_t = p_d d_{t-1} + \upsilon_t \tag{14}$$

where shocks to the transitory and persistent components are,

$$\varepsilon_t \sim i.i.d.N\left(0, \sigma_\varepsilon^2\right)$$

and

$$v_t \sim i.i.d.N\left(0, \sigma_v^2\right)$$

Finally, since one of the central bank's target variables is the output gap, which is the deviation of output from its hypothetical level in the frictionless economy, we also have the following set of equations defining the frictionless economy,[4]

$$\begin{aligned}
y_t^* - c_t^* &= (1+\gamma)\, h_t^* && (15)\\
y_t^* &= \alpha h_t^* + (1-\alpha) k_t^* - (1-\alpha) z_t && (16)\\
y_t^* &= \frac{c}{y} c_t^* + \frac{\text{inv}}{y} \text{inv}_t^* && (17)\\
k_{t+1}^* &= \frac{1-\delta}{Z}\left(k_t^* - z_t\right) + \left(1 - \frac{1-\delta}{Z}\right)\text{inv}_t^* && (18)\\
q_t^* &= \eta_k \left(\text{inv}_t^* - k_t^* + z_t\right) && (19)\\
r_t^* &= \frac{\text{mc}(1-\alpha)\frac{y}{k}Z}{\text{mc}(1-\alpha)\frac{y}{k}Z + (1-\delta)}\left(\mathrm{E}_t y_{t+1}^* - k_{t+1}^* + \mathrm{E}_t z_{t+1}\right) && (20)\\
&\quad + \frac{1-\delta}{\text{mc}(1-\alpha)\frac{y}{k}Z + (1-\delta)}\mathrm{E}_t q_{t+1}^* - q_t^* &&\\
-c_t^* &= -\mathrm{E}_t c_{t+1}^* - \mathrm{E}_t z_{t+1} + r_t^* && (21)\\
\widehat{y}_t &= y_t - y_t^* && (22)
\end{aligned}$$

Thus, I define the frictionless variables conditional on the hypothetical level of capital stock that exists when the economy has been under flexible prices and without credit-market frictions, as in Neiss and Nelson (2003). I also conducted the analysis in this paper by defining the frictionless economy conditional on the actual level of capital stock, as in Woodford (2003). All of the conclusions in this paper remain valid under the Woodford approach. I follow Neiss and Nelson because this approach allows me to illustrate my results in a particularly sharp way.

For ease of presentation, write the model economy in the state-space format, as in Svensson (2006):

$$\begin{bmatrix} X_{t+1} \\ Hx_{t+1|t} \end{bmatrix} = A \begin{bmatrix} X_t \\ x_t \end{bmatrix} + Bi_t + \begin{bmatrix} C \\ 0 \end{bmatrix} \varepsilon_{t+1} \tag{23}$$

[4] Like Gilchrist and Saito (2006), in the frictionless economy, there are no nominal rigidities and credit-market frictions. The reason that I define the frictionless economy as the flex-price economy in the absence of credit-market frictions as opposed to in the presence of credit-market frictions is because it can be argued that a goal of the central bank is to lead the economy as close as possible to the "distortion-free" state. In this model economy, credit-market frictions are distortions in the form of asymmetric information in financial markets that in turn gives rise to fluctuations in the external finance premium. As will be shown later, the central bank can in fact stabilize the external finance premium. At the micro-level, unlike the distortions arisen from monopolistic competition that are beyond central banks' authority to deal with, most central banks, including the Federal Reserve, are capable of dealing with the distortions in financial markets. As pointed out by Bernanke (2002), "[T]he Fed has been entrusted with the responsibility of helping to ensure the stability of the financial system...by supporting such objectives as more transparent accounting and disclosure practice and working to improve the financial literacy and competence of investors."

where X_t is an n_X-vector of predetermined variables, x_t is an n_x-vector of non-predetermined variables, i_t is an n_i-vector of instruments , and ε_t is an n_ε-vector of exogenous zero-mean iid shocks. The matrices A, B, C, and H are of dimension $(n_X + n_x) \times (n_X + n_x)$, $(n_X + n_x) \times n_i, n_X \times n_\varepsilon$ and $n_x \times n_x$, respectively. For any vector z_t, $z_{t+1|t}$ denotes the rational expectation $\mathrm{E}_t z_{t+1}$.

It is practical to partition A and B conformably with X_t and x_t,

$$A \equiv \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}, \qquad B \equiv \begin{bmatrix} B_1 \\ B_2 \end{bmatrix}$$

Under this format, the system includes nine predetermined variables, twenty non-predetermined variables, two shocks and one instrument. Appendix A includes the detail on how to present the GS model into the canonical format (23).

3 Monetary policy

3.1 Policy rule to respond strongly to inflation

I close the model by specifying how the central bank conducts its monetary policy. According to conventional wisdom, an optimal strategy is for the central bank to set the nominal interest rate to respond strongly to inflation. In other words, there is no further gain from responding to asset prices and other financial indicators beyond the extent to which they affect the central bank's forecast of inflation.

Such strategy can be modelled via a Taylor-type instrument rule, a common practice since Taylor (1993). Under the financial accelerator framework, several authors suggest that an optimal strategy is for the central bank to adopt the following Taylor-type instrument rule (thereafter BG base-case rule):[5]

$$i_t = 2\pi_t \tag{24}$$

The coefficient on inflation of two is chosen (by the earlier literature) to render determinacy and to ensure that the magnitude of monetary-policy tightening is large enough to suppress inflationary pressures.[6] The idea is to create a rise (fall) in the real interest rate in response to a positive (negative) shock to the economy.

[5] See Bernanke and Gertler (1999), Gilchrist and Leahy (2002) and Gilchrist and Saito (2006). In its original version, as in Bernanke and Gertler (1999), the expected inflation, $\mathrm{E}_t\pi_{t+1}$, is used in the rule, instead of π_t. Nonetheless, using π_t in fact leads to a better macroeconomic outcome. The reason is, according to the Phillip curve (11), $\pi_t = \kappa \mathrm{mc}_t + \beta \mathrm{E}_t\pi_{t+1}$. Thus, setting the nominal interest rate to respond to π_t is equivalent to responding to $\mathrm{E}_t\pi_{t+1}$ as well as mc_t. mc_t depends on the output gap, and this causes the rule with π_t to perform better than that with $\mathrm{E}_t\pi_{t+1}$ alone. Therefore, I focus on the rule that responds to π_t, as in Gilchrist and Saito (2006). The stabilization performance of the rules that respond to $\mathrm{E}_t\pi_{t+1}$ is available upon request.

[6] In the analysis in this paper, I also choose the coefficient "optimally" to minimize the central bank loss function.

3.2 Optimal policy under commitment

As a benchmark for comparison, I examine macroeconomic outcomes generated by optimal policy under commitment. That is, the central bank is mandated with an intertemporal loss function in period 0 with the constant discount factor δ $(0 < \delta < 1)$ and a relative weight on output-gap variability equal to $\lambda > 0$,

$$\mathrm{E}_0 \sum_{t=0}^{\infty} (1-\delta)\, \delta^t L_t \tag{25}$$

where

$$L_t = \frac{1}{2}[\pi_t^2 + \lambda \widehat{y}_t^2] \tag{26}$$

To derive optimal policy under commitment, the central bank minimizes (25), once-and-for-all in period $t = 0$, subject to (23) for $t \geq 0$ and to given initial predetermined variables. To be more specific, the monetary policy problem is to minimize the following Lagrangian:

$$\mathcal{L}_0 = \mathrm{E}_0 \sum_{t=0}^{\infty} (1-\delta)\delta^t \left[\begin{array}{c} L_t + \Xi_t^{'} \left(Hx_{t+1} - A_{21}X_t - A_{22}x_t - B_2 i_t\right) \\ +\xi_{t+1}^{'} \left(X_{t+1} - A_{11}X_t - A_{12}x_t - B_1 i_t - C\varepsilon_{t+1}\right) \end{array} \right] + \frac{1-\delta}{\delta}\xi_0^{'} \left(X_0 - \overline{X}_0\right) \tag{27}$$

where ξ_{t+1} and Ξ_t are vectors of n_X and n_x Lagrange multipliers of the upper and lower blocks, respectively, of the canonical system (23). $\overline{X}_0$ is the given initial predetermined variables. Appendix B provides an algorithm on how to solve this problem using the recursive saddle-point method.

It should be noted that (26) is the metric adopted in the earlier literature to evaluate the *relative* performance of Taylor-type instrument rules.[7] It corresponds to the idea that the goal of monetary policy is to minimize the volatility of inflation and the output gap. The earlier literature concludes that rule (24) is optimal by comparing its performance measured by (26) with other Taylor-type instrument rules.

Optimal policy under commitment, on the other hand, gives the first-best macroeconomic outcome that the central bank is capable of implementing under the financial accelerator economy.[8] Thus, optimal policy under commitment can provide a benchmark for comparison in evaluating the *absolute* performance of rule (24).

4 Performance of benchmark monetary policy rules

Table 3 compares macroeconomic outcomes of the BG base-case rule (24) with those generated by optimal policy under commitment. It is evident that the

[7] To be more specific, most earlier papers set λ to unity.

[8] This first-best macroeconomic outcome can be implemented via *inflation forecast targeting*. See Svensson and Woodford (2005).

BG base-case rule is far from being optimal. Under the BG base-case rule, inflation and the output gap, which are the target variables in this case, are relatively volatile. As a result, the loss, which is the overall performance of a policy rule, is 0.2843 under rule (24), compared to 0.0085 under optimal policy under commitment.

I also go beyond the earlier literature by choosing the coefficient in the BG base-case rule to minimize (25), instead of only using the ad-hoc coefficient of two. The macroeconomic outcomes of the optimized rules are shown in the parentheses. The loss of the optimized rule is 0.2119, which is 26% lower than the ad-hoc version. In any event, this is still far from being able to match the first-best outcome under optimal policy.[9]

The same implication can be drawn from figure 1, which compares the impulse responses to an unexpected disturbance to productivity growth under the BG base-case rule with those under optimal policy. The dashed lines are those under the BG base-case rule. The solid lines are those under optimal policy. As highlighted in the figure, when compared to optimal policy, the BG base-case rule fails badly to stabilize the economy. In particularly, under the BG base-case rule, the economy is subject to volatile boom-bust cycles. Following an unexpected rise in productivity growth, there is a run-up in credit. This leads to a surge in investment and thus asset prices, which in turn causes entrepreneurs to take on even more debt and to make more investment. This is the reason why the economy overheats as output rises above its full employment level and inflation rises above its target.

Under optimal policy, on the other hand, the economy appears to be able to escape from the vicious cycle of asset booms and busts. As a consequence, optimal policy allows the central bank to successfully stabilize both inflation and the output gap.

4.1 Countercyclicality of net worth in the optimal equilibrium

An important mechanism that allows optimal policy under commitment to perform exceptionally well is the fact that under the optimal equilibrium the evolution of net worth is *countercyclical*, not procyclical as prescribed by the BG base-case rule. Consider an experiment in which productivity growth rises unexpectedly during period t. In the case that the central bank follows the BG

[9] It should be noted that the optimized coefficient is excessively large. This is an unsatisfactory feature of the optimized Taylor-type instrument rules because they prescribe an incredibly aggressive response of the interest-rate instrument to inflation. In practice, inflation numbers are available but often with measurement errors or possibilities to get revised later. Committing to a rule with an excessively large feedback coefficient makes it more likely for the central bank to respond to a small measurement error by setting the interest-rate instrument into a wrong direction by large percentage points, a mistake that may easily send the economy into a recession or an inflationary spiral. And since the excessively large optimized coefficient does not materially improve the economic performance, I will focus on the ad-hoc version of the rules. In any event, all the conclusions derived in this paper remain the same whether I use the optimized version or the ad-hoc version.

base-case rule, net worth will jump by the same magnitude as the rise in the growth of productivity. The reason is that net worth depends on the difference between the return on capital realized during period t and the cost of borrowing. The cost of borrowing in period t is actually locked in by the loan contract that was determined in period $t-1$ and thus unaffected by unexpected disturbances or policy. Following the BG base-case rule, the central bank then adjusts the interest-rate instrument which in the current period does not affect the rational expectations equilibrium of the non-predetermined variables, as shown in (36). Thus, the unexpected rise in the growth of productivity leads to an increase in the realized return on capital and a one-to-one rise in net worth. This is evident from the impulse responses of net worth in figure 1, in which under rule (24) net worth rises one-to-one immediately after the shock.

More intuitively, after the unexpected rise in productivity growth, entrepreneurs will realize that the same amount of resources can lead to more output. That is, the return on their investment becomes higher. Thus, the entrepreneurs will be willing to put more of their own funds into the investment projects, which will lower the probability that the entrepreneurs will default and thereby leading to a decline in the external finance premium. This in turn leads to a lower borrowing cost, and thereby a surge in investment. Asset prices then rise, causing the external finance premium to decline further and thus reinforcing the propagation mechanism. Hence, the financial accelerator mechanism works well in propagating and magnifying a seemingly small disturbance into a sizable destabilizing force. This is the reason why the BG base-case rule fails to contain the destabilizing effect created in the financial market from passing through to the real sector.

Under optimal policy under commitment, on the other hand, net worth falls by a modest amount. The countercyclicality of net worth is a key mechanism that allows optimal policy under commitment to stabilize the economy in the presence of credit-market frictions. This is because the modest fall in net worth prevents the external finance premium from dropping sharply. Such a benign fluctuation in the external finance premium then allows optimal policy under commitment to prevent disturbances in the financial market from developing into a volatile cycle of credit and asset booms and busts.

5 Alternative Taylor-type instrument rules

The analysis in the previous section suggests that it appears to be suboptimal for the central bank to follow the BG base-case rule, a Taylor-type instrument rule that has been used extensively in the literature. This raises a question on the economic performance of other Taylor-type instrument rules, whether these rules can deliver better economic outcomes or even match the first-best outcome under optimal policy. In other words, it is interesting to examine whether the conclusions derived in the previous section are robust to different specifications of Taylor-type instrument rules.

The first alternative Taylor-type instrument rule to be examined is the classic

Taylor (1993) rule:

$$i_t = 1.5\pi_t + 0.5\widehat{y}_t \tag{28}$$

Thus, instead of setting the interest-rate instrument to respond to inflation only, rule (28) also prescribes the central bank to respond to fluctuations in the output gap. The idea is since the goal of the central bank is to stabilize not only inflation, but also the output gap, it makes more sense for the central bank to respond to both target variables. The coefficients of 1.5 and 0.5 are chosen by Taylor (1993). Bernanke and Gertler (2001) suggest that the rule of the same form with the coefficients on inflation of 3 and on the output gap of unity appears to perform reasonably well under the financial accelerator model (thereafter, BG output-gap rule). Nonetheless, the rule in which the coefficients are chosen to minimize the central bank loss function will also be examined.

The second alternative Taylor-type instrument rule to be evaluated is the classic Taylor with the one-period lagged nominal interest rate:

$$i_t = 1.5\pi_t + 0.5\widehat{y}_t + 1.1i_{t-1} \tag{29}$$

The coefficient on the lagged interest rate is 1.1, which is greater than unity. This feature is what Rotemberg and Woodford (1999) call *superinertia*, which has been reported by several, including Levin and Williams (2003), to allow Taylor-type instrument rules to perform reasonably well across several benchmark macroeconomic models. A variant of the Taylor rule with interest-rate smoothing is also examined in Gilchrist and Leahy (2002)

$$i_t = 0.9i_{t-1} + (1 - 0.9)1.1\pi_t$$

in which, the central bank sets the nominal interest rate to respond only to inflation and the one-period lagged interest rate, and not to the output gap (thereafter, GL interest-rate smoothing rule).[10]

The next rule produces the best macroeconomic performance among all the Taylor-type instrument rules examined in Gilchrist and Saito (2006) (thereafter, GS rule):

$$i_t = r_t^* + 2\pi_t + 0.1(q_t - q_t^*)$$

That is, under the GS rule, the central bank sets the interest-rate instrument to respond, not only to inflation, but also to the natural interest rate as well as the asset-price gap.

Finally, the analysis in the previous section suggests that net worth may play a key role on the transmission mechanism. Therefore, consider including net worth into the rule as follows:

$$i_t = 2\pi_t + 0.37n_t$$

This rule, which prescribes the central bank to respond to net worth as well as inflation, is examined in Gilchrist and Leahy (2002) [thereafter, net worth rule].

[10] Note again that in the original version in Gilchrist and Leahy (2002), the expected inflation $\mathrm{E}_t\pi_{t+1}$ is included in the rule, instead of inflation. But responding to inflation in fact leads to a lower loss than responding to the expected inflation due to the same reason as described in the case of the BG base-case rule.

5.1 The performance of alternative Taylor-type instrument rules

Table 4 presents macroeconomic outcomes of the alternative Taylor-type instrument rules. It is evident that all the alternative Taylor rules, either the ad-hoc version or the optimized version, are from being optimal. The best performer among the alternative Taylor rules is the GS rule, which results in a loss of 0.2212, still far from being able to replicate the first-best outcome generated under optimal policy.[11]

The results here suggest that not only the BG base-case rule, but also all the standard Taylor-type instrument rules that are commonly used in the literature fail to stabilize the economy in the presence of credit and asset booms and busts. In such an environment, it may not be an optimal strategy for the central bank to mechanically set interest rates to respond to some economic factors, according to Taylor-type instrument rules.

Figure 2 presents the impulse responses of net worth to an unexpected rise in productivity growth. The solid lines are those under the alternative Taylor rules. The dashed lines are those under optimal policy. It is clear from the figure that net worth is procyclical under all the Taylor-type instrument rules considered while under the optimal equilibrium net worth is countercyclical. As suggested earlier, this is the reason underlying the inability of Taylor rules to stabilize the economy. In particular, following the rise in productivity growth, the increase in net worth causes the external finance premium to decline. This induces entrepreneurs to increase their borrowing and to make more investment, which in turn causes asset prices to rise. Net worth thus rises even further. This is the propagating mechanism underlying the financial accelerator that turns out to work well in magnifying small, initial disturbances into volatile credit and asset booms and busts.

6 Empirical evidence on countercyclicality of net worth

Several studies provide evidence on a shift in the monetary policy regime at the onset of the Volcker chairmanship of the FOMC. Along with the regime switch is an empirical fact that the volatility of the US economy has declined sharply since the mid-1980s.[12]

Table 5 reports the correlation between productivity and the real value (CPI-adjusted) of all shares listed in the NYSE during the pre-Volcker era (1954-1979)

[11] I also evaluate a set of 96 Taylor rules, using almost every reasonable combination of economic variables in the rules and optimized coefficients. Several of them, however, present unconventional monetary policy strategy of responding to combinations of economic variables that are unusual in policy debates and not often used in the literature. In any event, no rules come close to match the first-best outcome under optimal policy. Therefore, I will focus on the rules presented in the previous subsection, which are regularly used by researchers and can be related to real-world policymaking.

[12] See for instance Stock and Watson (2002) and Gail, Lopez-Salido and Valles (2003).

and since the Volcker chairmanship of the FOMC (1979-2007). The real value of all shared listed in the NYSE is a proxy for net worth in the financial accelerator economy. Both variables are HP-detrended.

It is evident from the table that prior to 1979Q3, a commonly determined monetary policy break date, net worth is positively correlated with productivity. After 1979Q3, on the other hand, the correlation between productivity and net worth is mildly negative. As noted in figure 2, such a negative correlation between productivity and net worth is a salient feature of the economic behaviors under optimal policy. In this sense, the analysis in this paper suggests that the monetary policy regime since the Volcker chairmanship is close to optimal and might be characterized as optimal policy under commitment.

It should be noted that the same conclusion is still valid when 1984Q1 is used as the breakdate instead. 1984Q1 is identified by many authors as a breakpoint in output growth volatility.[13]

7 Engineering a countercyclicality in net worth

As noted earlier, net worth is countercyclical under the optimal equilibrium. The countercyclicality of net worth is a key mechanism that allows the central bank to avoid credit and asset booms and busts and thus to stabilize inflation and the output gap simultaneously and instantaneously. The question is why net worth is countercyclical under the optimal equilibrium.

7.1 Making a credible commitment as a stabilization instrument

In order to understand the key mechanism that allows the central bank to create a countercyclicality in net worth, it is useful to re-examine the possible policy options that the central bank can use to stabilize the economy. Apparently, in real-world monetary policymaking, the central bank does not solely rely on short-term nominal interest rates as its instrument. For instance, as highlighted in figure 3, the federal funds rate, the benchmark policy rate of the Federal Reserve, has been kept constant at 5.25 percent since June 29, 2006. However, during this time span, economic conditions have been continuously changing, as shown in table 6. Does this imply that during this period, the Fed failed to take action, or did not attempt to fine tune the economy into the right direction?

It is true that the FOMC has not adjust the federal funds rate since June 29, 2006. Nonetheless, adjusting the federal funds rate is not the only channel that the Fed can influence the economy. One method that the FOMC has been used nowadays to influence the economy is to provide “guidance” or its view on the direction of the economy and its tentative stance on near-future monetary policy in the statements following each FOMC meeting.[14] During

[13] See for example Leduc and Sill (2006).

[14] For instance, amid sharp economic slowdown and concerns over the mortgage market, on March 21, 2007, the FOMC signalled its shift from the “tightening bias” to a “neutral bias”

the in-between-meeting period, the Fed can also influence the direction of the economy through public pronouncements and testimony by Fed governors and Reserve Bank presidents.

To understand the intellectual underpinning of such practice and how these "central bankers' talks" can affect the economy, consider iterating (11) forward to obtain:

$$\pi_t = \mathrm{E}_t \sum_{i=0}^{\infty} \beta^i \left[\kappa \mathrm{mc}_{t+i}\right]$$

where mc_{t+i} is the real marginal cost, which is a proxy for the excess demand. It can be shown that mc_{t+i} depends on the gap between the real interest rate and the natural interest rate, $i_{t+i} - \mathrm{E}_{t+i}\pi_{t+1+i} - r^*_{t+i}$, a measure of monetary policy stance. Thus, inflation depends not only on the current monetary-policy stance, but also on private agents' expectations on the Fed's future action. In this way, the Fed can lower inflation, by making a commitment, or a promise, to get tough on inflation going forward. If the Fed's commitment is credible, the expectations on the real marginal cost will be stabilized and the Fed can lower inflation without having to adjust the federal funds rate in the current period.

This is precisely what happens in the optimal equilibrium generated by optimal policy under commitment. Under optimal policy under commitment, the central bank does not solely rely on adjusting the nominal interest rate to stabilize the economy. This is highlighted in the last panel of figure 1 which compares the paths of the nominal interest rate under optimal policy and the BG base-case rule. Notice that although optimal policy under commitment can successfully stabilize inflation, optimal policy under commitment requires the central bank to raise the nominal interest rate much less than that prescribed by the BG base-case rule. The reason that optimal policy under commitment can stabilize inflation without having to aggressively raise the nominal interest rate is because under optimal policy the central bank makes a credible commitment that it will get tough on inflation in the future.

To be more specific, in our framework, the commitment terms correspond to $\Xi'_{t-1}H$ in the dual loss function (33), shown in Appendix B.[15] According to the way that the model economy is arranged into the canonical system as in (30) and (31) in Appendix A, it can be shown that the central bank's commitment

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by dropping a reference to "additional firming" language that it had used since June 29, 2006, despite keeping the federal funds rate constant at 5.25 percent.

[15] To make it easier to see intuitively, consider a simple case, without a loss of generality, that x_t, the non-predetermined variable, consists of only π_t. $\Xi'_{t-1}H$ was determined from the previous period. If $\Xi'_{t-1}H > 0$, this will induce the central bank to implement $\pi_t < 0$ in order to minimize $\widetilde{L}_t$ (on the other hand, $\Xi'_{t-1}H < 0$ will induce the central bank to deliver $\pi_t > 0$). That is, $\Xi'_{t-1}H > 0$, which again was determined in the previous period, is a commitment made by the central bank in the past that constrains the central bank's action in the current period, to deliver $\pi_t < 0$. In the case that x_t consists of more than one variables, we simply have to rearrange terms in $\Xi'_{t-1}H$ for each non-predetermined variable to get each variable's commitment term.

on its policy stance towards future inflation is:

$$\frac{1}{\delta}\Xi_1 + \frac{1}{\delta}\Xi_9 + \Xi_3$$

where Ξ_1, Ξ_9 and Ξ_3 are the Lagrange multipliers on the non-predetermined equations, in the order shown in (31).

Figure 4 displays the impulse response of the central bank's commitment on its policy stance on inflation following an unexpected rise in productivity growth.[16] Thus, under optimal policy, the central bank makes a strong commitment that it will "get tough" on inflation, especially after period 37 onward. This strong commitment to fight inflation even after productivity growth has returned to the trend allows the central bank to stabilize inflationary expectations and thus inflation in the current period, without having to excessively adjust the nominal interest rate.

7.2 Optimal policy responses amid credit and asset booms and busts

Figure 5 presents the impulse response of the central bank's commitment on its policy stance towards the return on capital, r_t^k. The figure suggests that under optimal policy under commitment, the central bank responds to the unexpected rise in productivity growth by making a commitment to keep the rate of return on capital below the trend going forward. This is the reason why in the optimal equilibrium, net worth is countercyclical and the economy can avoid a volatile cycle of credit and asset booms and busts.

Intuitively, consider first the scenario in which the central bank follows a Taylor-type instrument rule. Following an unexpected rise in productivity growth and thus the beginning of the boom phase, the central bank will respond by mechanically raising the nominal interest rate. This will raise the borrowing costs. But as highlighted in the last panel of figure 1, this is only one-time tightening to respond to this surge in productivity growth. As soon as productivity growth returns to the trend, the central bank will lower interest rates as prescribed by the Taylor-type rule. Meanwhile, the rise in productivity growth above the trend implies that entrepreneurs can utilize their resources more efficiently going forward. Thus, without a firm commitment from the central bank to maintain the tightening stance after productivity growth returns to its trend, entrepreneurs can expect an unusually high rate of return on their investment. This is why under Taylor rules, entrepreneurs put more of their own funds into the investment projects at the beginning of the boom phase, which causes net worth to rise sharply above the trend, as shown in figure 2. The external finance premium then falls, causing investment and asset prices to rise. Once it becomes clear that the excessive surge in productivity growth is unsustainable and productivity growth returns to its trend, asset prices and

[16] A positive (negative) number means that the central bank promises to create an inflation rate higher (lower) than if it did not make the promise.

investment thus fall sharply. Therefore, following Taylor rules, such as the BG base-case rule, the central bank fails to prevent asset booms and busts, which in turn lead to the poor stabilization performance of Taylor rules, as highlighted in tables 3 and 4.

Optimal policy under commitment, on the other hand, allows the central bank to avoid the volatile credit and asset booms and busts. The reason is under optimal policy under commitment, the central bank responds to the unexpected rise in productivity growth by making a credible commitment to keep the rate of return on capital below the trend, as shown in figure 5. If the commitment is credible, the return on capital will be expected to remain below the trend. The entrepreneurs thus will be discouraged to put their own funds into the investment projects, which in turn causes net worth to fall modestly below the trend, as shown in figure 2. The external finance premium will then be stabilized and this is why under optimal policy, the central bank can kill off the distortions in the financial markets before they can develop into credit and asset booms and busts.

8 Conclusions

This paper examines optimal policy responses amid credit and asset booms and busts. Conventional wisdom is for the central bank to respond to asset prices and other financial indicators only insofar as these factors signal future changes in inflation. In particular, several studies conclude that it is optimal for the central bank to follow a Taylor-type instrument rule that responds strongly to inflation. Nonetheless, the present paper finds that such a strategy is far from being optimal.

The discrepancy is due to the fact that the earlier papers evaluate the strategy by comparing its performance with a restricted set of Taylor rules. Given that the performance of the Taylor rules in the comparison group is mediocre, the performance of the strategy to respond strongly to inflation appears to be impressive.

The present paper, on the other hand, compares the performance of the strategy to respond strongly to inflation, and its variants in the Taylor family, with optimal policy under commitment. The optimal equilibrium generated by optimal policy under commitment is the first-best macroeconomic outcome that the central bank is capable of implementing. Thus, it can be argued that optimal policy under commitment serves as a more appropriate benchmark for policy evaluation.

Using optimal policy under commitment as a benchmark allows the present paper to discover that the monetary policy strategy of responding strongly to inflation and its variants in the Taylor family fail badly to stabilize the economy. Following an unexpected rise in productivity growth, the central bank is unsuccessful in averting a volatile cycle of asset booms and busts and thus unable to maintain price stability and full-employment output. Optimal policy under commitment, on the other hand, can successfully stabilize both inflation and the output gap while avoiding the vicious cycle of credit and asset booms and busts.

In subsequent research, I hope to consider several extensions to the work so far:

First, it would be interesting to apply the analysis to a model economy with richer dynamics. The GS model can be extended by including a larger set of structural shocks and adding structure to enhance dynamic propagation.[17] The model then can be estimated using the Bayesian techniques. This may allow the stochastic simulations generated by the model to be more consistent with data.

Second, in the present paper, the interpretation of optimal monetary policy is that the central bank operates under the regime of inflation targeting [See Svensson and Woodford (2005)]. Alternatively, it can be interpreted as the central bank optimizing welfare. That is, the central bank's loss function can be derived from taking a Taylor approximation to households' utility, as in Rotemberg and Woodford (1999). It is interesting to learn which variables the central bank should target, in the presence of credit-market frictions.

Third, the analysis in this paper is based on the linear-quadratic paradigm in which the model economy is log-linearized and the objective function is quadratic.[18] An alternative method is that of Schmitt-Grohe and Uribe (2004) in which the first order condition with respect to the original, non-linearized model economy is derived and the first order condition, along with the model economy, is then linearized.[19]

Finally, under the commitment equilibrium, it is assumed that the central bank can make a credible promise that will constrain its action in the future. An important topic for future research is how to *implement* the commitment equilibrium. In other words, how can we design a mechanism that induces the central bank to deliver its own promise made from the past and thereby makes its promise credible to private agents?

[17] For instance, AR(1) exogenous disturbances to net worth and the external finance premium in the spirit of Christiano, Motto and Rostagno (2005) can be included.

[18] The problem with this approach, which will become relevant when we use the Rotemberg and Woodford approximation to derive the central bank loss function, is that the welfare approximation is only valid if the steady state is undistorted. Nonetheless, in the presence of monopolistic competition, the steady state is distorted, unless some unrealistic, ad-hoc government subsidies are assumed. Kim and Kim (2003) show that approximations to distorted models can be significantly inaccurate such that welfare conclusions derived are completely counterintuitive.

[19] I have followed this approach but the preliminary analysis is that there is no solution to the resulting system of linearized first-order conditions and the model economy. This is because the number of non-predetermined variables is greater than that of unstable eigenvalues.

A Presenting the GS model into the state-space format

The GS model (1), (2), (3), (4), (5), (7), (6), (9), (10), (11), (12), (13), (14) and (15)-(22) can be presented in the canonical system (23), by defining the following sets of predetermined and non-predetermined variables,

$$X_t = \{k_t, s_{t-1}, n_t, \pi_{t-1}, \varepsilon_t, d_t, k_t^*, i_{t-1}, \mathrm{mc}_{t-1}\} \tag{30}$$

$$x_t = \left\{ \begin{array}{c} c_t, z_t, \pi_t, r_t^k, y_t, \mathrm{mc}_t, q_t, \mathrm{inv}_t, s_t, h_t, k_{t+1}, n_{t+1}, \widehat{y}_t, y_t^*, h_t^*, \\ c_t^*, k_{t+1}^*, \mathrm{inv}_t^*, q_t^*, r_t^* \end{array} \right\} \tag{31}$$

The elements of the corresponding matrices A, B and C are available upon request.

Note that the key to make the analysis of optimal policy in this paper work is to define k_{t+1} and n_{t+1} as non-predetermined variables. This classification however is not out of ordinary. Remind you that under the GS model, k_{t+1} and n_{t+1} are in fact determined in period t. When one solves a rational expectations model on *dynare* or *gensys,* a convention in these programs is that variables dated t are always known at t. Thus, to assemble the model into these programs, one needs to write k_{t+1} and n_{t+1} as k_t and n_t, or treat k_{t+1} and n_{t+1} in the same way as all other variables dated t.

B Solving optimal policy under commitment

Notice that problem (27) is not recursive, because non-predetermined variables, x_t, depend on expected future non-predetermined variables Hx_{t+1}. Thus, the practical dynamic-programming method cannot be used directly.

Nonetheless, as pointed out in Svensson (2006), this problem can be solved using the recursive saddle-point method of Marcet and Marimon (1999) by introducing a fictitious vector of Lagrange multipliers, Ξ_{-1}, equal to zero,

$$\Xi_{-1} = 0 \tag{32}$$

Then, the discounted sum of the upper term in the Lagrangian can be written:

$$\begin{aligned} & \mathrm{E}_0 \sum_{t=0}^{\infty} (1-\delta)\delta^t \left[L_t + \Xi_t^{'} \left(Hx_{t+1} - A_{21}X_t - A_{22}x_t - B_2 i_t \right) \right] \\ = & \sum_{t=0}^{\infty} (1-\delta)\delta^t \left[L_t + \Xi_t^{'} \left(-A_{21}X_t - A_{22}x_t - B_2 i_t \right) + \frac{1}{\delta} \Xi_{t-1}^{'} Hx_t \right] \end{aligned}$$

It follows that the loss function (26) can be rewritten in terms of the dual period loss:

$$\widetilde{L}_t \equiv L_t + \gamma_t^{'} \left(-A_{21}X_t - A_{22}x_t - B_2 x_t \right) + \frac{1}{\delta} \Xi_{t-1}^{'} Hx_t \tag{33}$$

where Ξ_{t-1} is a new predetermined variable in period t and γ_t is introduced as a new control. Ξ_{t-1} and γ_t are related by the dynamic equation,

$$\Xi_t = \gamma_t \tag{34}$$

The optimal policy under commitment problem can then be reformulated as the recursive dual saddle-point problem:

$$\max_{\{\gamma_t\}_{t\geq 0}} \min_{\{x_t, i_t\}_{t\geq 0}} \mathrm{E}_0 \sum_{t=0}^{\infty} (1-\delta)\delta^t \widetilde{L}_t$$

subject to (34) and,

$$X_{t+1} = A_{11}X_t + A_{12}x_t + B_1 i_t + C\varepsilon_{t+1} \tag{35}$$

Notice that the recursive dual saddle-point problem is recursive where $\{x_t, i_t, \gamma_t\}$ are controls and $\{X_t, \Xi_{t-1}\}$ are predetermined. Here, we can use the standard solution for the Linear Quadratic Regulator(LQR) problem. The solution is in the form of the policy function of the control variables and the evolution of the predetermined variables

$$\begin{bmatrix} x_t \\ i_t \\ \gamma_t \end{bmatrix} = F \begin{bmatrix} X_t \\ \Xi_{t-1} \end{bmatrix} \tag{36}$$

$$\begin{bmatrix} X_{t+1} \\ \Xi_t \end{bmatrix} = M \begin{bmatrix} X_t \\ \Xi_{t-1} \end{bmatrix} + \begin{bmatrix} C \\ 0 \end{bmatrix} \varepsilon_{t+1} \tag{37}$$

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Table 1: Summary of the model variables

Variable	Explanation
c_t	consumption
z_t	productivity growth
i_t	nominal interest rate
π_t	inflation
r_t^k	real rate of return on capital
y_t	output
k_{t+1}	capital at the end of period t
mc_t	real marginal cost
q_t	price of capital
s_t	external finance premium
n_{t+1}	net worth at the end of period t
inv_t	investment
h_t	labor supply
ε_t	transitory shock to productivity
d_t	persistent component of productivity
υ_t	persistent shock to productivity
$\widehat{y}_t$	output gap
r_t^*	natural interest rate

Table 2: Baseline calibration of the model parameters and the steady-state level of some key variables

Parameter	Explanation	Baseline calibration
β	discount factor	0.984
α	labor share	2/3
γ	inverse of labor supply elasticity	0.8
δ	depreciation rate	0.025
η_k	elasticity of asset prices	0.25
$\varepsilon/(\varepsilon-1)$	steady-state markup	1.1
υ	Calvo parameter	0.75
$k/n-1$	steady-state leverage ratio	0.8
χ	elasticity of the finance premium	0.05
μ	mean technology growth rate	0.00427
σ_ε	standard deviation of the transitory shock	0.01×100
σ_υ	standard deviation of the persistent shock	0.001×100
ρ_d	AR(1) coefficient of the persistent shock	0.95

Table 3: Macroeconomic performance of the BG base-case rule and optimal policy under commitment

Rule	Loss	$var(\pi_t)$	$var(\widehat{y}_t)$	$var(i_t - i_{t-1})$
BG base-case	0.2843	0.0549	0.5137	0.0138
	(0.2238)	(6.55E-12)	(0.4476)	(0.0035)
Optimal policy	0.0085	0.0012	0.0158	0.0024

Table 4: Macroeconomic performance of the alternative Taylor-type instrument rules

Rule	Loss	$var(\pi_t)$	$var(\widehat{y}_t)$	$var(i_t - i_{t-1})$
Optimal policy	0.0085	0.0012	0.0158	0.0138
Classic Taylor	0.2948	0.1391	0.4505	0.0105
	(0.2160)	(0.0072)	(0.4248)	(0.0030)
BG output-gap rule	0.2444	0.0603	0.4284	0.0043
Superinertia	0.2249	0.0453	0.4045	0.0009
	(0.2021)	(0.0434)	(0.3607)	(1.48E-05)
GL interest-rate smoothing	1.9784	0.7916	3.1651	0.0072
	(0.2165)	(0.0133)	(0.4197)	(3.09E-04)
GS rule	0.2212	0.0009	0.4416	0.3799
	(0.2030)	(0.0354)	(0.3705)	(0.3899)
Net worth rule	0.3175	0.0359	0.5990	0.3442
	(0.2214)	(8.54E-05)	(0.4427)	(0.0075)

Table 5: The correlation between productivity and net worth

Period	Correlation
1954Q1-1979Q2	0.3782
1954Q1-1983Q4	0.3075
1979Q3-2007Q1	-0.0655
1984Q1-2007Q1	-0.0804

Source: DataStream and the author's calculation

Table 6: Selected US economic indicators, 2006Q1-2007Q2

Economic indicator	2006				2007	
	Q1	Q2	Q3	Q4	Q1	Q2
GDP growth (p.a. %)	5.6	2.6	2.0	2.5	0.6	na
CPI (YoY %)	3.6	4.0	3.3	1.9	2.4	2.6
TIPS-based expected inflation (p.a. %)	2.6	2.4	2.2	2.0	2.3	na

Source: US Bureau of Economic Analysis, Federal Reserve Bank of Cleveland

Figure 1: Impulse responses to an unexpected rise in productivity growth under the BG base-case rule and optimal policy

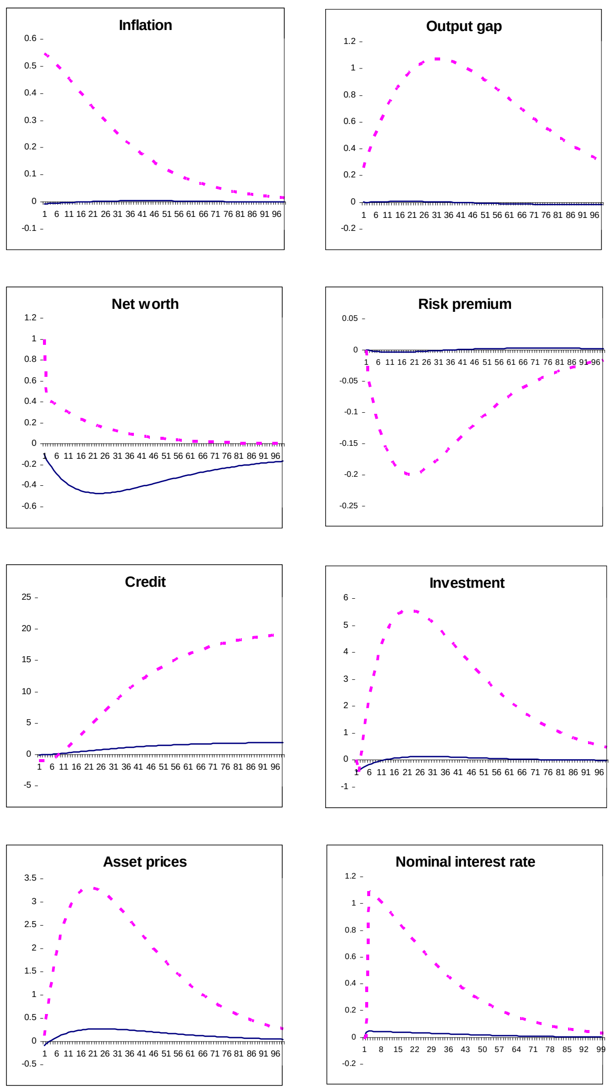


Figure 2: The impulse responses of net worth under alternative Taylor-type instrument rules

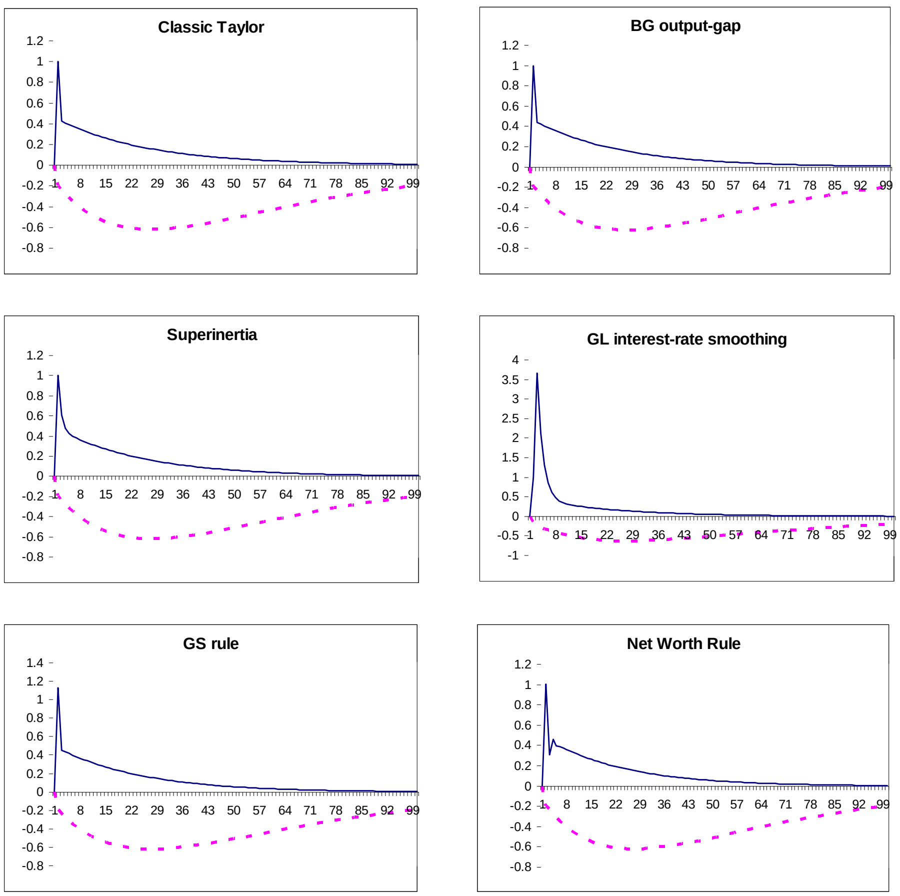


Figure 3: US federal funds target rate

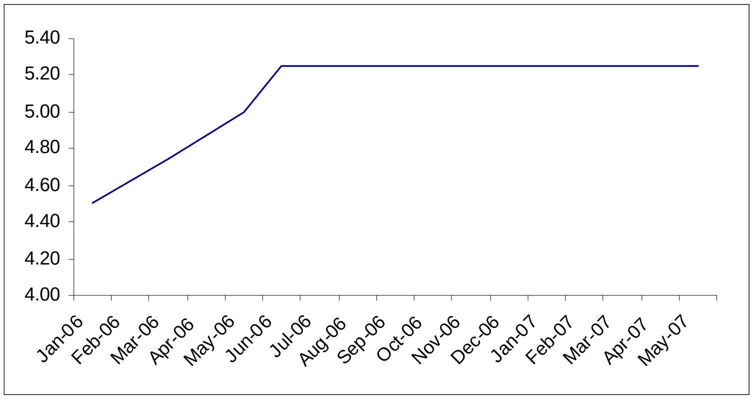
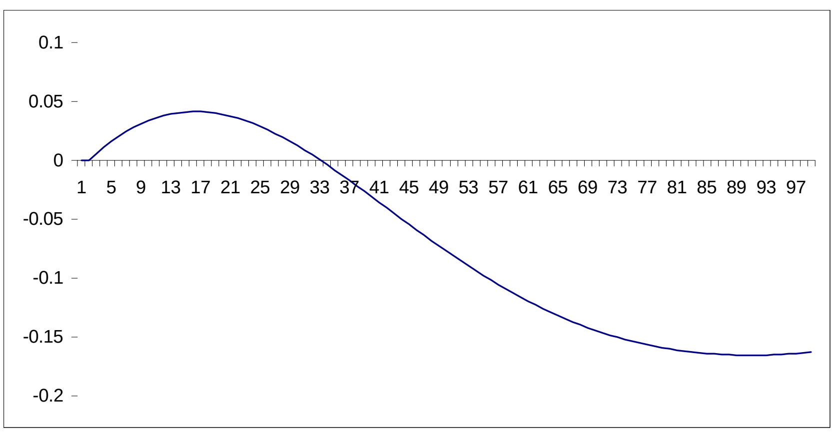
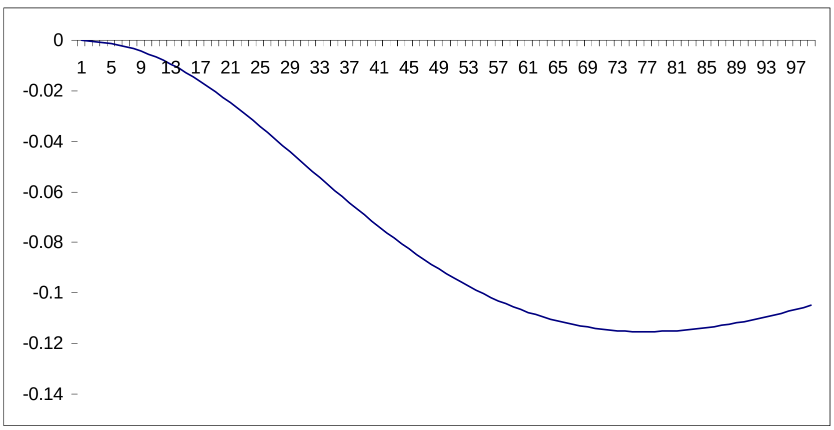


Figure 4: Central bank's commitment on fighting inflation following an unexpected rise in productivity growth



Source: The central bank's commitment on its policy stance towards inflation following an unexpected rise in productivity growth. The positive (negative) numbers imply that the central bank has promised to create inflation in that period higher (lower) than if it did not make the promise.

Figure 5: Central bank's commitment on its policy stance toward the rate of return on capital



Note: The central bank's commitment on its policy stance towards the return on capital following an unexpected rise in productivity growth. The positive (negative) numbers imply that the central bank has promised to keep the return on capital in that period above (below) the trend.