Monetary Policy, Inflation and Rational Asset Price Bubbles*

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Abstract

This paper studies monetary policy in the New Keynesian model with rational asset price bubbles. The model features a financial cost channel through which the shadow cost of borrowing affects marginal cost and inflation. A bubble generates a boom by mitigating borrowing constraints and stimulating investment and hiring. But inflation remains moderate due to a fall in the cost of borrowing. Against this backdrop, Ramsey-optimal monetary policy calls for tightening to curb the boom. Strict inflation targeting is counterproductive in the short run as it exacerbates the boom. For obtaining these results the financial cost channel and nominal wage rigidities are essential.

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1 Introduction

In central bank and academic circles a heated debate has taken place over how monetary policy should react to asset price booms or bubbles. One influential view among policy makers prior to the financial crisis of 2007-2009 was that monetary policy should focus on inflation stabilization in a regime of flexible inflation targeting.[1] Another prominent view was that monetary policy should respond to credit and asset markets in some circumstances.[2] Views on the issue have been evolving following the financial crisis, and in spite of their substantial differences several policy makers agree that they should remain open to using monetary policy as a supplementary tool to address financial imbalances.[3]

These developments aside, the advancement of the literature on monetary policy in asset price bubbles lags far behind the literature on rational bubbles, which has grown rapidly following the financial crisis.[4] In particular, monetary policy analyses in asset price bubbles in the New Keynesian framework – a standard workhorse of monetary policy analyses for many central banks – remain scarce.

Thus motivated, this paper studies monetary policy in the New Keynesian model with rational asset price bubbles. To this end, it embeds a rational asset bubble framework developed by Miao et al. (2015) into a monetary business cycle model à la Christiano et al. (2005). In the model a bubble emerges in the stock market value of firms through a feedback loop mechanism supported by self-fulfilling beliefs. A bubble boosts the stock market value of firms, increases their collateral value and borrowing capacity, and stimulates their economic activity and profits. Because of the self-fulfilling nature, the existence of bubble is independent of monetary policy. This paper focuses on a bubble equilibrium in which an exogenous shock affects the size of a bubble.

In the model a bubble has both inflationary and deflationary effects. Inflationary pressure of a bubble arises from a well-known wealth effect. A bubble increases the stock market value of firms, stimulates employment and production, and puts upward pressure on unit labor cost and thereby inflation. Deflationary pressure has to do with the fact that marginal cost depends not only on unit labor cost but also on the shadow cost of borrowing.

[1]See Bernanke and Gertler (1999, 2001), Bernanke (2002), and Kohn (2006) for this view

[2]See Cecchetti et al. (2000) and Borio and Lowe (2002) for this view. See also Trichet (2005) for a view that emphasizes a role of monetary and credit developments in monetary policy conduct.

[3]See Carney (2009), Bernanke (2010), King (2012), Shirakawa (2012), and Poloz (2015). For a view for and against using monetary policy to address financial imbalances, see Borio (2014) and Svensson (2011) respectively.

[4]See Farhi and Tirole (2012), Martin and Ventura (2012), Miao et al. (2015), Aoki and Nikolov (2015), and Hirano et al. (2015) for the recent literature on rational bubbles.

A bubble mitigates firms' borrowing constraints, lowers the shadow cost of borrowing, and adds downward pressure on marginal cost and thereby inflation. Indeed, the shadow cost of borrowing appears endogenously as a cost push shock in the Phillips curve as in Carlstrom et al. (2010). This paper calls this channel through which a bubble affects inflation as *a financial cost channel*. As a result of these two opposing effects, inflation remains moderate in a bubble, consistent with facts about stock market booms in the United States and other countries as documented by Bordo and Wheelock (2007) and Christiano et al. (2010).

This paper calibrates the model to the US economy and analyzes monetary policy in asset price bubbles. The analysis reveals four main findings.

First, in response to an increase in a bubble Ramsey-optimal monetary policy – optimal policy from a timeless perspective (Woodford, 2003) – calls for monetary tightening in the short run to curb a boom more than what would be warranted by inflation stabilization. Interestingly, the Ramsey policy barely affects the size of a bubble. This feature implies that inefficiencies that can be addressed by monetary policy are rooted not in a bubble itself but in the responses of the real economy to a bubble. Monetary policy, a blunt tool that affects the economy broadly, can address such inefficiencies in the model.

Second, strict inflation targeting, which stabilizes inflation completely, exacerbates an excessive boom caused by a bubble in the short run, though it contributes to curbing the boom in the long run. Stabilizing inflation requires stabilizing marginal cost. Because deflationary pressure through the financial cost channel dominates inflationary pressure through the wealth effect in the short run, strict inflation targeting calls for monetary easing at the onset of a boom. The monetary easing fuels the heated economy, making an excessive boom even excessive in the short run and thereby induces a substantial welfare loss. In short, the divine coincidence (Blanchard and Gali, 2007) does not hold in this model because of the financial cost channel.

Third, a monetary policy rule that responds strongly to nominal output performs the best close to Ramsey-optimal monetary policy among various rules. If a monetary policy rule responds strongly only to output instead, then it brings severe monetary tightening and worsens welfare as inflation drops sharply. Adding a strong response to inflation to this rule mitigates such severe tightening and brings an appropriate level of tightening, achieving outcomes close to those under the Ramsey policy. A monetary policy rule that responds to a bubble performs poorly and tends to worsen welfare. This is a logical consequence of the first finding that a bubble itself is not a cause of inefficiencies that can be addressed by monetary policy.

Fourth, for obtaining these results the combination of nominal wage rigidities and the financial cost channel is essential. Without nominal wage rigidities, a bubble-led boom would be no more excessive: there remains only small room for monetary policy to improve welfare. Even such room can be filled by strict inflation targeting. When nominal wages are flexible, an increase in real wages dominates the fluctuation of marginal cost, undermining the financial cost channel. In addition, such an increase in real wages lowers demand for labor, dampening the effects of bubbles. Put differently, in the case of sticky wages, real wages are relatively suppressed, which boosts demand for labor, stimulates investment, and causes an excessive boom. But, even in this case, if there were no financial cost channel, inflation would rise in the boom because a bubble has a wealth effect only. Consequently, strict inflation targeting would improve welfare substantially. Therefore, both nominal wage rigidities and the financial cost channel are indispensable in obtaining the main results.

This paper is motivated by influential papers by Bernanke and Gertler (1999, 2001), who study the New Keynesian model with bubbles and argue for inflation stabilization in a regime of flexible inflation targeting in addressing bubbles. In the model a bubble is not perfectly rational and a welfare measure is not fully micro-founded. Cecchetti et al. (2000) use the same model and argue for monetary policy that responds to asset prices as well as inflation and output. Dupor (2005), Detken and Smets (2004), and Smets and Wouters (2005) analyze Ramsey-optimal monetary policy in the New Keynesian model with non-fundamental shocks to asset prices or investment and show that Ramsey policy deviates from the sole pursuit of inflation stability.

Literature on monetary policy and rational bubbles has grown recently. Gali (2014) analyses bubbles as a store of value and argues that raising nominal interest rates may be welfare-reducing because doing so increases bubbles and hampers consumption smoothing. Asriyan et al. (2016) study monetary policy subject to the zero lower bound in a flexible-price economy where bubbles pop up and crash. Dong et al. (2017) study monetary policy rules in the New Keynesian model with land bubbles but without nominal wage rigidities. In Asriyan et al. (2016) and Dong et al. (2017) bubbles facilitate firms' borrowing as in this paper. A distinguished feature of this paper is that it highlights the role of nominal wage rigidity and the financial cost channel which shape optimal monetary policy.

The rest of the paper is organized as follows. Section 2 presents the model with the financial cost channel and defines Ramsey-optimal monetary policy. Section 3 calibrates the model. Section 4 analyzes monetary policy quantitatively and presents the main results of the paper. Section 5 concludes the paper.

2 Model

The model incorporates the rational asset price bubble framework developed by Miao et al. (2015), modified to add working capital to a borrowing constraint, into an otherwise standard monetary business cycle model à la Christiano et al. (2005). The presence of working capital gives rise to a financial cost channel through which a bubble affects inflation by changing the shadow cost of borrowing.

This section describes a standard part of the model first and then proceeds to a description of a model pertaining to rational asset price bubbles. Next it clarifies a financial cost channel by deriving the Phillips curve. It follows by a description of an alternative model with no financial cost channel and the definition of Ramsey-optimal monetary policy.

2.1 Standard part of the model

Households There is a continuum of households with measure unity, each indexed by $j \in (0,1)$. Each household has preferences characterized by a utility function given by:

$$E_t \sum_{s=0}^{\infty} \beta^s \left[\log\left(C_{t+s}\right) - \psi \frac{L_{t+s}(j)^{1+\nu}}{1+\nu} \right], \quad 0 < \beta < 1,\ \psi, \nu > 0,$$

where C_t is consumption at time t and $L_t(j)$ is specialized labor supply. The household consumes C_t, saves in risk-free nominal bond D_t, and purchases shares of the aggregate stock price of wholesale firms, s_t, at price P_t^s. The budget constraint is given by:

$$P_t C_t + D_t + P_t^s s_{t+1} \leq W_t(j) L_t(j) + R_{t-1} D_{t-1} + (\Pi_t^s + P_t^s) s_t + \Theta_t(j),$$

where P_t is the price level, $W_t(j)$ is the nominal wage for the specialized labor, R_t is the risk-free nominal interest rate, Π_t^s is the aggregate dividend paid by wholesale firms, and $\Theta_t(j)$ includes lump-sum profits brought by firms and other transfer which will be elaborated below.

The model of the labor market is taken from Erceg et al. (2000) in which households can change their nominal wage only with probability $0 < 1-\xi_w < 1$ in each period. A competitive employment agency combines a continuum of specialized labor into homogeneous labor L_t according to an aggregation technology: $L_t = \left(\int_0^1 L_t(j)^{\frac{1}{\lambda_w}} dj\right)^{\lambda_w}$ with $\lambda_w > 1$. Perfect competition leads to a demand curve: $L_t(j) = \left(W_t(j)/W_t\right)^{-\frac{\lambda_w}{\lambda_w - 1}} L_t$ where W_t is the nominal wage for the homogeneous labor. Household j sets nominal wage $W_t(j)$ to maximize:

$$E_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left[\Lambda_{t+s} W_t(j) L_{t+s}(j) - \psi \frac{L_{t+s}(j)^{1+1/\nu}}{1+1/\nu} \right],$$

subject to the demand curve for $L_t(j)$, where Λ_t is the household's Lagrange multiplier on the budget constraint. To insure against the opportunity of wage changes, households trade a contingent claim and its net cash flow is included in $\Theta_t(j)$ in the budget constraint.

Wholesale firms There is a continuum of wholesale firms with measure unity, each indexed by f. Firm f combines capital K_t^f and homogeneous labor L_t^f to produce homogeneous wholesale good, Y_t^f, in accordance with a Cobb-Douglas production function:

$$Y_t^f = (K_t^f)^\alpha (L_t^f)^{1-\alpha}, \quad 0 < \alpha < 1. \tag{1}$$

Financial frictions in a wholesale firms problem give rise to a rational asset price bubble. The details of the problem is described in the next subsection.

Retail and final good firms There is a continuum of retail firms with measure unity, each indexed by i. Retail firm i has a technology that transforms one unit of wholesale good into one unit of specialized retail good, $Y_t(i)$. Competitive final good firms combine a continuum of specialized retail goods to produce final good, Y_t, according to an aggregation technology: $Y_t = \left(\int_0^1 Y_t(i)^{\frac{1}{\lambda_p}} di \right)^{\lambda_p}$ with $\lambda_p > 1$. Perfect competition leads to a demand curve: $Y_t(i) = (P_t(i)/P_t)^{-\frac{\lambda_p}{\lambda_p - 1}} Y_t$, where $P_t(i)$ is the price of retail good i.

Retail firms face price change frictions à la Calvo (1983) in which they can change their price only with probability $0 < 1 - \xi_p < 1$ in each period. The problem of retail firm i is:

$$\max_{\{P_t(i)\}} E_t \sum_{s=0}^{\infty} (\beta\xi_p)^s \frac{\Lambda_{t+s}}{\Lambda_t} \left[P_t(i) Y_{t+s}(i) - P_{t+s}^w Y_{t+s}(i) \right],$$

subject to the demand curve for $Y_t(i)$, where P_t^w is the price of the wholesale good.

Investment good firm A representative investment good firm transforms one unit of the final good into one unit of the investment good subject to investment adjustment costs in the form of Christiano et al. (2005). It sells produced investment good at price P_t^I to wholesale firms. The problem of the investment good firm is:

$$\max_{\{I_t\}} E_t \sum_{s=0}^{\infty} \beta^s \frac{\Lambda_{t+s}}{\Lambda_t} \left\{ P_{t+s}^I I_{t+s} - \left[1 + \frac{S}{2} \left(\frac{I_{t+s}}{I_{t+s-1}} \right)^2 \right] P_{t+s} I_{t+s} \right\}, \quad S \geq 0,$$

where I_t is the amount of the investment good.

Central bank and resource constraint A central bank sets a nominal interest rate, R_t, by following a standard monetary policy rule that responds to the past interest rate, inflation, and output growth:

$$\log(R_t/R) = \rho_R \log(R_{t-1}/R) + (1-\rho_R)\left[\phi_\pi \log(\pi_t) + \phi_y \log(Y_t/Y_{t-1})\right], \tag{2}$$

where π_t is the gross inflation rate. The rule implies zero net inflation in steady state.

The resource constraint is given by $Y_t = C_t + I_t$.

2.2 Asset price bubbles

An asset price bubble emerges in the stock market value of wholesale firms. The model builds on Miao et al. (2015), extended to incorporate working capital. This subsection describes wholesale firms' problem and an asset price bubble. Then it introduces an exogenous shock and describes an aggregate bubble.

Wholesale firms There is a continuum of wholesale firms with measure unity, each indexed by f. In every period a fraction $0 < \delta_e < 1$ of wholesale firms exit the market and the same number of firms enter the market. New entrants are endowed with the start-up capital stock, K_s. For each f wholesale firm f has production technology (1) and owns capital stock. Capital stock evolves according to:

$$K_{t+1}^f = (1-\delta) K_t^f + \varepsilon_t^f I_t^f, \tag{3}$$

where $0 < \delta < 1$ is the capital depreciation rate, I_t^f is investment, and ε_t^f is an idiosyncratic shock with c.d.f $\Phi(\varepsilon)$ with support in a positive range. Investment is assumed to be irreversible: $I_t^f \geq 0$.

Wholesale firm f has to finance funds from households for investment, $P_t^I I_t^f$, and for working capital, $W_t L_t^f$, in advance of production. The firm's borrowing and repayment are completed within a period. For simplicity, the intra-temporal risk-free net interest rate is assumed to be zero.

Financial frictions limit wholesale firms' borrowing capacity. Wholesale firms have an agency problem such that they can default on loans and run away. Let $V_{t,\tau}(K_t^f, \epsilon_t^f)$ denote the stock market value of a wholesale firm with age τ, capital K_t^f, and idiosyncratic shock ϵ_t^f at time t. In case of default, a lender can seize a fraction $0 < \kappa < 1$ of K_t^f, but keeps the firm running and renegotiates the debt in the next period. Under the assumption that the firm has all the bargaining power, the lender would obtain the threat value of $V_{t+1,\tau+1}(\kappa K_t^f, \epsilon_{t+1}^f)$ in the next period. As a result, the firm's intra-temporal borrowing is constrained as:

$$P_t^I I_t^f + W_t L_t^f \leq (1-\delta_e)\, E_t \beta \frac{\Lambda_{t+1}}{\Lambda_t} \int V_{t+1,\tau+1}(\kappa K_t^f, \epsilon) d\Phi(\epsilon). \tag{4}$$

The left hand side corresponds to the amount of borrowing and the right hand side is the expected discounted value of what the lender would obtain if the firm defaulted. As long as constraint (4) holds, the firm never chooses to default.

Wholesale firm f with age τ chooses investment, $I_t^f \geq 0$, and labor, $L_t^f \geq 0$, to maximize its value:

$$\begin{aligned} V_{t,\tau}\left(K_t^f, \epsilon_t^f\right) = & \max_{\left\{I_t^f \geq 0,\, L_t^f \geq 0\right\}} P_t^w Y_t^f - \left(P_t^I I_t^f + W_t L_t^f\right) \\ & + (1-\delta_e)\, E_t \beta \frac{\Lambda_{t+1}}{\Lambda_t} \int V_{t+1,\tau+1}\left(K_{t+1}^f, \epsilon\right) d\Phi(\epsilon), \end{aligned}$$

subject to the production technology, (1), a law of motion for capital, (3), and the borrowing constraint, (4). Let ζ_t^f denote a Lagrange multiplier on the borrowing constraint for wholesale firm f. The first-order condition with respect to L_t^f yields

$$P_t^w = \frac{W_t\left(1+\zeta_t^f\right)}{(1-\alpha)\, Y_t^f / L_t^f}. \tag{5}$$

Equation (5) shows that the price of the wholesale good depends not only on the nominal unit labor cost, $W_t/(Y_t^f/L_t^f)$, but also on the shadow cost of borrowing, ζ_t^f.

The problem of wholesale firm f with age τ for a choice of I_t^f can be solved by guessing and verifying that the nominal value of the firm is given by:

$$V_{t,\tau}\left(K_t^f, \epsilon_t^f\right) = Q_t(\epsilon_t^f) K_t^f + B_{t,\tau}(\epsilon_t^f),$$

where $B_{t,\tau}(\epsilon_t^f) \geq 0$ represents a bubble as a function of ϵ_t^f. Because the problem is linear in K_t^f and I_t^f, it features a bang-bang solution: there is a threshold, ϵ_t^*, such that the firm borrows up to the borrowing constraint (4) to invest $I_t^f > 0$ if the idiosyncratic shock is high enough to satisfy $\epsilon_t^f \geq \epsilon_t^*$; the firm does not invest, i.e., $I_t^f = 0$, if $\epsilon_t^f < \epsilon_t^*$. The derivation of the solution is dedicated to the technical appendix.

Define $B_{t,\tau} \equiv (1-\delta_e)E_t\beta(\Lambda_{t+1}/\Lambda_t)B_{t+1,\tau+1}(\epsilon_{t+1}^f)$, where ϵ_{t+1}^f is integrated out by the expectation operator. Then, as shown in the technical appendix, $B_{t,\tau}$ follows a low of motion:

$$B_{t,\tau} = (1-\delta_e)\, E_t\beta\frac{\Lambda_{t+1}}{\Lambda_t}B_{t+1,\tau+1}\,(1+G_{t+1})\,, \tag{6}$$

where

$$G_{t+1} = \int_{\varepsilon \geq \varepsilon_{t+1}^*} \left(\frac{\varepsilon}{\varepsilon_{t+1}^*} - 1\right) d\Phi\,(\varepsilon)\,.$$

To understand equation (6) it is useful to consider a hypothetical case of $\delta_e = 0$, $G_{t+1} = 0$, and no uncertainty. Then, equation (6) is reduced to $B_{t+1,\tau+1}/B_{t,\tau} = (\beta\Lambda_{t+1}/\Lambda_t)^{-1} = R_t$: the bubble grows at the rate of the interest rate. But in equation (6) the bubble does not have to grow at R_t because of term G_{t+1}, which represents the marginal benefit of a bubble. A bubble boosts wholesale firms' borrowing capacity by increasing their stock market value, as implied by the borrowing constraint (4). An increase in the capacity will allow the firms with $\epsilon_{t+1}^f \geq \epsilon_{t+1}^*$ to invest more, generating the extra return G_{t+1} in (6).

Sentiment shock and aggregate bubble Let $b_{t,\tau} = B_{t,\tau}/P_t$ denote the real value of a bubble attached to a wholesale firm with age τ at time t. In period t the economy has a sequence of bubbles, $\{b_{t,\tau}\}_{\tau=0}^{\infty}$. In principle $b_{t,\tau}$ can differ from $b_{t,\tau'}$ for $\tau \neq \tau'$. For simplicity, by following Miao et al. (2015), this paper assumes $b_{t,\tau} = b^*$ for all $\tau = 0, 1, 2, ...$ in steady state. The constant bubble is possible because of the presence of G_{t+1} in equation (6). To introduce a variation in $b_{t,\tau}$ around the steady state, a sentiment shock θ_t is introduced. The shock θ_t affects the relative value of bubbles for any two wholesale firms born in period t and $t+1$ for all $t+\tau$ with $\tau = 1, 2, ...$ as:

$$\frac{b_{t+\tau,\tau}}{b_{t+\tau,\tau-1}} = \theta_t, \quad \tau \geq 1. \tag{7}$$

Thus, the positive sentiment shock, $\theta_t > 1$, in period t causes the size of a bubble attached to wholesale firms born in period t to be greater than that attached to wholesale firms born in period $t+1$ for all future periods. The sentiment shock follows an AR(1) process,

$\log(\theta_t) = \rho_\theta \log(\theta_{t-1}) + \epsilon_{\theta,t}$ with $0 \leq \rho_\theta < 1$ and $\epsilon_{\theta,t} \sim i.i.d. N(0, \sigma_\theta^2)$. In steady state $\theta_t = 1$ and thereby bubbles $b_{t,\tau}$ becomes constant.

Let $b_t \equiv \sum_{\tau=0}^{\infty} (1-\delta_e)^\tau \delta_e b_{t,\tau}$ denote the aggregate bubble. Then, from equations (6) and (7), the aggregate bubble evolves according to:

$$b_t = (1-\delta_e) E_t \beta \frac{\Lambda_{t+1} P_{t+1}}{\Lambda_t P_t} \frac{m_t}{m_{t+1}} \theta_t b_{t+1} (1 + G_{t+1}), \tag{8}$$

where $m_t \equiv b_t / b_{t,0}$ follows:

$$m_t = m_{t-1} (1-\delta_e) \theta_{t-1} + \delta_e.$$

The derivation is dedicated to the technical appendix. Equation (8) implies that the positive sentiment shock, $\theta_t > 1$, increases the current aggregate bubble, b_t, relative to the future aggregate bubble, b_{t+1}.

Finally, with the aggregate bubble b_t in hand, ex-dividend market capitalization in real terms is given by $q_t K_{t+1} + b_t$, where $q_t = Q_t / P_t$ and $Q_t \equiv (1-\delta_e) E_t \beta (\Lambda_{t+1}/\Lambda_t) Q_{t+1} (\epsilon_{t+1}^f)$. The market capitalization consists of fundamental component $q_t K_{t+1}$ and bubble b_t.

This completes the description of the model.

2.3 Phillips curve and financial cost channel

A bubble increases wholesale firms‘ stock market value, loosens the borrowing constraint, and decreases the shadow cost of borrowing and thereby the price of the wholesale good – the marginal cost – through the working capital channel, adding downward pressure on inflation. The New Keynesian Phillips curve in this model summarizes this connection between a bubble and inflation.

For simplicity, the idiosyncratic shock, ε_t^f, is assumed to follow a Pareto distribution, $\Phi : [1, \infty) \to [0, 1]$:

$$\Phi(\varepsilon) = 1 - \varepsilon^{-\eta}, \quad \eta > 0.$$

Log-linearizing a solution to the retail firms' problem around the steady state yields the Phillips curve as:

$$\pi_t = \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p} \widehat{ulc}_t + \beta E_t \pi_{t+1} + \chi \hat{\zeta}_t. \tag{9}$$

where $ulc_t \equiv W_t L_t / (P_t Y_t)$ is the real unit labor cost, ζ_t is the average of the Lagrange multiplier on borrowing constraint (4) over f in the wholesale firm's problem, or the shadow cost of borrowing for short, and variables with a hat denote a derivation from the steady state. The sign of parameter χ attached to the shadow cost of borrowing in (9) is positive, given by

$$\chi \equiv \frac{\alpha^2 \eta \left(\varepsilon^*\right)^{-\eta} \left(1-\xi_p\right)\left(1-\beta \xi_p\right)}{\left[\alpha \eta+1-\left(\varepsilon^*\right)^{-\eta}\right]\left[\alpha\left(\eta-1\right)+1-\left(1-\alpha\right)\left(\varepsilon^*\right)^{-\eta}\right] \xi_p}>0.$$

The Phillips curve (9) shows that the shadow cost of borrowing emerges endogenously as a cost push shock. In particular, a decrease in the shadow cost, $\hat{\zeta}_t < 0$, adds downward pressure on inflation. Therefore, an increase in the aggregate bubble not only adds upward pressure on inflation by stimulating the aggregate demand through a wealth effect, but also adds downward pressure on inflation by decreasing the shadow cost of borrowing and thereby lowering the marginal cost. This paper calls the latter new mechanism as the *financial cost channel* and calls the model as the model with the financial cost channel.

2.4 Alternative model: no financial cost channel

To understand the role of financial cost channel in the quantitative analysis in the next section, it is useful to consider an alternative model with no such a channel. The alternative model is identical to the model presented above, except that the borrowing constraint (4) is replaced by:

$$P_t^I I_t^f + \omega K_t^f \leq \left(1-\delta_e\right) E_t \beta \frac{\Lambda_{t+1}}{\Lambda_t} \int V_{t+1,\tau+1}(\kappa K_t^f, \epsilon) d\Phi(\epsilon). \tag{10}$$

The only difference between new borrowing constraint (10) and original one (4) is that working capital $W_t L_t^f$ in (4) is replaced by ωK_t^f with $\omega > 0$ in (10). The value of ω is set so that the real wage w and the bubble-capital ratio b/K in steady state become equal to those in the original model. By doing so, all variables in steady state become close to those of the original model.[5]

Replacing $W_t L_t^f$ in (4) by κK_t^f in (10) implies that the borrowing constraint becomes irrelevant for the choice of labor. Consequently, in this alternative model the Phillips curve is reduced to:

$$\pi_t = \frac{\left(1-\xi_p\right)\left(1-\beta \xi_p\right)}{\xi_p} \widehat{ulc}_t + \beta E_t \pi_{t+1}. \tag{11}$$

No shadow cost of borrowing, $\hat{\zeta}_t$, appears in equation (11), a critical and only difference from the original Phillips curve, (2). Therefore, in contrast to the original model, this

[5]Because in the original model the Lagrange multiplier appears in the first-order condition with respect to labor in the wholesale firms' problem while it does not in the alternative model, the steady state does not become identical perfectly between the two models.

model does not have a financial cost channel.

2.5 Ramsey-optimal monetary policy and welfare cost

Ramsey-optimal monetary policy helps us understand properties of desirable monetary policy from a welfare view point. In addition, it plays a role as a benchmark in computing welfare cost of other monetary policy. Formally, it is derived as follows. A benevolent central banker chooses a sequence of endogenous variables including a nominal interest rate to maximize the average household utility:

$$\mathcal{W}^r(\mu) = \max E_0 \sum_{t=0}^{\infty} \beta^s \zeta_t \left[\log\left((1-\mu)C_t^r\right) - \psi \frac{\int_0^1 L_t^r(j)^{1+\nu} dj}{1+\nu} \right],$$

subject to the constraints that the variables satisfy the all equilibrium conditions but monetary policy rule (2), where superscript r denotes Ramsey policy and μ is set to zero. The central banker is assumed to have full commitment and to honor commitments made in the past – a timeless perspective monetary policy (Woodford, 2003) –. The resulting policy is called Ramsey-optimal monetary policy. This paper uses the method proposed by Schmitt-Grohe and Uribe (2005) to compute the Ramsey policy quantitatively.

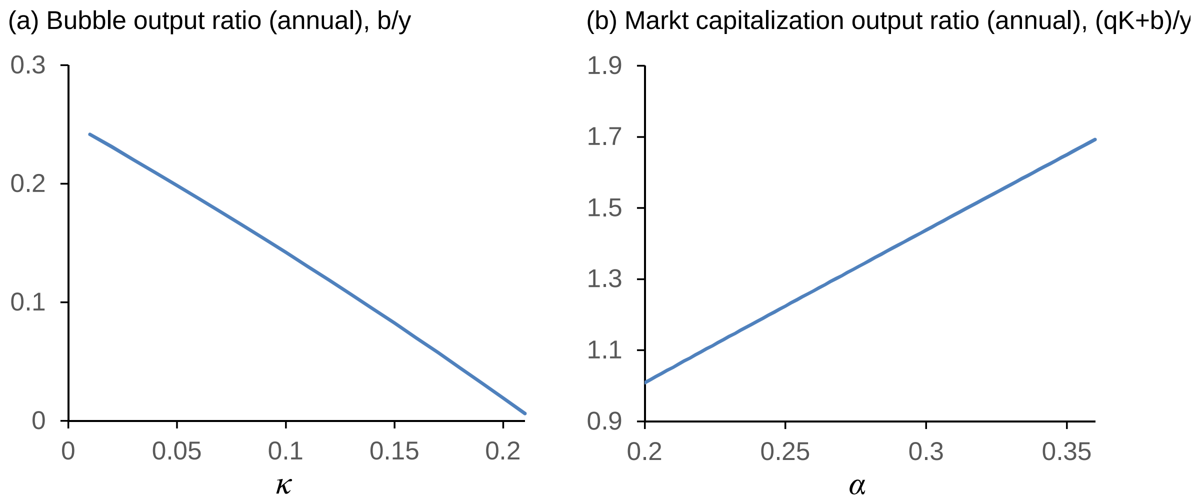
The welfare cost of adopting an alternative policy instead of the Ramsey policy is defined as a fraction of consumption μ under the Ramsey policy that a household would be willing to give up to be as well off under an alternative policy as under the Ramsey policy. That is, the welfare cost μ is given by a solution to $\mathcal{W}^r(\mu) = \mathcal{W}^a$, where $\mathcal{W}^a$ denotes the average household utility under an alternative policy.

3 Calibration

This section calibrates the model with the financial cost channel to the US economy. The model period is quarterly. The model parameters are divided into three sets. The first set contains parameters that are standard in monetary business cycle models: $\{\beta,\ \psi,\ \nu,\ \delta,\ \lambda_p,\ \lambda_w,\ \xi_p,\ \xi_w,\ S,\ \rho_R,\ \phi_\pi,\ \phi_y\}$. The second set pertains to financial frictions and an asset price: $\{\eta, \kappa, \alpha, \delta_e,\ K_s\}$. The third set pertains to a sentiment shock, $\{\rho_\theta, \sigma_\theta\}$.

First, regarding the standard parameters, this paper sets the value of the parameters in line with the literature on monetary business cycle models. The preference discount factor is $\beta = 1.03^{-1/4}$, implying an annualized steady-state real interest rate of three percent.

Figure 1: Steady state analysis on κ and α



The coefficient of the disutility of labor, ψ, is set so that homogeneous labor is normalized to unity in steady state. The elasticity of labor supply is $\nu = 1$. The capital depreciation rate is $\delta = 0.025$. The gross markups for prices and wages are $\lambda_p = \lambda_w = 1.15$. The degree of nominal rigidities for prices and wages are $\xi_p = \xi_w = 0.75$, implying the average duration of price or wage change of a year. The degree of the investment adjustment cost is set to $S = 1.86$ following the empirical result by Eberly et al. (2012). For the monetary policy rule the degree of interest rate smoothing is $\rho_R = 0.7$, the coefficient on inflation is $\phi_\pi = 1.5$, and the coefficient on output growth is $\phi_y = 0.25$.

Second, regarding the parameters pertaining to financial frictions and an asset price, the parameter of Pareto distribution $\Phi(\epsilon) = 1 - \epsilon^{-\eta}$ is set to $\eta = 13.265$ so that a fraction of wholesale firms that do not invest in steady state matches the ratio of US manufacturing plants that do not make positive investment of 18.5 annual percent (Cooper and Haltiwanger, 2006). Parameter κ, which is a fraction of collateralizable capital in borrowing constraint (4), is a key determinant of the size of a bubble. A bubble output ratio in steady state decreases as κ increases and becomes zero when κ reaches about 0.21 as shown in Figure 1(a). Because bubbles are not observable in practice, it is unavoidable that one has to take an agnostic view on the size of a bubble. Therefore, κ is set to the medium value of 0.11 as a benchmark. Capital share α is a key parameter that determines fundamental component qK of market capitalization in steady state. Given $\kappa = 0.11$ it affects a market capitalization output ratio as shown in Figure 1(b). Capital share α is set

Table 1: Parameter values

Parameter	Value	Description	Calibration target
		Standard parameters	
β	0.9926	Preference discount factor	Annual real interest rate of 3% in SS
ψ	0.6585	Disutility of labor	$L = 1$ in SS
ν	1	Inverse of Frisch elasticity of labor supply	Standard
δ	0.025	Capital depreciation rate	Annual depreciation rate of 10%
λ_p, λ_w	1.15	Markups	Price (wage) markup of 15%
ξ_p, ξ_w	0.75	Degree of nominal rigidities	Average duration of 1 year
S	1.86	Investment adjustment costs	Eberly et al. (2012)
ρ_R	0.7	Taylor rule, past interest rate	Standard
ϕ_π	1.5	Taylor rule, inflation	Standard
ϕ_y	0.25	Taylor rule, output growth	Standard
		Financial frictions, asset bubbles, and sentiment shocks	
η	13.265	Distribution of idiosyncratic shock	Inaction rate of annual 18.5%
κ	0.11	Borrowing constraint	See Section 3.1
α	0.2689	Capital share	$(qK + b)/Y = 1.3$ in SS
δ_e	0.02	Exit rate of wholesale firms	Miao et al. (2015)
K_s	$0.2 \times K$	Initial capital, newly entered wholesale firms	Miao et al. (2015)
ρ_θ	0.5	Persistence, sentiment shocks	Data on market capitalization
σ_θ	0.25	Standard deviation, sentiment shocks	See Section 3.1

to $\alpha = 0.2689$ for the model to match the average US market capitalization output ratio of about 1.3 in the period of 1995Q1–2016Q1, where market capitalization is measured by equities of all domestic sectors in Flow of Funds and output is measured by annual GDP.[6] Finally this paper follows Miao et al. (2015) and sets the exit rate of wholesale firms at $\delta_e = 0.02$ and the start-up capital for newly born wholesale firms at $K_s = 0.2 \times K$, where K is capital in steady state.

Third, regarding parameters pertaining to a sentiment shock, the autocorrelation of a sentiment shock is set to $\rho_\theta = 0.5$ for the model to match the autocorrelation of the growth rate of market capitalization of 0.065 observed in the data. In doing so, the model is simulated for 1000 times with sample size equal to that of the actual data. And the model statistics is calculated by taking the average of corresponding statistics for the simulated series. Similar to the size of a bubble, there is no strong evidence on how much fluctuation

[6]If market capitalization is measured by equities of nonfinancial corporate business in Flow of Funds or Wilshire 5000 index instead, a market capitalization output ratio is dropped to about 1. As is clear from Figure 1(b), the ratio of 1 leads to α around 0.2, lower than its standard parameter region.

of market capitalization is caused by a change in the size of a bubble. Again this paper takes an agnostic view and set the standard deviation of a sentiment shock to $\sigma_\theta = 0.25$. With this value the simulation shows that the model generates about 10% of the standard deviation of the growth rate of market capitalization of 0.089 observed in the data. In light of the estimated result by Miao et al. (2015) that a sentiment shock explains about 73–98% of the volatility of stock price measured by the S&P composite index, this model's 10% contribution of a sentiment shock is much more modest.

Table 1 summarizes the calibrated parameter values. Admittedly, the values of some parameters, especially those related to a bubble, lack empirical support. For this reason, Section 4.4 complements this shortcoming by conducting a sensitivity analysis regarding these parameters including κ, α, ρ_θ, and σ_θ.

4 Monetary Policy Analysis

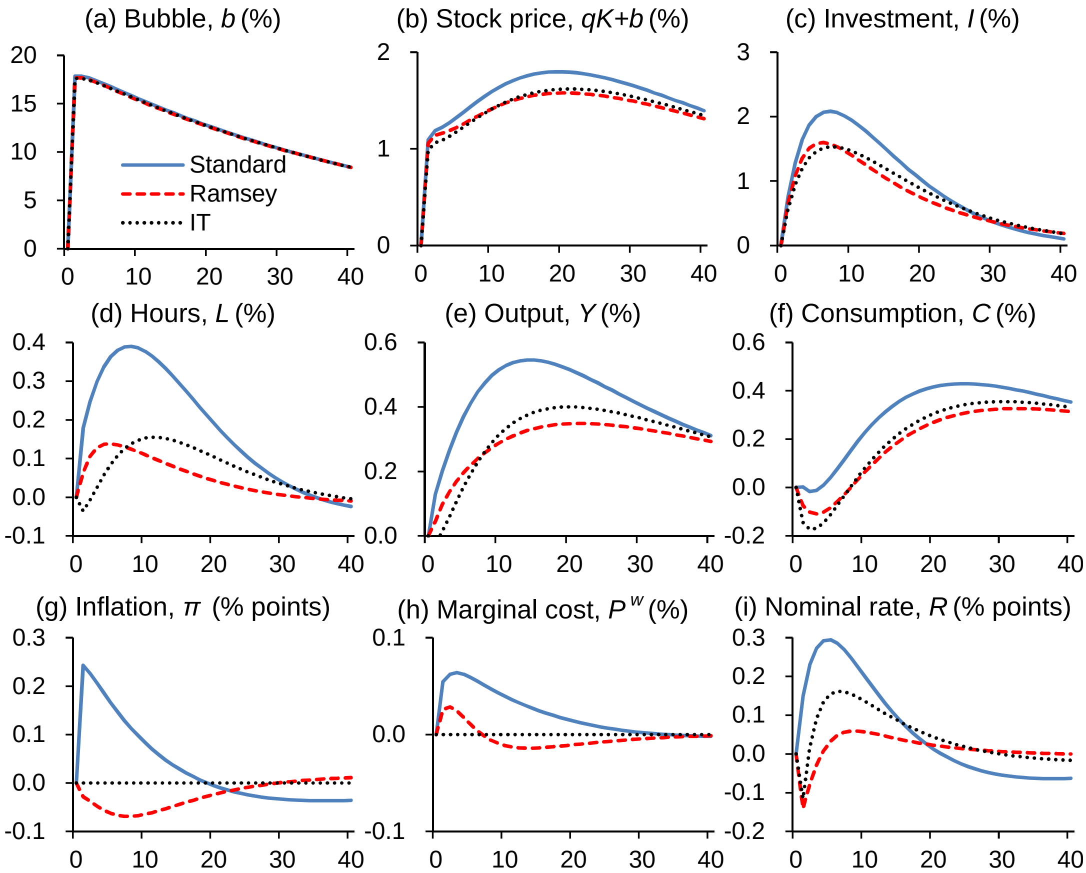
This section quantitatively analyzes the two models – the model with and without the financial cost channel – and aims to derive policy implications. The two models employ the same parameter values set in Section 3. For each model three types of monetary policy are considered: standard monetary policy rule (2), Ramsey-optimal monetary policy defined in Section 2.5, and strict inflation targeting under which inflation is perfectly stabilized.

This section is organized as follows. Section 4.1 studies the model *without* the financial cost channel and shows that the conventional view holds, i.e., focusing on stabilizing inflation is effective in addressing asset price bubbles. Section 4.2 studies the model *with* the financial cost channel and presents a new result that the conventional view does not necessarily hold. Section 4.3 focuses on simple monetary policy rules and derives welfare implications for the conduct of monetary policy. Section 4.4 conducts a sensitivity analysis regarding key parameters to main results in this section.

4.1 No financial cost channel and conventional view

Consider the model without the financial cost channel presented in Section 2.4 in which the Phillips curve has the standard New Keynesian form, given by equation (11). Figure 2 plots impulse responses to a positive sentiment shock, $\epsilon_{\theta,0} = \sigma_\theta$, for the model for three different monetary policies: Standard (standard monetary policy rule (2)), Ramsey (Ramsey-optimal monetary policy), and IT (strict inflation targeting).

Figure 2: Impulse responses to a sentiment shock: Model *without* the financial cost channel



Notes: 'Standard' denotes the standard monetary policy given by equation (2), 'Ramsey' denotes Ramsey-optimal monetary policy defined in Section 2.5, and 'IT' denotes strict inflation targeting. On y-axis '(%)' represents a percent change from the steady state and '(% points)' represents a difference from the steady state in annual percentage points.

In the case of the standard monetary policy rule, the positive sentiment shock increases both a bubble and a stock price (Figure 2(a) and (b)). The increase in a stock price mitigates the borrowing constraint, allowing the wholesale firms to invest and hire more. The economy booms as investment, hours worked, output, and consumption all increase (Figure 2(c)–(f)). Inflation rises as the marginal cost increases through the standard Phillips curve (Figure 2(g) and (h)). Thus, the increase in a bubble has expansionary effects on the real economy associated with a rise in inflation.

Three findings emerge when comparing the case of standard monetary policy rule (2) with the case of Ramsey-optimal monetary policy. First, the Ramsey policy calls for curbing the boom as the responses of investment, hours worked, output, and consumption are all restrained under the Ramsey policy relative to the standard monetary policy rule (Figure 2(c)–(f)). In other words, the boom is excessive under the standard monetary policy rule. Second, the Ramsey policy has little effect on the size of a bubble (Figure 2(a)). The first two results suggest that inefficiencies in a bubble that can be addressed by monetary policy have to do with the responses of the real economy but not with the size of a bubble itself. Indeed, as will be shown in Section 4.4 it is nominal rigidities, especially nominal wage rigidities, that generate excessive responses to a sentiment shock. Third, the Ramsey policy curbs the boom by stabilizing inflation. As shown in Figure 2(g) the volatility of inflation becomes much smaller under the Ramsey policy relative to the standard monetary policy rule.

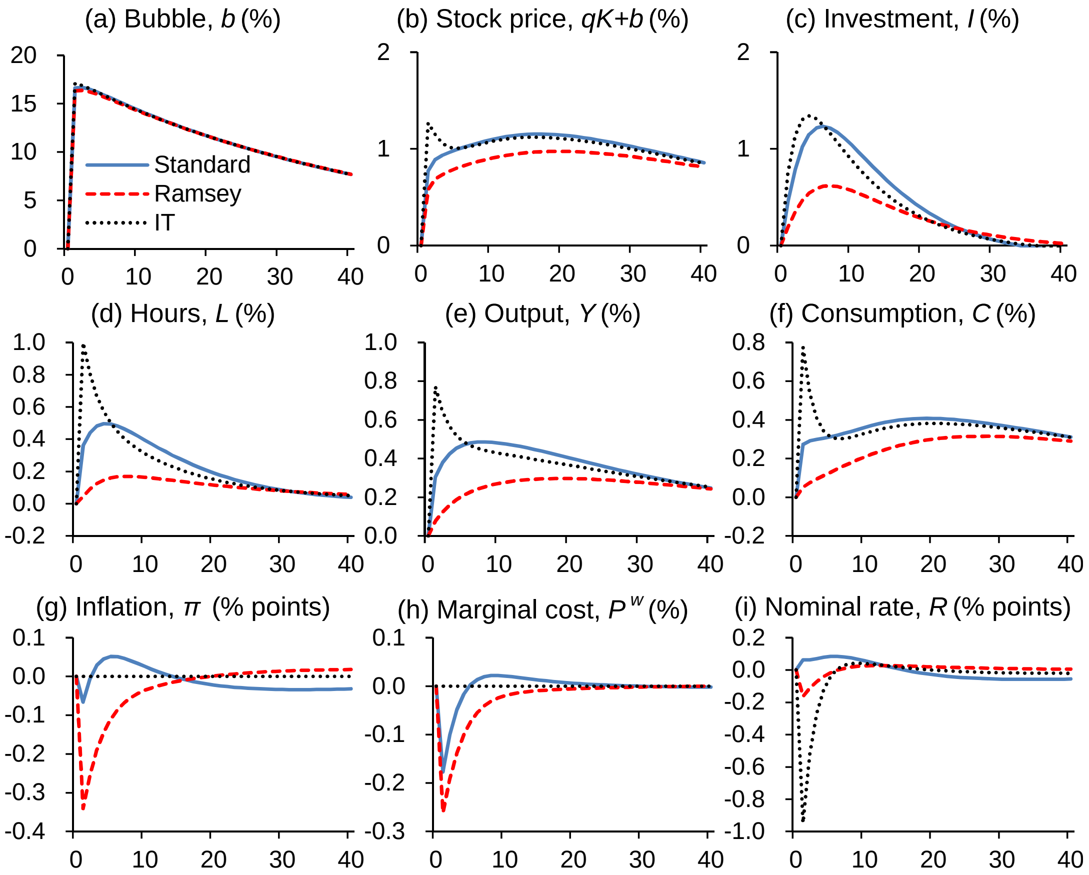
The third finding on the Ramsey policy implies that monetary policy that focuses on stabilizing inflation is effective in addressing a bubble, i.e., the conventional view holds. Indeed, strict inflation targeting – an extreme policy that stabilizes inflation completely – performs well as the responses of investment, hours worked, output, and consumption become close to those under the Ramsey policy (Figure 2(c)–(f)). Under strict inflation targeting welfare cost μ is reduced to about less than 10 percent of that under the standard monetary policy rule. Section 4.3 will discuss welfare implications of monetary policy in detail.

4.2 Financial cost channel and new result

Now consider the model with the financial cost channel. Unlike the model in the previous subsection, in this model the shadow cost of borrowing affects inflation as shown in the modified Phillips curve, (9). Figure 3 plots impulse responses to the same positive sentiment shock as in the previous subsection for the model for three different monetary policies: Standard, Ramsey, and IT.

In the case of the standard monetary policy rule, the positive sentiment shock increases both a bubble and a stock price and generates a boom in the real economy (Figure 3(a)–(f)) as in the model without the financial cost channel. The distinguished feature of the model with the financial cost channel lies in the response of inflation and the marginal cost: inflation remains moderate as the marginal cost drops in the first few periods (Figure 3(g) and (h)). The marginal cost drops sharply at the onset of the shock because of a decline in the shadow cost of borrowing ζ_t – the average of the Lagrange multiplier on borrowing constraint (4) over the wholesale firms – as a result of an increase in a bubble and a stock

Figure 3: Impulse responses to a sentiment shock: Model *with* the financial cost channel



Notes: 'Standard' denotes the standard monetary policy given by equation (2), 'Ramsey' denotes Ramsey-optimal monetary policy defined in Section 2.5, and 'IT' denotes strict inflation targeting. On y-axis '(%)' represents a percent change from the steady state and '(% points)' represents a difference from the steady state in annual percentage points.

price. The drop in the marginal cost feeds through to inflation and even causes inflation to drop initially when the real economy booms. In short, an increase in a bubble lowers the shadow cost of borrowing and thereby the marginal cost, and adds downward pressure on inflation.

The moderate inflation in a boom in the real economy poses a challenge for a benevolent central banker: a trade-off between stabilizing the real economy and stabilizing inflation. In face of the trade-off, Ramsey-optimal monetary policy weighs on stabilizing the real economy. As shown in Figure 3(c)–(f), the Ramsey policy curbs the boom by mitigating the excessive responses of investment, hours worked, output, and consumption. Curbing the boom, in turn, induces a decrease in the unit labor cost and adds further downward pressure on inflation. Consequently, inflation drops sharply in the short run under the Ramsey policy (Figure 3(g)). Indeed, a drop in inflation under the Ramsey policy in this model is more than three time as large as that in the model without the financial cost channel.

The result of the Ramsey policy implies that the conventional view, which holds in the model without the financial cost channel, does not necessarily hold in this model. In the case of strict inflation targeting in which inflation is stabilized completely, hours worked, output, and consumption overshoot in the initial periods (Figure 3(d)-(f)). These responses are driven by a sharp reduction in the nominal interest rate (Figure 3(i)) – significant monetary easing – for stabilizing the marginal cost that drops substantially through the financial cost channel (Figure 3(h)). Inflation is disrupted by a drop in the shadow cost of borrowing and thereby fails to serve as an effective indicator of the excessive boom in the short run. Consequently, strict inflation targeting calls for monetary easing when monetary tightening is required and ends up causing an overshooting of the real economy in the short run.

While strict inflation targeting causes the instability in the short run, it stabilizes investment, hours worked, output, and consumption in the medium run for somewhat, making the responses of these variables close to those under the Ramsey policy (Figure 3(c)-(f)). On balance, welfare cost under strict inflation targeting is about 80 percent of that under the standard monetary policy rule (Table 2 in Section 4.3). This result makes a stark contrast with the result in the previous subsection in which the corresponding number is less than 10 percent for the model without the financial cost channel. Strict inflation targeting is much less effective in the model with the financial cost channel and is even counterproductive in the short run as it causes an overshooting of the real economy.

4.3 Monetary policy rules and welfare costs

This subsection continues to focus on the model with the financial cost channel. It studies simple monetary policy rules and tackles key questions about monetary policy and bubbles.

First, is monetary policy that focuses on stabilizing inflation effective in addressing bubbles? Yes, the policy can be effective to some extent. Strict inflation targeting improves welfare moderately. The welfare cost is reduced to 0.0805 percent from 0.1015 percent in the case of the standard monetary policy rule where $\phi_\pi = 1.5$ (Table 2, the first and second rows). Strict inflation targeting, however, induces excessive volatility in the real economy in

Table 2: Monetary policy rules and welfare costs

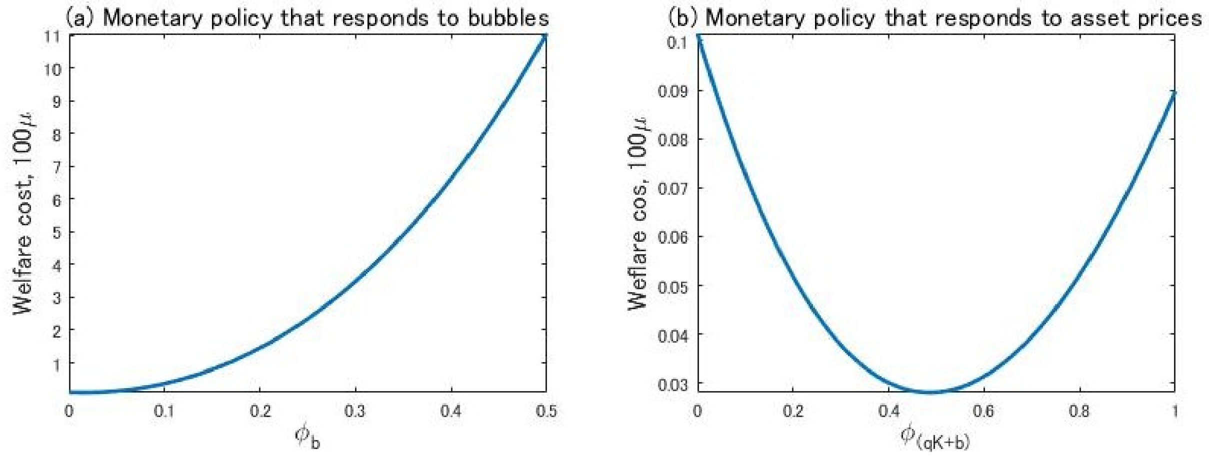
Monetary policy rule / Coefficient	ϕ_x	ϕ_π	ϕ_y	ρ_R	Welfare cost μ (%)
Model with financial cost channel					
Standard	–	1.5	0.25	0.7	0.1015
Strict inflation targeting	–	–	–	–	0.0804
Inflation focused	–	10	0.25	0.7	0.0625
Output focused	–	1.5	10	0.7	0.5298
Nominal output focused	–	10	10	0.7	0.0036
Bubble ($x = b$) optimized	0.015	1.5	0.25	0.7	0.0928
Stock price ($x = qK + b$) optimized	0.48	1.5	0.25	0.7	0.0281
Model without financial cost channel					
Standard	–	1.5	0.25	0.7	0.1672
Strict inflation targeting	–	–	–	–	0.0157
Inflation focused	–	10	0.25	0.7	0.0214
Output focused	–	1.5	10	0.7	0.7949
Nominal output focused	–	10	10	0.7	0.0087

the short-run as shown in the previous subsection. In the case of flexible inflation targeting with a strong focus on inflation stabilization – monetary policy rule (2) with $\phi_\pi = 10$ but other parameters fixed –, which is called the 'inflation focused' rule, the welfare cost is reduced further to 0.0625 percent (Table 2, the third row). Yet, these rules still induce a significant welfare loss relative to Ramsey-optimal monetary policy. The responses of real variables such as output and hours worked are still excessive relative to those under Ramsey policy.

Second, if the inflation focused rule is not enough to address bubbles, how about monetary policy that focuses on stabilizing output? In the case of monetary policy rule (2) with $\phi_y = 10$ and other parameters fixed, which is called the 'output focused' rule, welfare cost is increased to 0.5298 percent, more than ten times of the welfare cost under the standard monetary policy rule (Table 2, the fourth row). The output focused rule, which puts too much weight on output stabilization, is counterproductive as it dampens real economic activity and lowers inflation too much. Indeed, the responses of real variables and inflation fall far below the responses under Ramsey-optimal monetary policy. Excessive stabilization of the real economy worsens welfare considerably by undermining the positive effects of the expansionary bubble.

Third, if the inflation or output focused rule does not work well, how about the combination of the two policies, i.e., monetary policy that focuses on stabilizing nominal output?

Figure 4: Welfare costs under monetary policy that responds to asset price developments



In the case of monetary policy rule (2) with $\phi_\pi = \phi_y = 10$ and other parameter fixed, which is called the 'nominal output focused' rule, welfare cost is reduced substantially to 0.0036 percent, about one-thirtieth of the welfare cost under the standard monetary policy rule (Table 2, the fifth row). The output focused part of the rule, $\phi_y = 10$, dampens real economic activity and lowers inflation, but the inflation focused part, $\phi_\pi = 10$, boosts the economy by stabilizing inflation. These two forces are harmonized well, making the responses of the economy close to those under Ramsey-optimal monetary policy. The nominal output focused rule is quite effective in addressing bubbles.

Fourth, is it effective to design monetary policy to respond to a bubble? No, even if a bubble is observable and monetary policy is designed to respond to a growth rate of a bubble optimally to minimize welfare cost, such policy has little effect on welfare cost (Table 2, the sixth row).[7] Rather, monetary policy that responds to a bubble is often counterproductive as shown in Figure 4(a). In this model, a bubble is mainly driven by a sentiment shock and a bubble itself is not the source of inefficiency that can be addressed by monetary policy. Monetary policy that responds to a bubble strongly dampens the real economy too much and worsens welfare considerably.

Fifth, if monetary policy that responds to a bubble is not effective, how about monetary policy that responds to an asset price? In the case of monetary policy rule (2) with coefficient on a growth rate of an asset price of $\phi_{(qK+b)} = 0.48$, which is chosen to minimize welfare cost (Figure 4(b)), and with other parameters fixed, welfare cost is reduced to

[7]The same result holds for monetary policy that responds to a deviation of bubble from its steady state level.

0.0281, but the extent of welfare improvement is far below that under the nominal output focused rule (Table 2, the seventh row).[8] Hence, the monetary policy rule that responds to an asset price can be effective to some extent, but the role of an asset price is limited in improving welfare.

4.4 Sensitivity analysis

This subsection conducts a sensitivity analysis regarding key model parameters on main results on monetary policy in asset price bubbles in Sections 4.1–4.3. The main results to be examined are summarized as follows. First, strict inflation targeting substantially reduces welfare cost relative to the standard monetary policy rule in the model without the financial cost channel. Second, strict inflation targeting induces a sizable welfare loss in the model with the financial cost channel. Third, in the model Ramsey-optimal monetary policy calls for tightening to curb a boom caused by an increase in a bubble and thereby deviates from inflation stabilization in the short run. Fourth, the nominal output focused rule achieves outcomes close to the Ramsey policy in the model.

Borrowing constraint parameter κ This parameter affects the size of a bubble. A low value of κ implies a tight borrowing constraint and increases a bubble-output ratio, and vice versa as was shown in Figure 1(a). A change in the value of κ from the benchmark case of 0.11 does not affect the main results, but generates a subtle difference. A decrease in the value of κ to 0.08 increases a bubble-output ratio and thereby induces a greater welfare loss under the standard monetary policy rule (Table 3, the second row). The opposite applies to the case of an increase in the value of κ to 0.14 (Table 3, the third row). Interestingly, in the case of $\kappa = 0.14$ strict inflation targeting performs poorly than the standard monetary policy rule.

Capital share α This parameter affects the size of capital and thus a ratio of market capitalization to output as was shown in Figure 1(b). The main results continue to hold for both a higher value of $\alpha = 0.3$ and a lower value of $\alpha = 0.25$ from the calibrated value of $\alpha = 0.2689$ (Table 3, the fourth and the fifth rows). A slight difference is that as α becomes greater the welfare cost of strict inflation targeting becomes smaller in the model with the financial cost channel. This is because a high value of α implies a high share of investment expenditure in borrowing constraint (4) and thus the financial cost channel

[8] If the monetary policy rule responds to a deviation of the asset price from its steady state level instead, it performs poorly and does not improve welfare significantly.

Table 3: Welfare costs μ (%) under alternative parameter values

Model	*Model with financial cost channel*			*Model without it*	
Case/Monetary policy rule	Standard	IT	Nominal output focused	Standard	IT
1. Benchmark	0.1015	0.0804	0.0036	0.1672	0.0157
2. $\kappa = 0.08$	0.1902	0.1119	0.0044	0.2947	0.0267
3. $\kappa = 0.14$	0.0417	0.0454	0.0008	0.0741	0.0083
4. $\alpha = 0.3$	0.1018	0.0639	0.0025	0.1601	0.0145
5. $\alpha = 0.24$	0.1000	0.0915	0.0041	0.1691	0.0164
6. $\rho_\theta = 0.9$	1.7900	1.5424	0.1169	3.7140	0.3634
7. $\sigma_\theta = 0.5$	0.6346	0.5023	0.0223	1.0451	0.0980
8. $\eta = 19.785$	0.0593	0.1069	0.0093	0.1107	0.0096
9. $\eta = 11.438$	0.1302	0.0741	0.0031	0.1986	0.0192
10. $\xi_w = 0.01$	0.0026	0.0002	0.0062	0.0102	0.0002

Notes: Monetary policy rules "Standard", "IT (strict inflation targeting)", and "Nominal output focused" correspond those in Table 2.

becomes relatively less strong as α increases.

Sentiment shock parameters ρ_θ and σ_θ If the AR(1) coefficient of the sentiment shock is raised from 0.5 to 0.9 or the standard deviation of the shock is raised from 0.25 to 0.5, welfare cost increases for the all monetary policy rules, but the main results continue to hold (Table 3, the sixth and seventh rows).[9]

Idiosyncratic shock parameter η In calibration this parameter was set to match the investment inaction rate of annual 18.5%. Even if the parameter value is changed to $\eta = 19.785$ or $\eta = 11.438$, which correspond to the inaction rate of 5% and 25% respectively, the main results continue to hold (Table 3, the eighth and ninth rows). The case of a lower inaction rate and thus a higher value of η may be more relevant to practice because the calibration target value of an inaction rate is based on plant-level data. In firm-level data an inaction rate would be lower. In the case of a lower inaction rate of 5%($\eta = 19.785$) strict inflation targeting worsens welfare substantially in the model with the financial cost channel. A higher value of η leads to a lower inaction rate, which implies more wholesale firms make positive investment and have the binding borrowing constraint. Thus, a lower inaction rate enhances the financial cost channel and amplifies downward pressure on inflation caused by an increase in a bubble. Consequently, stabilizing inflation becomes more costly in the short run.

[9] Miao et al. (2015) estimate that the AR(1) coefficient of a sentiment shock is 0.93.

Nominal wage rigidity ξ_w The main results about the model with the financial cost channel no more hold in the case of nearly no nominal wage rigidities, i.e., $\xi_w = 0.01$ (Table 3, the tenth row). Strict inflation targeting is nearly optimal, outperforming the nominal output focused rule. The welfare cost under the standard monetary policy rule is negligible. An increase in a bubble does not cause an excessive boom that can be addressed by monetary policy.

To understand a role of nominal wage rigidities it is useful to focus on the effect of the nominal wage on the nominal marginal cost given by (5). In the benchmark case, the wage is sticky so that the financial cost channel – a drop in ζ_t^f in (5) – dominates the fluctuation of the marginal cost in response to a positive sentiment shock. In response to a positive sentiment shock the wage does not rise as it would in the case of no nominal wage rigidity. The relatively low wage boosts labor demand, which, in turn, stimulates investment and consumption, and thereby amplifies the effect of the shock. In the case of nearly no nominal wage rigidities, however, it is an increase in the wage that dominates the fluctuation of the marginal cost. Consequently, inflation rises, so that strict inflation targeting becomes quite effective in improving welfare as in the case of the model with no financial cost channel.

5 Conclusion

This paper contributes to the literature on monetary policy in asset price bubbles by studying it in the New Keynesian model with rational asset price bubbles. It highlights a role of two frictions – a financial cost channel and nominal wage rigidities – for optimal monetary policy to deviate from inflation stabilization in addressing a bubble. With these frictions in place optimal monetary policy calls for tightening to curb a boom caused by a bubble more than what would be warranted by inflation stabilization although it barely affects the size of a bubble. A key implication of this paper is that monetary policy, albeit blunt and affects the economy broadly, may have a role in addressing a bubble by curbing the resulting boom more than required by inflation stabilization if an increase in asset prices amplifies economic activity through frictions. In the case of a collapse in a bubble, a similar implication applies: monetary policy may have a role in supporting the economy by pulling out substantial monetary easing even if it overshoots inflation.

A few caveats are worth mentioning in concluding the paper. First, this paper focuses on monetary policy and abstracts regulation and macro-prudential policy which are in general considered to be the first line of defense along with supervision in addressing financial stability issues. If such tools that target asset price bubbles are available, do they serve as the first line of defense in the model in this paper? They may do, but even if they affect the size of a bubble directly, monetary policy would still have a role to play in addressing inefficiencies caused by the two frictions that amplify the effect of a bubble. A potential interaction between macro-prudential policy and monetary policy for addressing bubbles remains to be an open question. Second, while a bubble emerges in the stock market value of firms in the model, some point out that it is housing, land, or credit bubbles that damage the economy the most and thus requires close monitoring. In the model, although a bubble is associated with an increase in borrowing, such an increase does not pose a systemic risk that causes a collapse in asset prices. A boom and a collapse in asset price bubbles are driven mainly by an exogenous shock in the model. Third, while there is ample evidence that supports nominal wage rigidity, it remains an open question whether a financial cost channel is strong enough for supporting the main results of this paper. These caveats notwithstanding, this paper may be useful by clarifying a role of the two frictions regarding optimal monetary policy in rational asset bubbles in the New Keynesian framework.

References

[1] Aoki, Kosuke and Kalin Nikolov, 2015, "Bubbles, Banks and Financial Stability," *Journal of Monetary Economics*, 74: 33–51.

[2] Asriyan, Vladimir, Luca Fornaro, Alberto Martin, and Jaume Ventura, 2016, "Monetary Policy for a Bubbly World," *NBER Working Paper Series* 22639.

[3] Bernanke, Ben S., 2002, "Asset-Price "Bubbles" and Monetary Policy," Remarks, Before the New York Chapter of the National Association for Business Economics, New York, Octorber, 2002.

[4] Bernanke, Ben S., 2010, "Monetary Policy and the Housing Bubble," Speech at the Annual Meeting of the American Economic Association, Atlanta, Georgia.

[5] Bernanke, Ben S. and Mark Gertler, 1999, "Monetary Policy and Asset Price Volatility," Paper Presented at Federal Reserve Bank of Kansas City Annual Conference, Jackson Hole.

[6] Bernanke, Ben S. and Mark Gertler, 2001, "Should Central Banks Respond to Movements in Asset Prices?," *The American Economic Review*: *Papers and Proceedings*, 91(2): 253–57.

[7] Blanchard, Oliver and Jordi Gali, 2007, "Real Wage Rigidities and the New Keynesian Model," *Journal of Money, Credit and Banking*, 39(s1): 35–65.

[8] Bordo, Michael D., and David C. Wheelock, 2007, "Stock Market Booms and Monetary Policy in the Twentieth Century," *Federal Reserve Bank of St. Louis Review*, 89(2): 91–122.

[9] Borio, Claudio, 2014, "Monetary Policy and Financial Stability: What Role in Prevention and Recovery,"BIS Working Papers No.440.

[10] Borio, Claudio, and Philip Lowe, 2002, "Asset Prices, Financial and Monetary Stability: Exploring the Nexus,"BIS Working Papers No.114.

[11] Calvo, Guillermo, 1983, "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics* 12: 383–98.

[12] Carlstrom, Charles T., Timothy S. Fuerst, and Matthias Paustian, 2010, "Optimal Monetary Policy in a Model with Agency Costs, " *Journal of Money, Credit and Banking*, Supplement to 42(6), 37-70.

[13] Carney, Mark, 2009, "Some considerations on using monetary policy to stabilize economic activity,"Remarks to a symposium sponsored by the Federal Reserve Bank of Kansas City, Jackson Hole, Wyoming.

[14] Cecchetti, Stephen G., Hans Genberg, John Lipsky, and Sushil Wadhwani, 2000, "Asset Prices and Central Bank Policy," *The Geneva Report on the World Economy* No.2, ICMB and CEPR

[15] Christiano, Lawrence J., Martin Eichenbaum and Charles Evans, 2005, "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy*, 113(1): 1–45.

[16] Christiano, Lawrence J., Cosmin Ilut, Roberto Motto, and Massimo Rostagno, 2010, "Monetary Policy and Stock Market Booms," Paper presented at Federal Reserve Bank of Kansas City Annual Conference, Jackson Hole.

[17] Cooper, Russell W., and John C. Haltiwanger, 2006, "On the Nature of Capital Adjustment Costs," *Review of Economic Studies*, 73(3): 611–633.

[18] Detken, Carsten, and Frank Smets, 2004, "Asset Price Booms and Monetary Policy, "European Central Bank, Working Paper Series, No.364, May.

[19] Dong, Feng, Jianjun Miao, and Pengfei Wang, 2017, "Asset Bubbles and Monetary Policy, "*manuscript*, Boston University.

[20] Dupor, Bill, 2005, "Stabilizing Non-foundamental Asset Price Movements under Discretion and Limited Information," *Journal of Monetary Economics,* 52: 727–747.

[21] Eberly, Janice, Sergio Rebelo, and Nicolas Vincent, 2012, "What Explains the Lagged-Investment Effect?" *Journal of Monetary Economics,* 59(4): 370–380.

[22] Erceg, Christopher J., Dale W. Henderson, and Andrew T. Levin, 2000, "Optimal Monetary Policy with Staggered Wage and Price Contracts," *Journal of Monetary Economics*, 46: 281–313.

[23] Farhi, Emmanuel and Jean Tirole, 2012, "Bubbly Liquidity," *Review of Economic Studies*, 79(2), 678-706.

[24] Gali, Jordi, 2014, "Monetary Policy and Rational Asset Price Bubbles, " *American Economic Review*, 104(3): 721–752.

[25] Hirano, Tomohiro, Masaru Inaba, and Noriyuki Yanagawa, 2015, "Asset Bubbles and Bailouts," *Journal of Monetary Economics*, 76: S71–S89.

[26] King, Mervyn, 2012, "Twenty Years of Inflation Targeting,"The Stamp Memorial Lecture, London School of Economics, 9 October.

[27] Kohn, Donald L., 2006, "Monetary Policy and Asset Prices, "At *Monetary Policy: A Journey from Theory to Practice*, a European Central Bank Colloquium held in honor of Otmar Issing, Frankfurt, Germany.

[28] Martin, Alberto and Jaume Ventura, 2012, "Economic Growth with Bubbles," *The American Economic Review*, 102(6), 3033-3058.

[29] Miao, Jianjun, Pengfei Wang, and Zhiwei Xu, 2015, "A Bayesian DSGE Model of Stock Market Bubbles and Business Cycles," *Quantitative Economics*, 6: 599–635.

[30] Poloz, Stephen S., 2015, "Integrating Financial Stability into Monetary Policy, "National Association for Business Economics, Washington, D.C., 12 October.

[31] Schmitt-Grohe, Stephanie and Martin Uribe, 2005, "Optimal Fiscal and Monetary Policy in a Medium-Scale Macroeconomic Model," in Gertler, Mark and Kenneth Rogoff, eds., *NBER Macroeconomics Annual*, MIT Press: Cambridge MA, 383-425.

[32] Smets, Frank and Rafael Wouters, 2005, "Welfare Analysis of Non-Fundamental Asset Price and Investment Shocks: Implications for Monetary Policy," BIS Papers No. 22: 146–166.

[33] Shirakawa, Masaaki, 2012, "Central banking – before, during, and after the crisis –,"Remarks at a conference sponsored by the Federal Reserve Board and the International Journal of Central Banking, Washington DC.

[34] Svensson, Lars E. O., 2011, “Monetary Policy after the Crisis, ”Speech at the conference *Asia’s role in the post-crisis global economy*, held at Federal Reserve Bank of San Francisco, 29 November.

[35] Trichet, Jean-Claude, 2005, “Asset Price Bubbles and Monetary Policy, ”Mas lecture, 8 June, Singapore.

[36] Woodford, Michael D., 2003, *Interest and Prices*, Princeton University Press, Princeton, New Jersey.