What Asset Prices Should be Targeted by a Central Bank?

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ABSTRACT

This paper investigates the monetary policy design for restoring equilibrium determinacy. Our interests are whether a central bank should respond to asset price fluctuations, and if so, what asset prices should be targeted. We show that a monetary policy response to the price of a productive tangible asset (capital price) is helpful for equilibrium determinacy, while that to the price of an intangible asset that reflects a firm's profit (share prices) is a source of equilibrium indeterminacy. This result comes from the two assets' prices moving in opposite directions in response to a permanent increase in inflation.

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1 INTRODUCTION

Should monetary policy respond to asset prices? This classic policy question has been investigated by many researchers, and with varying results. On the one hand, we find studies, such as Bernanke and Gertler (2001) and Gilchrist and Leahy (2002), that show the unimportance of responding to assets. In this line, we also find Iacoviello (2005) that shows that if the central bank wants to minimize output and inflation fluctuations, little is gained by responding to asset prices. On the other hand, Faia and Monacelli (2007) identify a scenario in which monetary policy should respond to increases in asset prices by lowering the nominal interest rate.

One important issue to consider when studying whether the central bank should respond to asset prices is if incorporating such actions in a model can lead to equilibrium indeterminacy. In this regard, Carlstrom and Fuerst (2007) show that equilibrium indeterminacy arises if monetary policy responds to asset prices in a sticky-price economy without productive assets (e.g., capital). They focus on share prices – that reflect monopolistic competitive firms' profits – as asset price. It is well known that, in standard sticky-price models, conditions for equilibrium determinacy are highlighted by the Taylor principle – if a permanent increase in the inflation rate occurs, the central bank should increase the nominal interest rate by more than one percent. Since an increase in inflation reduces firms' profits and share prices decline, a monetary policy responding to share prices implicitly weakens the overall reaction to inflation. This is a source of equilibrium indeterminacy in their model.

The objective of this paper is to study whether the equilibrium indeterminacy results found by Carlstrom and Fuerst (2007) are applicable to other types of assets. To this end, we extend the model of Carlstrom and Fuerst (2007) by introducing a productive real asset: capital. Our model is a standard Calvo-pricing sticky one with two types of assets: capital and share. Capital is used to produce a good and its price is a discounted sum of future real rental prices. Share is non-productive assets, and its price is a discounted

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sum of future monopolistic profits of firms. We show that it is important to distinguish between capital and share prices from an equilibrium determinacy perspective. As also shown by Carlstrom and Fuerst (2007), an increase in inflation implies low firm profits and low share prices in our model. On the other hand, an increase in inflation also implies a high rental rate of capital and high capital prices. This difference in the effects on share and capital prices is the key to interpreting the result presented in this work. A monetary policy responding to capital prices implicitly strengthens the overall reaction to inflation, while that responding to share prices implicitly weakens the overall reaction to inflation. Therefore, a monetary policy responding to capital prices is helpful for equilibrium determinacy, while that responding to share prices is a source of equilibrium indeterminacy.

One of the strengths of this model is that there are empirical counterparts of assets in our model:[1] the capital price and share price in the model can be interpreted as the value of net worth and that of intangible assets in actual data, respectively.[2] It is often considered that the market value of a firm consists of the value of its net worth and its intangible assets, as Hall (2001) estimates the value of intangible assets as the difference between stock market index and net worth. On a firm's balance sheet, as in the Flow of Funds Tables in the U.S., a firm's net worth consists of its tangible assets (nonfinancial assets) and net financial assets (financial assets minus liabilities)[3]. The price of capital in the model corresponds to the value of tangible assets. Moreover, because firms have no leverage in the model, net financial assets are zero, and the value of tangible assets equals their net worth. The share prices that reflect firms' future monopolistic profits

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[1] The author is grateful to a referee for suggesting this connection.

[2] In this paper, we use the term "share price," following the convention in Carlstrom and Fuerst (2007). However, this term is not essential. What is important is that this asset price reflects the present value of monopolistic competitive firms. A major reason the "share price" in this model differs from the market value of a firm in actual data is that capital stock is owned by households in this model.

[3] For instance, see the sheet named "B.102 Balance Sheet of Nonfarm Nonfinancial Corporate Business" in the Flow of Funds Tables.

correspond to the value of intangible assets. Therefore, our sticky-price model with capital can break the value of a firm into two components: the value of net worth (capital price) and that of intangibles (share price).

There are two approaches to analyzing a monetary policy that responds to asset price fluctuations. One is to evaluate from the viewpoint of equilibrium determinacy as in the present paper. Bullard and Schaling (2002) and Calstrom and Fuerst (2007) employ this approach, and both of them find that a monetary policy responding to asset prices is a source of equilibrium indeterminacy. Bullard and Schaling (2002) use one-period claims to random nominal quantities as asset, and Carlstrom and Fuerst (2007) use share. We find that in the case of a monetary policy responding to capital price fluctuations, the result is overturned. The other approach is to evaluate from the viewpoint of welfare or of variances in output and inflation. Bernanke and Gertler (2001), Gilchrist and Leahy (2002), Iacoviello (2005), and Faia and Monacelli (2007) employ this approach. In these models, financial markets are imperfect while we analyze the economy with perfect credit markets. They also focus on one type of asset price, while the current paper focuses on multiple types of asset prices.

The rest of this paper is organized as follows. Section 2 introduces our model. Section 3 presents the main result of this paper, its interpretation, and policy implications. Section 4 determines the robustness of our results. We consider three cases: (i) the case where firms own capital stock, (ii) the case where capital stock evolves over time, and (iii) the case where both nominal prices and nominal wages are sticky. Section 5 concludes.

2 THE MODEL

In this section, we introduce the log-linearized system of the model.[4] We extend the model of Carlstrom and Fuerst (2007) by introducing a productive real asset: capital. It is based on a standard sticky-price model. Households choose consumption c_t, supply labor h_t, and hold capital stock k_t, nominal bond b_t, and share s_t as assets. Price stickiness occurs in the monopolistic competitive intermediate-goods sector.

The household's Euler equation for the nominal bond is

$$\sigma(c_{t+1} - c_t) = r_t - \pi_{t+1}, \tag{1}$$

where c_t, r_t, and π_t denote consumption, nominal interest rate, and inflation rate, respectively, and parameter $\sigma > 0$ is relative risk aversion. The intratemporal optimization condition of the household is

$$\sigma c_t + \gamma h_t = w_t, \tag{2}$$

where w_t denotes the real wage, and γ is the inverse of Frisch elasticity. The current share price is given as a discounted sum of future dividends and share prices:

$$q_t = \beta q_{t+1} + (1 - \beta)d_{t+1} + (\pi_{t+1} - r_t), \tag{3}$$

where q_t and d_t denote share prices and dividends, respectively. Parameter $\beta \in (0, 1)$ is the discount factor of the household. The analogue of the current capital price is given by

$$q_t^K = \beta q_{t+1}^K + (1 - \beta)r_{t+1}^K + (\pi_{t+1} - r_t), \tag{4}$$

where q_t^K and r_t^K denote capital prices and the rental rate of capital stock.

The production function is

$$y_t = \alpha k_t + (1 - \alpha)h_t, \tag{5}$$

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[4]The details of the model are described in Appendix A.

where y_t, k_t, and h_t denote output, capital, and labor, respectively, and parameter $\alpha \in (0, 1)$ is the cost share of capital. Cost minimization implies

$$w_t = y_t - h_t + z_t, \tag{6}$$

$$r_t^K = y_t - k_t + z_t, \tag{7}$$

where z_t denotes the real marginal cost. The intermediate-goods firms set their prices subject to Calvo-type price staggeredness. The price can be re-optimized only at period t with probability $1 - \kappa$. Following Yun (1996), the New Keynesian Phillips curve is obtained as

$$\pi_t = \lambda z_t + \beta \pi_{t+1}, \tag{8}$$

where

$$\lambda = \frac{(1 - \kappa)(1 - \kappa\beta)}{\kappa}.$$

The monopolistic rent of firms is paid to households as dividend, and is given by

$$d_t = y_t - \frac{Z}{1 - Z} z_t, \tag{9}$$

where parameter $Z \in [0, 1]$ is the steady-state real marginal cost.

The total supply of shares is one, and the total supply of nominal bonds is zero: $b_t = 0$. For simplicity, it is assumed that the total supply of capital stock is fixed: $k_t = 0$. Then, the resource constraint is

$$c_t = y_t. \tag{10}$$

Finally, the central bank follows the Taylor rule:

$$r_t = \tau_\pi \pi_t + \tau_q q_t + \tau_{qk} q_t^K, \tag{11}$$

where $\tau_\pi > 0$, $\tau_q \geq 0$, and $\tau_{qk} \geq 0$ are the central bank's stances on inflation, share prices, and capital prices, respectively.

3 MAIN RESULTS

As shown by Carlstrom and Fuerst (2007), the dividend is given by

$$d_t = -Az_t, \tag{12}$$

where

$$A \equiv \frac{Z(1 + \sigma + \gamma) - 1 + \alpha(1 - Z\sigma)}{(1 - Z)[\sigma + \gamma - \alpha(\sigma - 1)]}.$$

Following Carlstrom and Fuerst (2007), we employ the following assumption on A:

ASSUMPTION 1. $A > 0$.

Under this assumption, an increase in the real marginal cost decreases the dividend. It is also shown that

$$r_t^K = Bz_t, \tag{13}$$

where

$$B \equiv \frac{\sigma(1 - \alpha) + 1 + \gamma}{\sigma(1 - \alpha) + \alpha + \gamma} > 0.$$

This equation implies that an increase in the real marginal cost increases the rental rate of capital.

This difference between the effects of the real marginal cost on the dividend and those on the rental rate of capital is the key to interpreting the main result of this paper.

The equilibrium system is reduced to the following matrix form:

$$
\begin{bmatrix}
1 & \chi & 0 & 0 \\
\beta & 0 & 0 & 0 \\
1 & -(1-\beta)A & \beta & 0 \\
1 & (1-\beta)B & 0 & \beta
\end{bmatrix}
\begin{bmatrix}
\pi_{t+1} \\
z_{t+1} \\
q_{t+1} \\
q_{t+1}^K
\end{bmatrix}
=
\begin{bmatrix}
\tau_\pi & \chi & \tau_q & \tau_{qk} \\
1 & -\lambda & 0 & 0 \\
\tau_\pi & 0 & 1 + \tau_q & \tau_{qk} \\
\tau_\pi & 0 & \tau_q & 1 + \tau_{qk}
\end{bmatrix}
\begin{bmatrix}
\pi_t \\
z_t \\
q_t \\
q_t^K
\end{bmatrix},
$$

where

$$\chi \equiv \frac{\sigma(1-\alpha)}{\sigma(1-\alpha)+\alpha+\gamma} > 0.$$

The first equation is the consumption Euler equation, equation (1), the second equation is the New Keynesian Phillips curve, equation (8), the third equation is the Euler equation for shares, equation (3), and the fourth equation is the Euler equation for capital, equation (4).

If $\tau_q = \tau_{qk} = 0$, share and capital prices do not affect inflation and the real marginal cost, although the latter two variables do affect capital and share prices. It is straightforward to demonstrate that $\tau > 1$ is necessary and sufficient for equilibrium determinacy.

For the main proposition, we employ the following assumption:

ASSUMPTION 2. $\beta > \frac{1+\gamma}{\sigma(1-\alpha)+1+\gamma}$.

This condition is satisfied under reasonable calibrations. For example, if $\sigma = \gamma = 2$ and $\alpha = 0.3$, this condition implies that $\beta > 0.682$.

The main result of this paper is as follows:

PROPOSITION 1. *Under Assumptions 1 and 2, a necessary and sufficient condition for equilibrium determinacy is*

$$(\tau_\pi - 1)\lambda - \tau_q A(1-\beta) + \tau_{qk} B(1-\beta) > 0.$$

Proof. See Appendix B. □

In the case where $\alpha = 0$ and $\tau_{qk} = 0$, Proposition 1 is reduced to the condition discussed by Carlstrom and Fuerst (2007). Our result implies that even if $\tau_\pi > 1$, equilibrium indeterminacy arises if

$$\tau_q > \frac{(\tau_\pi - 1)\lambda}{(1-\beta)A}. \tag{14}$$

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In the case where $\tau_q = 0$, our result implies that even if $\tau_\pi < 1$, equilibrium determinacy arises if

$$\tau_{qk} > \frac{(1 - \tau_\pi)\lambda}{(1 - \beta)B}. \tag{15}$$

Therefore, Proposition 1 implies that monetary policy with positive responses to share prices ($\tau_q > 0$) is a source of equilibrium indeterminacy. Conversely, monetary policy responding to capital prices ($\tau_{qk} > 0$) is a source of equilibrium determinacy.

This result is highlighted by the Taylor principle: a permanent increase in the inflation rate leads to a more-than-proportionate increase in the inflation rate. A one-percentage point permanent increase in the inflation rate causes the marginal cost to increase by $(1 - \beta)/\lambda$ due to the Phillips curve. This decreases dividends and share prices by $A(1 - \beta)/\lambda$ and increases the rental rate of capital and capital prices by $B(1 - \beta)/\lambda$. Thus, monetary policy responding to share prices implicitly weakens the overall reaction to inflation, while monetary policy responding to capital prices implicitly strengthens the overall reaction to inflation. Therefore, monetary policy responding to capital prices is a source of equilibrium determinacy, while that responding to share prices is a source of equilibrium indeterminacy.

When we address monetary policy and asset price fluctuations, it is rare to discuss the types of assets. Our result implies that it is important to distinguish between capital and share prices because they have different monetary policy implications. This result also implies that monetary policy responding to capital prices is good from an equilibrium determinacy perspective.

4 ROBUSTNESS

4.1 *Case where Firms Own Capital Stock*

We have assumed that households own both capital and shares in Section 2. One might think that if firms own capital stock, share prices reflect capital prices and then our result is likely to be overturned.

In this subsection, we consider a model where intermediate-goods firms own capital stock. In this case, the dividend is given as the output minus wage payments and new capital purchases.[5] Then, the dividend includes the income from capital, and the share price includes the value of capital stock.

In this case, the linearized version of the dividend is given by

$$d_t = -\tilde{A}z_t, \tag{16}$$

where

$$\tilde{A} \equiv \frac{(1-\alpha)[Z(1+\sigma+\gamma)-1-\alpha\sigma\gamma]}{[1-(1-\alpha)Z][\sigma+\gamma-\alpha(\sigma-1)]}.$$

Other values are as in the previous model. Finally, Proposition 1 holds if we replace A by $\tilde{A}$ and assume that $\tilde{A} > 0$.

This assumption—$\tilde{A} > 0$—holds under standard calibrated parameter values. This could be interpreted such that the effect of a permanent increase in inflation on share prices is larger than that on capital prices.

4.2 *Endogenous Capital Stock*

To this point, we have assumed, for analytical simplicity, that the total supply of capital stock is fixed. In this section, we consider a case where capital evolves over time.[6]

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[5]The model in level form is in Appendix C.

[6]The details of the model with endogenous capital, equilibrium, and log-linearized systems are shown in Appendix D.

In this case, the evolution of capital stock is

$$k_{t+1} = (1 - \delta)k_t + \delta i_t, \tag{17}$$

where $\delta \in (0, 1)$ is the depreciation rate of capital. The adjustment cost is the same as that employed by Carlstrom and Fuerst (2005), and the capital price given by the first-order condition for investment is

$$q_t = (1 - \eta)i_t, \tag{18}$$

where $\eta \in (0, 1)$ represents the adjustment costs of investment.

Because the model with endogenous capital cannot be solved analytically, we apply numerical analysis to investigate the determinacy regions. We employ the following parameter values. Discount factor β is 0.99; relative risk aversion σ is 2; Frisch elasticity of labor γ is 2; parameter of the New Keynesian Phillips curve λ is 0.019; and steady-state real marginal cost Z is 0.85. These values are taken from Carlstrom and Fuerst (2007). We also set the cost weight of capital in the production function, α, to 0.3 and the adjustment cost of investment, η, to 0.5.

Figure 1 shows the determinacy region in the (τ_q, τ_π) plane. The region with diamonds indicates equilibrium determinacy, and the other region indicates either equilibrium indeterminacy or no stationary equilibrium. The vertical axis is the central bank's stance on inflation, τ_π. The horizontal axis is the central bank's stance on share prices, τ_q. We set $\tau_{qk} = 0$. As in Figure 1, an increase in τ_q shrinks the determinacy region of τ_π. Then, as found in Section 3, monetary policy responding to share prices is a source of equilibrium indeterminacy.

Figure 2 shows the determinacy region in the (τ_{qk}, τ_π) plane. The horizontal axis is the central bank's stance on share prices, τ_{qk}. We set $\tau_q = 0$. In contrast to the implications of Figure 1, increases in τ_{qk} enlarge the determinacy region of τ_π. Thus, monetary policy responding to capital prices is a source of equilibrium determinacy.

Finally, we find that our results in Section 3 are robust in the case where capital stock evolves over time.

4.3 *Nominal Wage Rigidity*

We have assumed that nominal wages are flexible in Section 2. However, Carlstrom and Fuerst (2007) find that a permanent increase in inflation increases share prices in a sticky-wage economy. This result might seem to suggest that the difference between capital and share prices is less important when nominal wages are sticky. In this subsection, we consider an economy in which nominal wages are also sticky.

We introduce nominal wage rigidity à la Erceg, Henderson, and Levin (2000) to the model presented in the previous subsection. In our economy, nominal prices and nominal wages are sticky, capital stock evolves over time, and there is an adjustment cost of investment.[7]

In this case, the linearized labor supply behavior is given by

$$\sigma c_t + \gamma h_t = z h_t + w_t, \tag{19}$$

where $z h_t$ is the monopoly distortion, which measures the difference between the household's marginal rate of substitution and real wage. Erceg, Henderson, and Levin (2000) demonstrate that the nominal wage adjustment is given by

$$\pi_t^w = \beta \pi_t^w + \lambda^w z h_t, \tag{20}$$

where π_t^w denotes the nominal wage inflation:

$$\pi_t^w = (w_t - w_{t-1}) + \pi_t, \tag{21}$$

where w_t denotes the log-deviation of the real wage from a steady state.

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[7]The linearized equilibrium system is described in Appendix E.

To investigate determinacy regions of the equilibrium, we employ numerical analyses. Nominal wage-stickiness parameter λ^w is 0.035, which is as in Carlstrom and Fuerst (2007). Other values are the same as in the previous section.

Figure 3 shows the determinacy region in the (τ_q, τ_π) plane. Figure 4 shows the determinacy region in the (τ_{qk}, τ_π) plane. Figures 3 and 4 show that an increase in τ_q shrinks the determinacy region of τ_π and that an increase in τ_{qk} enlarges the determinacy region of τ_π. Thus, our results are robust in the case where prices and wages are sticky. It is also found that Figures 3 and 4 are quite similar to Figures 1 and 2 and that the sticky wage has little quantitative impact on the determinacy regions in this case.

5   CONCLUDING REMARKS

In this paper, we considered a monetary policy rule that responds to asset prices in a standard sticky-price model with shares, whose prices reflect the firms' profits, and with a productive real asset, capital. In our model, a monetary policy responding to capital prices is helpful for equilibrium determinacy, while that responding to share prices is a source of equilibrium indeterminacy.

The key to interpreting our result is the different effects of inflation on the two asset prices. An increase in inflation implies low firm profits and low share prices. Conversely, it also implies a high rental rate of capital and high capital prices. Then, a monetary policy responding to capital prices strengthens the overall reaction to inflation while that responding to share prices weakens the same.

When addressing monetary policy and asset price fluctuations, it is rare to discuss the types of assets. However, we found that it is important to distinguish between capital and share prices because they have different monetary policy implications, and that a monetary policy responding to capital prices is good from an equilibrium determinacy perspective.

Our result implies that the relationship between inflation and asset prices is important. If a permanent increase in inflation reduces asset prices, as is the case with the share prices in this paper, a central bank should not respond to asset price fluctuations because such fluctuations are a source of equilibrium indeterminacy. Conversely, a permanent increase in inflation increases asset prices such as capital prices, and as such, the central bank's response to asset prices is feasible. The qualitative and quantitative relationships between inflation and asset prices remain to be addressed, and these relationships merit further empirical research. Future work also includes estimating an empirical monetary policy rule following the argument considered in this paper.

APPENDIX A: THE MODEL

The details of the model in Section 2 are given as follows.

A.1 Households

Households begin period t with M_t cash balances, B_t one-period nominal bonds that pay R_{t-1} gross risk-free interest rate, S_t shares of stock that sell at price Q_t, and K_t units of capital stock that sell at price Q_t^K.

The utility function is

$$U\left(C_t, H_t, \frac{M_{t+1}}{P_t}\right) = \frac{C_t^{1-\sigma}}{1-\sigma} - \phi\frac{H_t^{1+\gamma}}{1+\gamma} + V\left(\frac{M_{t+1}}{P_t}\right),$$

where $\sigma > 0$, $\gamma > 0$, $V(\cdot)$ is increasing and concave, C_t denotes consumption, H_t denotes labor supply, and M_{t+1}/P_t denotes real cash balances at the end of period t.

Households' budget constraint is

$$P_t C_t + M_{t+1} + B_{t+1} + P_t Q_t S_{t+1} + P_t Q_t^K K_{t+1}$$
$$\leq P_t W_t H_t + M_t + R_{t-1} B_t + P_t(Q_t + D_t)S_t + P_t(R_t^K + Q_t^K)K_t + X_t,$$

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where W_t denotes the wage rate, R_t^K denotes the rental rate of capital, D_t denotes share dividends, and X_t denotes monetary injection.

Households' first-order conditions are

$$\phi C_t^\sigma H_t^\gamma = W_t,$$

$$C_t^{-\sigma} = \beta C_{t+1}^{-\sigma} \cdot \frac{R_t}{\Pi_{t+1}},$$

$$C_t^{-\sigma} Q_t = \beta C_{t+1}^{-\sigma} \left[Q_{t+1} + D_{t+1} \right],$$

$$C_t^{-\sigma} Q_t^K = \beta C_{t+1}^{-\sigma} \left[Q_{t+1}^K + R_{t+1}^K \right],$$

where $\Pi_{t+1} \equiv P_{t+1}/P_t$ denotes gross inflation. The first equation is the intratemporal optimization condition, the second is the Euler equation for consumption, the third is the Euler equation for shares, and the last is the Euler equation for capital.

By these Euler equations, familiar asset prices equations are obtained:

$$Q_t = \left[Q_{t+1} + D_{t+1} \right] \frac{\Pi_{t+1}}{R_t},$$

$$Q_t^K = \left[Q_{t+1}^K + R_{t+1}^K \right] \frac{\Pi_{t+1}}{R_t}.$$

A.2 Firms

There are monopolistically competitive intermediate-goods firms and competitive final-goods firms.

The production technology of final-goods firms is

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\theta-1}{\theta}} dz \right)^{\frac{\theta}{\theta-1}},$$

where θ denotes the elasticity of substitution and $Y_t(i)$ denotes the outputs of intermediate goods indexed by i. The demand curve for $Y_t(i)$ is

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\theta} Y_t,$$

16

where $P_t(i)$ denotes the price level of intermediate goods indexed by i. The price index for intermediate goods is given by

$$P_t = \left(\int_0^1 P_t(z)^{1-\theta} dz \right)^{\frac{1}{1-\theta}}.$$

The intermediate-goods firms are monopolistically competitive, and they produce intermediate goods $Y_t(i)$ employing capital service $K_t(i)$ and labor $H_t(i)$ from households. The production function is

$$Y_t(i) = K_t(i)^\alpha H_t(i)^{1-\alpha},$$

where $0 < \alpha < 1$. The cost-minimization problem implies

$$W_t = (1 - \alpha) Z_t \frac{Y_t(i)}{H_t(i)},$$

$$R_t^K = \alpha Z_t \frac{Y_t(i)}{K_t(i)},$$

where Z_t denotes real marginal cost.

The intermediate-goods firms set their prices subject to Calvo-type price staggeredness. The price can be re-optimized only at period t with probability $1 - \kappa$. Following Yun (1996), the New Keynesian Phillips curve is obtained as

$$\pi_t = \lambda z_t + \beta \pi_{t+1},$$

where

$$\lambda = \frac{(1 - \kappa)(1 - \kappa\beta)}{\kappa},$$

and where π_t and z_t denote the log-deviation from a steady state of Π_t and Z_t, respectively.

A.3 Equilibrium

The central bank follows the Taylor rule:

$$r_t = \tau_\pi \pi_t + \tau_q q_t + \tau_{qk} q_t^K,$$

where the lowercase letters r_t, q_t, and q_t^K denote the log-deviations from the steady states of R_t, Q_t, and Q_t^K, respectively.

The market-clearing conditions are

$$K_t = \int_0^1 K_t(i)di,$$

$$H_t = \int_0^1 H_t(i)di.$$

We assume that the fixed supply of capital $K_t = K$.

The resource constraint is

$$C_t = Y_t.$$

In this paper, we focus on an equilibrium for which all monopolistic competitive firms are symmetrical. The firms' profits are paid out as dividends to the shareholders. For simplicity, it is assumed that the number of firms is equal to the number of households. Finally, the dividend of an intermediate-goods firm is given by

$$D_t = Y_t - W_t H_t - R_t^K K_t$$

$$= (1 - Z_t)Y_t.$$

APPENDIX B: PROOF OF PROPOSITION 1

Proof. It is easily shown that two of the roots are $1/\beta$. The two remaining roots are solutions of a characteristic equation:

$$F(x) = x^2 + F_1 x + F_2,$$

where

$$F_1 \equiv \frac{-\tau_q[\chi + A(1-\beta)] - \tau_{qk}[\chi - B(1-\beta)] - [\chi(1+\beta) + \lambda]}{\beta\chi},$$

$$F_2 \equiv \frac{\lambda\tau + \chi(1 + \tau_q + \tau_{qk})}{\beta\chi}.$$

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Because Assumption 2 is necessary and sufficient for $\chi - B(1 - \beta) > 0$, we have $F_1 < 0$.

It is shown that $F(0) = F_2 > 0$ and $F'(0) = F_1 < 0$. At $x = 1$, $F(x)$ is decreasing because

$$
\begin{aligned}
F'(1) &= 2 + F_1 \\
&= 2 - \frac{[\chi(1 + \beta) + \lambda] + \tau_q[\chi + A(1 - \beta)] + \tau_{qk}[\chi - B(1 - \beta)]}{\beta\chi} \\
&= \left(2 - \frac{1 + \beta}{\beta}\right) - \frac{\lambda + \tau_q[\chi + A(1 - \beta)] + \tau_{qk}[\chi - B(1 - \beta)]}{\beta\chi} < 0.
\end{aligned}
$$

Then, a necessary and sufficient condition for equilibrium determinacy is

$$
F(1) = \frac{(\tau_\pi - 1)\lambda - \tau_q A(1 - \beta) + \tau_{qk} B(1 - \beta)}{\beta\chi} > 0.
$$

$\square$

APPENDIX C: STICKY-PRICE ECONOMY WHERE FIRMS OWN CAPITAL STOCK

This appendix explains the model in Section 4.1 where intermediate-goods firms own capital stock.

In this case, households' budget constraint becomes

$$
\begin{aligned}
P_t C_t + M_{t+1} + B_{t+1} + P_t Q_t S_{t+1} \\
\leq P_t W_t H_t + M_t + R_{t-1} B_t + P_t (Q_t + D_t) S_t + X_t.
\end{aligned}
$$

The key is the definition of dividend (profit), and it is given by

$$
D_t = Y_t - W_t H_t - Q_t^K (K_{t+1} - K_t).
$$

In this case, the firms' cost-minimization problem is

$$
\sum_{t=0}^{\infty} \beta^t \lambda_t \left[W_t H_t + Q_t^K (K_{t+1} - K_t) \right]
$$

subject to the production technology, where $\beta^t \lambda_t = \beta^t C_t^{-\sigma}$ denotes the Lagrange multiplier of households' budget constraint. Firms' first-order conditions are

$$W_t = (1 - \alpha)Z_t \frac{Y_t(i)}{H_t(i)},$$

$$R_t^K = \alpha Z_t \frac{Y_t(i)}{K_t(i)},$$

$$C_t^{-\sigma} Q_t^K = \beta C_{t+1}^{-\sigma} \left[Q_{t+1}^K + R_{t+1}^K \right],$$

where R_t^K denotes the "shadow" rental price of capital. At equilibrium with a unit supply of capital, the dividend is rewritten as

$$D_t = [1 - (1 - \alpha)Z_t]Y_t.$$

Finally, the linearized equation is (16).

APPENDIX D: STICKY-PRICE ECONOMY WITH EN-DOGENOUS CAPITAL STOCK

Here, we provide details of the model in Section 4.2 with endogenous capital stock.

Household's budget constraint becomes

$$P_t C_t + P_t I_t + M_{t+1} + B_{t+1} + P_t Q_t S_{t+1} + P_t Q_t^K K_{t+1}$$
$$\leq P_t W_t H_t + M_t + R_{t-1} B_t + P_t (Q_t + D_t) S_t + P_t [R_t^K + (1 - \delta) Q_t^K] K_t + X_t,$$

where I_t is investment and $\delta \in (0, 1)$ is the depreciation rate of capital. We assume that the capital price varies because there is a standard quadratic adjustment cost of investment. The evolution of capital stock is

$$K_{t+1} = (1 - \delta)K_t + \Gamma(I_t),$$

where $\Gamma(\cdot)$ is increasing and concave with $\Gamma(0) = 0$. Following Carlstrom and Fuerst (2005), we the employ the functional form of $\Gamma(I_t)$ as

$$\Gamma(I_t) \equiv bI_t^\eta,$$

where η is between zero and one. The first-order condition for investment is

$$Q_t^K = \frac{1}{\Gamma'(I_t)}.$$

Parameter b is chosen such that $Q_t^K = 1$ in the steady state, its value in the no-adjustment cost economy. Then, $b = I^{1-\eta}/\eta$, where I denotes the steady-state investment. In this setting, the asset price equation for capital is the same as in the baseline model. The resource constraint is

$$C_t + I_t = Y_t.$$

Then, the equilibrium system is

$$\phi C_t^\sigma H_t^\gamma = W_t,$$

$$C_t^{-\sigma} = \beta C_{t+1}^{-\sigma} \cdot \frac{R_t}{\Pi_{t+1}},$$

$$Q_t = \left[Q_{t+1} + D_{t+1} \right] \frac{\Pi_{t+1}}{R_t},$$

$$Q_t^K = \left[(1-\delta)Q_{t+1}^K + R_{t+1}^K \right] \frac{\Pi_{t+1}}{R_t},$$

$$Q_t^K = \left[\frac{I_t}{I_{ss}} \right]^{1-\eta},$$

$$D_t = (1-Z_t)Y_t,$$

$$W_t = (1-\alpha)Z_t \frac{Y_t}{H_t},$$

$$R_t^K = \alpha Z_t \frac{Y_t}{K_t},$$

$$Y_t = K_t^{\alpha} H_t^{1-\alpha},$$

$$C_t + I_t = Y_t,$$

$$K_{t+1} = (1 - \delta)K_t + \Gamma(I_t),$$

$$r_t = \tau_{\pi}\pi_t + \tau_q q_t + \tau_{qk}q_t^K.$$

At the steady state with $H_{ss} = 1$, $Q_{ss}^K = 1$, and $\Pi_{ss} = 1$, the system becomes

$$\phi C_{ss}^{\sigma} = W_{ss},$$

$$R_{ss} = \frac{1}{\beta},$$

$$\left(\frac{1}{\beta} - 1\right)Q_{ss} = D_{ss},$$

$$\frac{1}{\beta} = (1 - \delta) + R_{ss}^K,$$

$$D_{ss} = (1 - Z_{ss})Y_{ss},$$

$$W_{ss} = (1 - \alpha)Z_{ss}Y_{ss},$$

$$R_{ss}^K = \alpha Z_{ss}\frac{Y_{ss}}{K_{ss}},$$

$$Y_{ss} = K_{ss}^{\alpha},$$

$$C_{ss} + \delta\eta K_{ss} = Y_{ss}.$$

From this system, we obtain

$$K_{ss} = \left[\frac{\alpha Z_{ss}}{\frac{1}{\beta} - 1 + \delta}\right]^{\frac{1}{1-\alpha}},$$

$$Y_{ss} = K_{ss}^{\alpha},$$

$$C_{ss} = Y_{ss} - \delta\eta K_{ss}.$$

The linearized equilibrium system is

$$\sigma c_t + \gamma h_t = w_t,$$

$$\sigma(c_{t+1} - c_t) = r_t - \pi_{t+1},$$

$$q_t = \beta q_{t+1} + (1 - \beta)d_{t+1} + (\pi_{t+1} - r_t),$$

$$q_t^K = \beta(1 - \delta)q_{t+1}^K + [1 - \beta(1 - \delta)]r_{t+1}^K + (\pi_{t+1} - r_t),$$

$$d_t = y_t - \frac{Z}{1 - Z}z_t,$$

$$w_t = z_t + y_t - h_t,$$

$$r_t^K = z_t + y_t - k_t,$$

$$y_t = \alpha k_t + (1 - \alpha)h_t,$$

$$\frac{C_{ss}}{Y_{ss}}c_t + \left(1 - \frac{C_{ss}}{Y_{ss}}\right)i_t = y_t,$$

$$\pi_t = \beta\pi_{t+1} + \lambda z_t,$$

$$k_{t+1} = (1 - \delta)k_t + \delta i_t,$$

$$q_t^K = (1 - \eta)i_t,$$

$$r_t = \tau_\pi \pi_t + \tau_q q_t + \tau_{qk} q_t^K.$$

APPENDIX E: STICKY PRICE-WAGE ECONOMY WITH ENDOGENOUS CAPITAL STOCK

The linearized equilibrium system of the model in Section 4.3 is

$$\sigma c_t + \gamma h_t = zh_t + w_t,$$

$$\sigma(c_{t+1} - c_t) = r_t - \pi_{t+1},$$

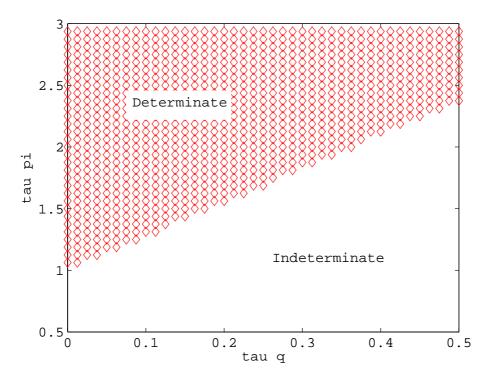$$q_t = \beta q_{t+1} + (1 - \beta)d_{t+1} + (\pi_{t+1} - r_t),$$

$$q_t^K = \beta(1-\delta)q_{t+1}^K + [1-\beta(1-\delta)]r_{t+1}^K + (\pi_{t+1} - r_t),$$

$$d_t = y_t - \frac{Z}{1-Z}z_t,$$

$$w_t = z_t + y_t - h_t,$$

$$r_t^K = z_t + y_t - k_t,$$

$$y_t = \alpha k_t + (1-\alpha)h_t,$$

$$\frac{C_{ss}}{Y_{ss}}c_t + \left(1 - \frac{C_{ss}}{Y_{ss}}\right)i_t = y_t,$$

$$\pi_t = \beta\pi_{t+1} + \lambda z_t,$$

$$\pi_t^w = \beta\pi_{t+1}^w + \lambda^w zh_t,$$

$$w_t - w_{t-1} = \pi_t^w - \pi_t^w,$$

$$k_{t+1} = (1-\delta)k_t + \delta i_t,$$

$$q_t^K = (1-\eta)i_t,$$

$$r_t = \tau_\pi\pi_t + \tau_q q_t + \tau_{qk}q_t^K.$$

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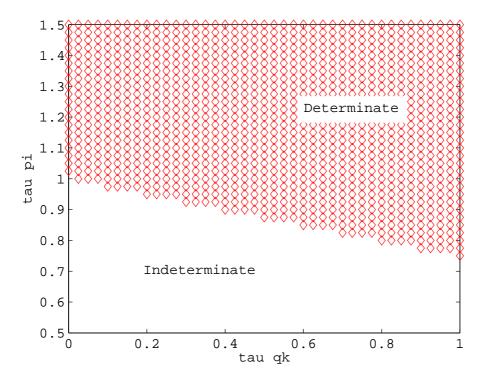
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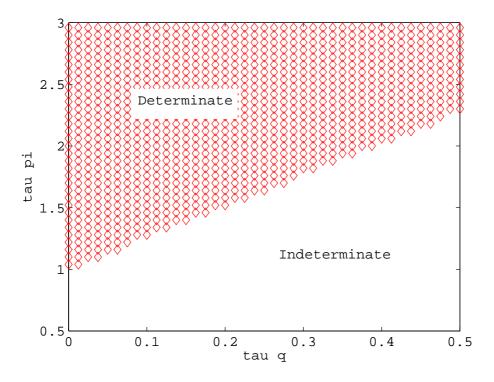FIGURE 1: Determinacy Region if Monetary Policy Responds to q_t (1): Endogenous Capital Stock

NOTE: The vertical axis is the central bank's stance on inflation: τ_π. The horizontal axis is the central bank's stance on q_t: τ_q. The other parameters are $\sigma = 2, \gamma = 2, \alpha = 0.3, \beta = .99, \lambda = 0.019, Z = 0.85, \delta = 0.025, \eta = 0.5$, and $\tau_{qk} = 0$.

FIGURE 2: Determinacy Region if Monetary Policy Responds to q_t^K (1): Endogenous Capital Stock
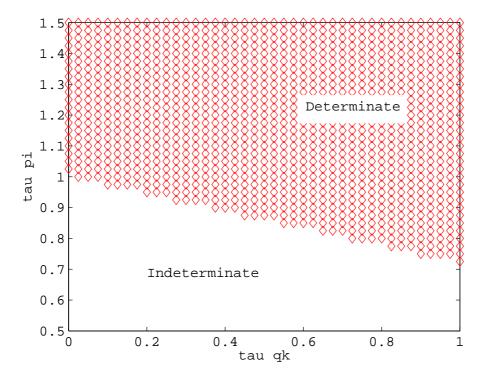

NOTE: The vertical axis is the central bank's stance on inflation: τ_π. The horizontal axis is the central bank's stance on q_t^k: τ_{qk}. The other parameters are $\sigma = 2$, $\gamma = 2$, $\alpha = 0.3$, $\beta = .99$, $\lambda = 0.019$, $Z = 0.85$, $\delta = 0.025$, $\eta = 0.5$, and $\tau_q = 0$.

FIGURE 3: Determinacy Region if Monetary Policy Responds to q_t (2): Sticky Price-Wage Economy with Endogenous Capital Stock

NOTE: The vertical axis is the central bank's stance on inflation: τ_π. The horizontal axis is the central bank's stance on q_t: τ_q. The other parameters are $\sigma = 2$, $\gamma = 2$, $\alpha = 0.3$, $\beta = .99$, $\lambda = 0.019$, $Z = 0.85$, $\delta = 0.025$, $\eta = 0.5$, $\lambda_w = 0.035$, and $\tau_{qk} = 0$.

FIGURE 4: Determinacy Region if Monetary Policy Responds to q_t^K (2): Sticky Price-Wage Economy with Endogenous Capital Stock

NOTE: The vertical axis is the central bank's stance on inflation: τ_π. The horizontal axis is the central bank's stance on q_t^k: τ_{qk}. The other parameters are $\sigma = 2$, $\gamma = 2$, $\alpha = 0.3$, $\beta = .99$, $\lambda = 0.019$, $Z = 0.85$, $\delta = 0.025$, $\eta = 0.5$, $\lambda_w = 0.035$, and $\tau_q = 0$.