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Nominal price rigidity, money supply endogeneity, and business cycles

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Abstract

This paper investigates the ability of nominal price rigidity to explain the co-movement of inflation with the cyclical component of output observed in the post-war U.S. data. A dynamic general equilibrium model is constructed with the introduction of monopolistic competition and nominal price rigidity in a standard real business cycle model, allowing for an endogenous money supply rule. It is then demonstrated that sticky price models can explain the observed associations between movements in inflation and output much better than flexible price models. This result depends little on whether money supply is assumed to be endogenous or not.

Key words: Nominal price rigidity; Inflation and output; Money supply endogeneity

JEL classification: E31; E32; E52

1. Introduction

This paper analyzes the character of fluctuations in aggregate economic activity in an economy with nominal price rigidity that is subject to both technology and monetary policy shocks. The introduction of money and nominal price rigidity into an otherwise standard real business cycle model is motivated by an attempt to account for the observed co-movement of aggregate output with inflation.

The correlation of changes in the rate of inflation with business cycles has been much remarked. Chadha and Prasad (1992), for example, show that the

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rate of inflation is consistently and usually strongly positively correlated with various measures of the cyclical component of output. This is demonstrated in Section 2 below for the case in which, following Beverage and Nelson (1981), the cyclical component of output is defined as the difference between the current level of output and its predicted long-run value, using a VAR model to construct the long-run forecast.

This finding is not easily reconciled with a model of temporary movements in output due to technology shocks, when the evolution of the money supply is not affected by these shocks. Technological improvements should both increase output and lower prices. This is demonstrated below in the case of a flexible price model similar to the one analyzed by Cooley and Hansen (1989). As those authors also found, monetary shocks have little effect on output at business cycle frequencies in such a model. Hence any correlation between inflation and transitory output fluctuations must be due to the effects of technology shocks, which then lead to a predicted correlation with the wrong sign.

The failure of this simple type of model may suggest that monetary shocks have greater effects on output than those predicted by the flexible price model. In particular, if an increased growth of money supply were to cause a significant temporary increase in output, then a positive correlation between transitory output fluctuations and inflation could be created. This requires an additional mechanism to propagate monetary shocks. In this model, firms set prices in advance by maximizing their present discount values in monopolistically competitive product markets, as in the models of Blanchard and Kiyotaki (1986) and Svensson (1986). One advantage of this approach is that the decision problems of the agents who set prices are made explicit. In addition, imperfect competition of this type can help to explain some puzzling empirical properties of the Solow residual, which is taken to be a measure of exogenous productivity changes in standard real business cycle models. Hall (1988) has demonstrated that a gap between price and marginal cost implies that the Solow residual can be an incorrect productivity change measure. Evans (1992) has shown that the Solow residual is Granger-caused by nominal variables such as money and nominal interest rate. This is a puzzle for a model with competitive firms, and for a model with nominal price rigidity in which prices are set to equal the expected marginal cost.

A number of other authors have recently considered the consequences of nominal contract or price rigidity in complete dynamic general equilibrium models. The papers by King (1990) and Cho and Cooley (1992) have explored the quantitative implications of nominal rigidities in models that have extended a standard real business cycle model, as this paper does. However, they do not provide explicit decision-theoretic models of price setting by individual agents. This paper does so by having firms set prices by maximizing their present discounted values of profit streams.

Svensson (1986) and Hairault and Portier (1992) share with the present paper the assumption that prices are set in advance by monopolistically competitive firms. Svensson, however, allows prices to be fixed for one period only, and has not evaluated the quantitative success of his model. The analysis of Hairault and Portier is closer in spirit to the present paper. However, they have analyzed a model with convex cost of price adjustment and money in the utility function. In this paper, by contrast, I impose a cash in advance constraint on consumption, with staggered multi-period price setting. The staggering used here is an extension of Calvo (1983), who has developed a continuous time model in which each firm is allowed to change its price only when a random signal is received. Moreover, Hairault and Portier have only analyzed the case of an exogenous process for the money supply, and have evaluated their model with reference to a different set of data moments than those that are emphasized here. In this paper, the primary emphasis is given to facts about the co-movement of output and inflation, as the observed relationship between these series is the main reason for the introduction of money and nominal rigidities into the model. While the predictions of the model are analyzed here for a smaller number of variables, the predicted joint stochastic process for those variables is analyzed in much greater detail.

Finally, the technology shock that makes output temporarily high might also cause higher inflation, if the money supply is increased, as suggested by King and Plosser (1984). This possibility is analyzed here by allowing for a very general form of response of money growth to current and lagged technology shocks.

The paper proceeds as follows. Section 2 presents empirical evidence on the co-movement of inflation with the stationary component of GNP. Section 3 describes the basic features of a nominal price rigidity model in which the degree of nominal price rigidity is determined by the average fraction of firms that revise their prices in each period as in Calvo (1983). The model also allows for permanent shift in the labor-augmenting technology progress as in King, Plosser, and Rebelo (1988b). Section 4 presents numerical results of simulations. It also discusses how to estimate money supply rules. Section 5 concludes that nominal price rigidity models can explain the observed associations between movements in price and output much better than flexible price models.

2. Cyclical behavior of aggregate price

This section presents empirical evidence on the co-movement of inflation with the stationary component of GNP at the quarterly frequency, to which the numerical predictions of the theoretical models will be subsequently compared. The joint stochastic process is characterized by a vector autoregression of the first difference of log real per capita GNP and the first difference of log GNP deflator in the post-war (1947–1987) United States.

One useful way of describing the bivariate autoregressive process is in terms of estimated impulse responses to two types of orthogonal innovations. Note that this way of characterizing the data remains valid regardless of any structural interpretation of these innovations – we need simply to orthogonalize the innovations in the same way as we report the numerical predictions of the theoretical models. The orthogonalization that is used here is like that of Blanchard and Quah (1989); it is assumed that one innovation (the 'permanent shock' in Fig. 1) has permanent effects on the level of output, while the other (the 'temporary shock' in Fig. 1) leads to only temporary movements of output. Blanchard and Quah have identified these as 'supply' and 'demand' shocks, respectively. In fact, according to all of the theoretical models which have been analyzed in this paper, this structural interpretation is justified. They all (to be developed below) imply that the permanent shock, as understood herein, should correspond to an exogenous labor-augmenting technology shock, while the temporary shock should correspond to an exogenous change in the growth rate of money supply. Hence the estimated responses to the permanent and temporary shock, respectively, are to be compared with the theoretical responses to technology shocks and to monetary shocks, respectively.

The orthogonalization is carried out as follows. Let $\phi_t = [\Delta \log Y_t \ \hat{\pi}_t]'$, where Y_t is real per capita GNP at date t and $\hat{\pi}_t$ is the rate of inflation ($= \Delta \log P_t$, where P_t is the GNP deflator at date t). Since ϕ_t is stationary,[1] a Wold moving average representation can be obtained by first estimating[2] a vector autoregression and then inverting it. Let the estimate be given by $\phi_t = \sum_{j=0}^{\infty} c(j) v_{t-j}$, where $\mathrm{cov}(v_t) = \Omega$, $c(0) = I_{2,2}$, 2×2 identity matrix, and v_t is a 2×1 vector of residuals. On the other hand, if a structural interpretation is given to the above equation, ϕ_t has the following representation: $\phi_t = \sum_{j=0}^{\infty} a(j) \varepsilon_{t-j}$, where $\mathrm{cov}(\varepsilon_t) = I_{2,2}$, $a(j)$ is a 2×2 matrix for all j. Here, $\varepsilon_t = [\varepsilon_{A,t} \ \varepsilon_{M,t}\ ]'$, $\varepsilon_{A,t}$ is permanent shock at date t, and $\varepsilon_{M,t}$ is temporary shock at date t. When these two different representations are compared, $a(j) = c(j)\ a(0)$ for all j. Hence, the identification of the 2×2 matrix $a(0)$ is sufficient for identifying all $a(j)$, given $c(j)$ for all j. This identification requires four equations for four unknowns. Since the estimated covariance matrix Ω gives three equations, only one additional equation is needed for the identification. Here, since temporary shocks have only temporary movements of output, the additional equation is given by $\sum_{j=0}^{\infty} a_{12}(j) = 0$. Consequently this leads the matrix, $a(0)$, to be identified.

In addition, the orthogonalization used here leads the logarithm of GNP to be decomposed into two types of orthogonal components, so $\log Y_t = \log Y_t^r + \log Y_t^d$. Here, $\Delta \log Y_t^r = \sum_{j=0}^{\infty} a_{11}(j) \varepsilon_{A,t-j}$ and $\Delta \log Y_t^d = \sum_{j=0}^{\infty} a_{12}(j) \varepsilon_{M,t-j}$.

[1] The stationarity of ϕ_t is examined using the Dickey–Fuller (DF) test. The t-statistics from the DF regressions of $\Delta \log Y_t$ and π_t are -8.59 and -5.77, respectively, which are all significant at the 5 percent significance level. It thus implies that the rate of inflation and the first difference of log real GNP are stationary.

[2] The lag of bivariate vector autoregression is chosen using the Akaike information criteria suggested in Granger and Newbold (1986). Then, for a chosen value, the likelihood ratio tests are performed as suggested in Doan (1992). As a result, the lag of the vector autoregression is 5.

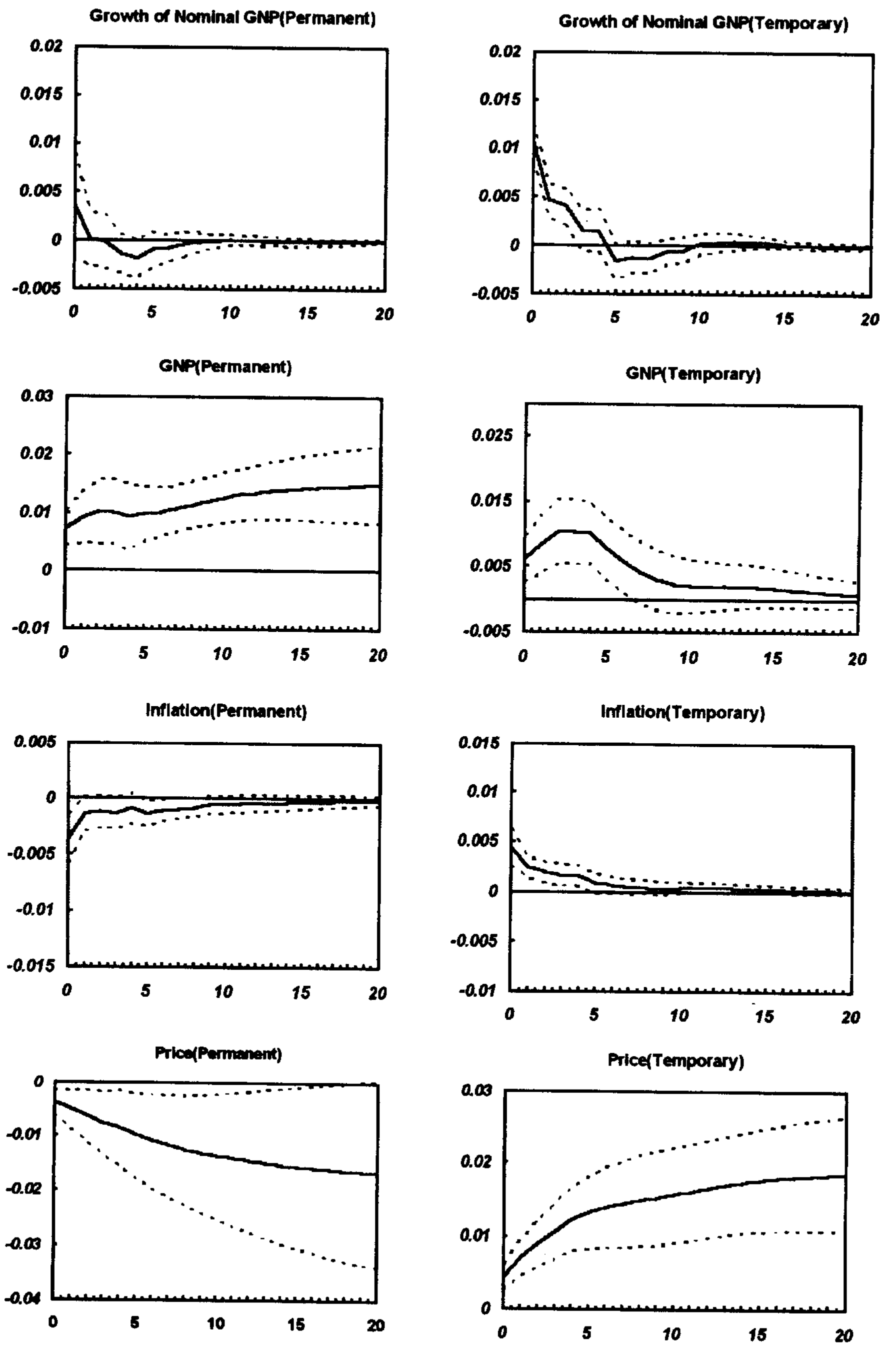

Fig. 1. Estimated impulse responses.

Hence log Y_t^r is the component of output that is affected by only permanent shocks and log Y_t^d is the one that is affected by only temporary shocks.

Furthermore, following Beveridge and Nelson (1981), one can define the stochastic trend of GNP as the long-run forecast of log Y_t. In this case, log Y_t can be represented as the sum of the random walk trend and stationary component. So $\log Y_t = \log Y_t^p + \log Y_t^s$, where log Y_t^p is the random walk component at date t and log Y_t^s is the stationary component at date t. Here, log Y_t^d and log Y_t^s are not necessarily the same because log Y_t^s is not only affected by temporary shocks but also permanent shocks, whereas log Y_t^d is only affected by temporary shocks. For this reason, in subsequent sections, I examine the correlations between the rate of inflation and these four types of output measures.

The estimated impulse responses are plotted in Fig. 1 with two standard errors bands. The 1 percent increase of standard deviation in the permanent shock causes increases in output growth and output level but gradual declines in the price level to a long-run level. On the other hand, temporary shocks exhibit a hump-shaped effect on output. This effect reaches its peak three to five quarters after a temporary shock. The shock also raises the rate of inflation at the initial period and then lowers it gradually, so the response of the price level displays gradual increases to a long-run level. In sum, the aggregate price is countercyclical with respect to permanent shocks but procyclical to temporary shocks.

Table 2 reports standard deviations and cross-correlations of inflation and output measures. The growth rate of GNP displays negative or small positive correlations with up to three lags and leads of the rate of inflation. Besides, the cross-correlations of inflation with the stationary component of GNP ($=$ log Y_t^s) and the component that is affected by only temporary shocks ($=$ log Y_t^d) are consistently positive, whereas the growth rate of the trend component ($= \Delta$ log Y_t^p) or the component that is affected by only permanent shocks ($= \Delta$ log Y_t^r) show consistently negative cross-correlations with the rate of inflation (except when the growth rate of the trend, which is white noise, leads the rate of inflation). In sum, this correlation structure leads one to conclude that the rate of inflation has strongly positive correlations with the cyclical component of output.

3. Model

The economy consists of infinitely lived households, firms, and government. The economy also contains a continuum of differentiated goods that are produced by monopolistically competitive firms. These differentiated goods are aggregated to produce a single composite good in which the utils of consumers and additions to the aggregate capital stock depend only upon the amount of the composite good. Also, the demand function faced by each firm is derived by specifying an aggregator for differentiated goods. In relation to this, I introduce the aggregator of differentiated goods used in Dixit and Stiglitz (1977) such that

$$D_t = \left(\int_0^1 D_t(i)^{(\varepsilon-1)/\varepsilon} \mathrm{d}i \right)^{\varepsilon/(\varepsilon-1)}, \tag{1}$$

where $\varepsilon > 1$, D_t is the number of units of the composite good at period t, $D_t(i)$ is the demand for good i, and $P_t(i)$ is the price of good i set by firm i. Each firm's demand then is determined as a solution that minimizes the total cost of obtaining D_t subject to the aggregator specified in Eq. (1). As a result of cost minimization, when the price index for the composite good is given by

$$P_t = \left(\int_0^1 P_t(i)^{1-\varepsilon} \mathrm{d}i \right)^{1/(1-\varepsilon)}, \tag{2}$$

the demand of firm i takes the following form:

$$D_t(i) = (P_t(i)/P_t)^{-\varepsilon} D_t. \tag{3}$$

Note that the demand function in Eq. (3) has the constant elasticity of ε.

On the other hand, firm i produces good i using capital and labor according to the production technology with a fixed labor cost given by

$$Y_t(i) = F(K_t(i), z_t(H_t(i) - H^o)) \tag{4}$$

where $H_t(i)$, H^o, and $Y_t(i)$ respectively denote total labor input, fixed labor cost, and output of firm i at date t, and z_t denotes the labor-augmenting technology level at date t. Here, the production function F displays the constant returns to scale for capital and net labor, $H_t - H^o$, and the technology process is the logarithmic random walk given by

$$z_t = z_{t-1} \exp(\gamma_t), \tag{5}$$

where γ_t is white noise and its unconditional mean is γ_z. The cost function of firm i, then, can be written as

$$TC_t(i) = \min_{H_t(i), K_t(i)} R_t K_t(i) + W_t H_t(i) \quad \text{s.t.} \quad D_t(i) = F(K_t(i), z_t(H_t(i) - H^o)),$$

where R_t and W_t are the nominal rental for capital service and nominal wage at date t, respectively.

In this paper, I assume that rentals and wages are perfectly flexible in perfectly competitive input markets. Hence, marginal cost is independent of the level of output. Cost minimization conditions then can be written as

$$W_t = MC_t z_t F_H(K_t(i), z_t(H_t(i) - H^o)), \tag{6}$$

$$R_t = MC_t F_K(K_t(i), z_t(H_t(i) - H^o)), \tag{7}$$

where F_K and F_H denote the marginal product of capital and net labor, respectively, and MC_t is the marginal cost at date t. Note that the cost minimization conditions specified in Eqs. (6) and (7) hold for aggregate quantities because the production function F is homogeneous of degree 1 in capital and net labor. In addition, when multiplying net labor and capital to both sides of Eqs. (6) and (7), respectively, and then summing up the resulting two equations, the cost function for firm i is given by $TC_t(i) = MC_tD_t(i) + W_tH^o$. Consequently, the instantaneous real profit at date t for firm i can be written as

$$\phi\left(\frac{P_t(i)}{P_t}, mc_t, D_t, W_t\right) = \left(\frac{P_t(i)}{P_t} mc_t\right)\left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} D_t - \frac{W_t H^o}{P_t}, \tag{8}$$

where mc_t ($= MC_t/P_t$) denotes the real marginal cost at date t.

Having described the instantaneous profit in period t, let's consider the price decision of firms based upon Calvo (1983). In each period, a fraction of firms, say $1 - \alpha$, gets to charge a new price and the other fraction, α, must charge the previous period's prices times average inflation π regardless of the time elapsed since the last price change, where $0 \leq \alpha < 1$. Hence, this Calvo-type staggering and the price index specified in Eq. (3) imply that when the new price commitment in period t is denoted by $P_{t,t}$, the price index in each period $t = 0, \ldots, \infty$ evolves over time according to the recursive form given by

$$P_t^{1-\varepsilon} = (1-\alpha)P_{t,t}^{1-\varepsilon} + \alpha\pi^{1-\varepsilon}P_{t-1}^{1-\varepsilon}, \tag{9}$$

where P_{-1} is given. Furthermore, since with a probability of α^k the new price commitment in period t will be charged in period $t+k$, $P_{t,t}$ is the solution to the maximization problem given by

$$\max_{P_{t,t}} \sum_{k=0}^{\infty} (\alpha\beta)^k \mathrm{E}_t \left[\frac{\Lambda_{t+k}}{\Lambda_t}\phi\left(\frac{\pi^k P_{t,t}}{P_{t+k}}, mc_{t+k}, D_{t+k}, W_{t+k}\right)\right],$$

where the real profit at date $t+k$ is discounted by $\beta^k(\Lambda_{t+k}/\Lambda_t)$ and Λ_t is explicitly defined later. The instantaneous real profit specified in Eq. (8) then leads the first-order condition for $P_{t,t}$ to be given by

$$P_{t,t} = \frac{\varepsilon \sum_{k=0}^{\infty}(\alpha\beta)^k \mathrm{E}_t[\Lambda_{t+k}P_{t+k}^{\varepsilon}D_{t+k}mc_{t+k}]}{(\varepsilon - 1)\sum_{k=0}^{\infty}(\alpha\beta\pi)^k \mathrm{E}_t[\Lambda_{t+k}P_{t+k}^{\varepsilon-1}D_{t+k}]}. \tag{10}$$

Here, the firm takes as given the aggregate demand, stochastic discount factor for asset prices, marginal cost, and price level. In addition, the substitution of $\alpha = 0$ into Eq. (10) yields the same optimization condition as in flexible price models given by

$$P_t = \varepsilon MC_t/(\varepsilon - 1). \tag{11}$$

The real marginal cost therefore is constant over time in flexible price models, whereas it varies in sticky price models.

Let's turn to the behavior of the representative household. The economy has the representative household with preference in period 0 given by

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \; U(x(C_{1t}, C_{2t}), L_t + bL_{t-1}), \tag{12}$$

where C_{1t}, C_{2t}, and L_t denote cash and credit consumption[3] goods, leisure in period t, and the discount factor, β, and preference parameter, b, satisfy $0 < \beta < 1$ and $|\,b\,| < 1$. Here, the nonzero values of b indicate that the current-period utility is not independent[4] of previous-period leisure. Also, in each period, the household faces a time constraint such that

$$L_t + H_t \le \overline{H}, \tag{13}$$

where H_t denotes hours worked and $\overline{H}$ is a fixed time endowment.

The household enters period t with nominal wealth N_t carried over from $t-1$ and receives a lump-sum transfer T_t before a centralized securities market opens. Therefore the household faces the following constraint at the securities market:

$$B_t + M_t^h \le N_t + T_t, \tag{14}$$

where B_t is the nominal value of nominal riskless bonds held by the household in period t and M_t^h is the demand for nominal balance in period t. After the securities market closes, the goods market opens and the household purchases goods under the cash-in-advance constraint.

$$P_t C_{1t} \le M_t^h. \tag{15}$$

At the end of each period, the household receives wages for hours worked, rentals for capital, and dividends from each firm. So the wealth of the household at the

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[3] It is assumed that $x(C_1, C_2)$ is C^2, concave and homogeneous of degree 1 in both arguments with $\lim_{C_1 \to 0} x_1(C_1, C_2) = \infty$, $\lim_{C_2 \to 0} x_2(C_1, C_2) = \infty$, $x_1(C_1, C_2) > 0$, $x_2(C_1, C_2) > 0$ for positive C_1 and C_2. In addition, every differentiated good can be purchased as a cash good or credit good and producer i produces both cash good i and credit good i, setting a common price $P_t(i)$. Furthermore, while $C_{1t} = (\int_0^1 C_{1t}(i)^{(\varepsilon-1)/\varepsilon} \mathrm{d}i)^{\varepsilon/(\varepsilon-1)}$ and $C_{2t} = (\int_0^1 C_{2t}(i)^{(\varepsilon-1)/\varepsilon} \mathrm{d}i)^{\varepsilon/(\varepsilon-1)}$, $H_t = \int_0^1 H_t(i)\mathrm{d}i$.

[4] The negative values of b indicate that leisure preferences are characterized by habit persistence, while the positive values imply that leisure is durable.

beginning of period $t+1$ is given by

$$N_{t+1} = B_t\theta_t + W_tH_t + (R_t + P_t(1-\delta))K_t + M_t^h \\ -P_t(C_{1t} + C_{2t} + K_{t+1}) + \Pi_t^h, \tag{16}$$

where the rate of depreciation, δ, satisfies $0 < \delta < 1$, and θ_t, K_t, and Π_t^h denote the gross nominal interest rate in period t, aggregate capital stock, and aggregate profit of firms given to the household. The household then decides on consumption demand, labor supply, and demand for money to maximize the utility function given in Eq. (12) subject to constraints (13), (14), (15), and (16).

The first-order conditions with respect to cash and credit consumption goods imply that

$$x_1(C_{1t}, C_{2t})/x_2(C_{1t}, C_{2t}) = \theta_t, \tag{17}$$

$$U_C(x(C_{1t}, C_{2t}), L_t + bL_{t-1})x_1(C_{1t}, C_{2t}) = \Lambda_t\theta_t, \tag{18}$$

where Λ_t is defined as $\Lambda_t = \mathrm{E}_t(\beta P_t \Lambda_{t+1}^h)$, Λ_t^h is the Lagrange multiplier for the budget constraint of the household specified in Eq. (16), and U_C denotes the partial derivative of U with respect to x. Note that, since $x(C_{1t}, C_{2t})$ is homogeneous of degree 1 in (C_{1t}, C_{2t}), Eq. (17) implies that the ratio of cash consumption goods to credit consumption goods ($= C_{1t}/C_{2t}$) can be expressed as a function of the nominal interest rate in an equilibrium. This implies that the ratio of cash consumption goods to consumption goods is also a function of the nominal interest rate, so $C_{1t}/C_t = h(\theta_t)$. Furthermore, for the convenience of the analysis in subsequent parts, let's define a new endogenous variable, Φ_t, such that

$$\Phi_t = \frac{U_L(x(C_{1t}, C_{2t}), L_t + bL_{t-1})}{U_C(x(C_{1t}, C_{2t}), L_t + bL_{t-1})}. \tag{19}$$

Eqs. (18) and (19) can be solved to yield the following consumption demand and labor supply functions:

$$\begin{aligned} C_t &= C(\Lambda_t, \theta_t, \Phi_t), \\ H_t &= -bH_{t-1} + H^s(\Lambda_t, \theta_t, \Phi_t). \end{aligned} \tag{20}$$

Besides, Eq. (19) leads the first-order condition for leisure in period t to be given by

$$\Lambda_t \frac{W_t}{P_t} = \Lambda_t\Phi_t e(\theta_t) + \mathrm{E}_t[\beta b \Lambda_{t+1}\Phi_{t+1}e(\theta_{t+1})], \tag{21}$$

where $e(\theta_t) = \theta_t/x_1(h(\theta_t), 1 - h(\theta_t))$. Also, the first-order conditions with respect to bonds and investment are given by

$$\Lambda_t = \mathrm{E}_t \left[\beta \frac{P_t \theta_{t+1}}{P_{t+1}} \Lambda_{t+1} \right], \tag{22}$$

$$\Lambda_t = \mathrm{E}_t \left[\beta \Lambda_{t+1} \left(\frac{R_{t+1}}{P_{t+1}} + 1 - \delta \right) \right]. \tag{23}$$

In addition, the cash-in-advance constraint holds with equality if the gross nominal interest rate, θ_t, is greater than 1. Hence, since it is assumed throughout the paper that $\theta_t > 1$ for all t, the demand for the real balance in each period is given by

$$M_t^h/P_t = h(\theta_t) C(\Lambda_t, \theta_t, \Phi_t). \tag{24}$$

Furthermore, the government supplies money through lump-sum transfer, T_t, so the money stock in period t is given by $M_t = M_{t-1} + T_t$, where $T_t = (\omega_t - 1)M_{t-1}$ and ω_t is the growth of money supply in period t.

Having described the behaviors of individual agents, let's turn to the aggregation of individual outputs. The aggregate demand, D_t, in each period must be equal to aggregate output, Y_t, if the outputs of different firms are aggregated according to the formula, $Y_t = (\int_0^1 Y_t(i)^{(\varepsilon-1)/\varepsilon} \mathrm{d}i)^{\varepsilon/(\varepsilon-1)}$, following the aggregator specified in Eq. (1). This definition of aggregate output is not useful, however, in writing the equilibrium relation between aggregate demand and aggregate factor demands. For using this aggregator, the relation between aggregate output and factors of production is given by $Y_t = (\int_0^1 F(K_t(i),\ z_t(H_t(i) - H^o))^{(\varepsilon-1)/\varepsilon} \mathrm{d}i)^{\varepsilon/(\varepsilon-1)}$. But it is desirable to be able to express aggregate output as a function of the aggregate factor inputs only. This is possible if one defines the aggregator, $Y_t^* = \int_0^1 Y_t(i)\mathrm{d}i$, so that $Y_t^* = F(K_t,\ z_t(H_t - H^o))$, where $K_t = \int_0^1 K_t(i)\mathrm{d}i$ and $H_t = \int_0^1 H_t(i)\mathrm{d}i$. Then one can relate Y_t^* to Y_t by using the alternative price index, $P_t^* = (\int_0^1 P_t(i)^{-\varepsilon} \mathrm{d}i)^{-1/\varepsilon}$. This is because $Y_t^* = \int_0^1 Y_t(i)\mathrm{d}i = (P_t/P_t^*)^{\varepsilon} Y_t$. Hence, the equilibrium relation between aggregate demand and aggregate factor inputs can be written as

$$C_t + K_{t+1} - (1 - \delta)K_t = (P_t^*/P_t)^{\varepsilon} F(K_t, z_t(H_t - H^o)). \tag{25}$$

In addition, Calvo-type staggering implies that the alternative price index evolves over time according to the following equation:

$$P_t^{*^{-\varepsilon}} = (1 - \alpha)P_{t,t}^{-\varepsilon} + \alpha\pi^{-\varepsilon} P_{t-1}^{*^{-\varepsilon}}. \tag{26}$$

Therefore, there are only two predetermined prices, $(P_{t-1},\ P_{t-1}^*)$, which affect subsequent equilibrium conditions, regardless of the size of α. This allows one to consider arbitrarily slow adjustment of prices without having to work with a large state space.

A symmetric equilibrium, then, is an allocation $\{C_t, H_t, K_{t+1}\}_{t=0}^{\infty}$, a sequence of prices and costate variables $\{P_{t,t}, P_t, P_t^*, \theta_t, W_t, mc_t, R_t, \Lambda_t, \Phi_t\}_{t=0}^{\infty}$ satisfying equilibrium conditions (6)–(7), (9)–(10), (20)–(24), and (25)–(26), given K_0, P_{-1}, P_{-1}^*, H_{-1}, and $\{M_t, z_t\}_{t=0}^{\infty}$. Furthermore, since z_t is a logarithmic random walk, these equilibrium conditions lead to a deterministic steady state in which consumption, real money balance, and capital grow at the same rate but labor is constant over time. In this case, as discussed in King, Plosser, and Rebelo (1988a), when one is interested in a stationary economy, it is helpful to use the relations given by

$$C_t = c_t z_t, \quad \Phi_t = \phi_t z_t, \quad K_{t+1} = k_{t+1} z_t, \quad R_t = r_t P_t, \quad W_t = w_t z_t P_t,$$

$$\Lambda_t = \lambda_t z_t^{-\eta}, \quad P_t = p_t z_t M_t, \quad P_t^* = p_t^* z_t M_t, \quad P_{t,t} = p_{t,t} z_t M_t,$$

where η is the inverse of the elasticity of intertemporal substitution. In particular, if these relations are substituted into equilibrium conditions, (6)–(7), (9)–(10), (20)–(24), and (25)–(26), then one can get equilibrium conditions for an allocation $\{c_t, H_t, k_{t+1}\}_{t=0}^{\infty}$, a sequence of prices and costate variables $\{p_{t,t}, p_t, p_t^*, \theta_t, w_t, mc_t, r_t, \lambda_t, \phi_t\}_{t=0}^{\infty}$, given k_0, p_{-1}, p_{-1}^*, H_{-1}, and $\{\omega_t, \gamma_t\}_{t=0}^{\infty}$, which in turn leads to a steady state in which c_t and k_{t+1} are constant over time.

The responses of model economies to changes in technology progress and money supply are then analyzed using the method of King, Plosser, and Rebelo (1988a, b). This implies that a stationary equilibrium involving small fluctuations around steady state is approximated by the solution to a log-linear approximation to the equilibrium conditions for the transformed variables. For this reason, let's denote the percentage deviations of all stationary variables around the steady state by using circumflex. Here, note that $\hat{p}_t = \hat{p}_t^*$. This implies that the linearized version of the social budget constraint specified in Eq. (25) is given by

$$\hat{k}_{t+1} = \frac{1}{\gamma_z}(\mu(\tilde{r}+\delta)+(1-\delta))(\hat{k}_t-\hat{\gamma}_t)+\frac{(\tilde{r}+\delta)\mu s_H}{\gamma_z(1-s_H)}\hat{H}_t-\frac{(\tilde{r}+\delta)s_c}{\gamma_z(1-s_H)}\hat{c}_t, \tag{27}$$

where μ $(= 1/mc)$ is the steady state markup, s_H $(= wH/y)$ is the steady state labor share, $\tilde{r}$ $(= r - \delta)$ is the steady state gross return on investment, and s_c $(= c/y)$ is the steady state fraction of consumption in output. Furthermore, linearizing equilibrium conditions (9) and (10) yields

$$\mathrm{E}_t[\Delta\hat{p}_{t+1}+\hat{\omega}_{t+1}] = \frac{\gamma_z^{\eta-1}}{\beta}\Delta\hat{p}_t + \frac{\gamma_z^{\eta-1}}{\beta}(\hat{\omega}_t-\hat{\gamma}_t)-\frac{(1-\alpha)(\gamma_z^{\eta-1}-\alpha\beta)}{\alpha\beta}\widehat{mc}_t, \tag{28}$$

where $\Delta \hat{p}_t = \hat{p}_t - \hat{p}_{t-1}$. Also, the consumption demand and labor supply equations given in Eq.(20) lead to

$$\begin{aligned} \hat{H}_t &= -b\hat{H}_{t-1} + (1+b)(\varepsilon_\lambda \hat{\lambda}_t + \varepsilon_\theta \hat{\theta}_t + \varepsilon_\phi \hat{\phi}_t), \\ \hat{c}_t &= c_\lambda \hat{\lambda}_t + c_\theta \hat{\theta}_t + c_\phi \hat{\phi}_t, \end{aligned} \tag{29}$$

where ε_j ($= j\partial H^s / H^s \partial j$) and c_j ($= j\partial c / c\partial j$) denote the Frisch elasticities of labor supply and consumption with respect to $j = \lambda, \theta, \phi$. Using that $\mathrm{E}_t[\hat{y}_{t+1}] = 0$, the linearization of equilibrium conditions for leisure in period t and Euler equations for investment and bonds specified in Eqs. (21)–(23) leads to

$$(1 + \beta b \gamma_z^{1-\eta})\hat{w}_t = \hat{\phi}_t + e_\theta \hat{\theta}_t + \beta b \gamma_z^{1-\eta} \mathrm{E}_t[\hat{\lambda}_{t+1} - \hat{\lambda}_t + e_\theta \hat{\theta}_{t+1} + \hat{\phi}_{t+1}], \tag{30}$$

$$\hat{\lambda}_t = \mathrm{E}_t\left[\hat{\lambda}_{t+1} + \frac{\tilde{r}+\delta}{1+\tilde{r}}\hat{mc}_{t+1} + \frac{(\tilde{r}+\delta)(1-\mu(1-s_H))}{\varepsilon_{HK}(1+\tilde{r})}(\hat{n}_{t+1} - \hat{k}_{t+1})\right], \tag{31}$$

$$\hat{\lambda}_t = \mathrm{E}_t[\hat{\lambda}_{t+1} + \hat{p}_t - \hat{p}_{t+1} - \hat{\omega}_{t+1} + \hat{\theta}_{t+1}], \tag{32}$$

where ε_{HK} is the elasticity of substitution between capital and net labor ($n_t = H_t - H^o$). The cash-in-advance constraint given in Eq. (24) implies that

$$\hat{p}_t = -(h_\theta + c_\theta)\hat{\theta}_t - c_\lambda \hat{\lambda}_t - c_\phi \hat{\phi}_t, \tag{33}$$

where h_θ is the elasticity of h with respect to θ. Finally, Eq. (6) holds for aggregate quantities, so its linearized version is given by

$$\hat{w}_t = \hat{mc}_t + \frac{\mu(1-s_H)}{\varepsilon_{HK}}(\hat{k}_t - \hat{y}_t - \hat{n}_t). \tag{34}$$

This set[5] of linear equations is reduced to the system of linear difference equations given by

$$G_1 \mathrm{E}_t[A_{t+1}] = G_2 A_t + G_3 B_t + G_4 \mathrm{E}_t[B_{t+1}], \tag{35}$$

where A_t is the column vector containing seven endogenous variables, $\hat{p}_t$, $\hat{mc}_t$, $\hat{\lambda}_t$, $\hat{H}_t$, $\hat{k}_t$, $\hat{p}_{t-1}$, $\hat{H}_{t-1}$, and B_t is the column vector containing $\hat{y}_t$ and $\hat{\omega}_t$. Here, G_1 and G_2 are 7×7 matrices and G_3 and G_4 are 7×2 matrices. In this case, one can show that a unique stationary solution exists when the matrix $G_1^{-1}G_2$

[5] In flexible price models, Eq. (28) is replaced by $\hat{mc}_t = 0$.

possesses four eigenvalues that are greater than 1 in absolute value and three eigenvalues that are less than 1 in absolute value, following Blanchard and Kahn (1980).

4. Quantitative results

This section begins with the description of the calibration of parameters and the estimation of money supply processes for numerical models and then goes on to numerical findings.

4.1. Parameters values and money supply rules

First, numerical models assume divisible labor supply in conjunction with a log utility function, so the intertemporal substitution has a unit elasticity ($\varepsilon_c = 1$). In turn, Frisch elasticities for consumption demand and labor supply satisfy $c_\phi = 0$, $\varepsilon_\theta = -e_\theta \varepsilon_w$, $\varepsilon_\phi = -\varepsilon_\lambda = -\varepsilon_w$, and $c_\lambda = -1$, where ε_w ($= \overline{H} - H/H$) denotes the intertemporal elasticity of labor supply. Also, the homogeneity of $x(c_1, c_2)$ implies that $e_\theta = \theta h(\theta)/[1 + h(\theta)(\theta - 1)]$ and $c_\theta = -h_\theta - 1$, so they are determined by h_θ, $h(\theta)$, and θ. Besides, absence of arbitrage and Euler equations for bonds and investment imply that $\theta = \omega(1 + \tilde{r})/\gamma_z$ and $\beta = \gamma_z^\eta/(1 + \tilde{r})$. Furthermore, firms are assumed to freely enter markets in the long run, whereas free entry is restricted in the short run. This leads fixed overhead labor to be given by $H_o = H[(\mu - 1)/\mu s_H]$, so the ratio of the overhead labor to total hours is determined by the steady state markup and labor share. In sum, deterministic steady state relations lead one to calibrate the values of free parameters such as ε_{HK}, b, ε_w, μ, δ, γ_z, $\tilde{r}$, s_H, ω, h_θ, $h(\theta)$, ε_c, and α other than parameters related to money growth path and exogenous technology progress. The values for these parameters are reported in Table 1, where they are taken from King, Plosser, and Rebelo (1988a) except for b, ω, $h(\theta)$, h_θ, μ, and α. The values for these parameters are determined as follows. The value of b is given by $b = -0.5$, which in turn implies habit persistence in leisure. Also, the habit persistence in leisure has been found in Eichenbaum, Hansen, and Singleton (1988) and Braun and Evans (1991). When money is defined as M1, the growth of M1, $\omega = 1.015$, and $h(\theta)$ ($= M_1/PC$) $= 0.34$. In addition, $h_\theta = -7$ which is based upon the estimated semi-elasticity of interest rate for money demand reported at Table 4 in Lucas (1988). The value of the steady state markup then is given by $\mu = 1.2$, which is close to estimates of average markup by Fernald and Basu (1993).

Secondly, money supply processes are estimated as follows. When the money supply is exogenous, the current growth rate of M1 is regressed on the

Table 1
Calibrated parameters

Parameter	Value	Descriptions of parameters
γ_z	1.004	Steady state growth of trend
δ	0.025	Rate of depreciation of capital stock
s_H	0.58	Steady state labor share ($= wH/Y$)
$\tilde{r}$	0.016	Steady state real rate of return ($= r - \delta$)
ω	1.015	Steady state growth of M1
ε_C	1	Intertemporal elasticity of consumption
ε_w	4	Intertemporal elasticity of labor supply
$h(\theta)$	0.34	Inverse of steady state consumption velocity ($= M_1/PC$)
h_θ	−7	Semi-interest elasticity of demand for money (percent)
ε_{HK}	1	Elasticity of substitution between capital and net labor
μ	1.2	Steady state markup
b	−0.5	Degree of habit persistence in leisure

Table 2
Estimated standard deviations and cross-correlations

Panel 1. Estimated standard deviations

Percentage (quarter)	$\Delta \log Y$	$\Delta \log Y^p$	$\Delta \log Y^r$	$\log Y^s$	$\log Y^d$	$\hat{\pi}$
Estimates from VAR	1.110	1.595	0.786	3.168	2.427	0.800

Panel 2. Estimated cross-correlations

	−3	−2	−1	0	1	2	3
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t$)	−0.200	−0.104	−0.048	−0.025	0.026	0.014	−0.028
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t^p$)	0	0	0	−0.451	−0.177	−0.151	−0.169
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t^r$)	−0.063	−0.121	−0.168	−0.530	−0.252	−0.223	−0.232
cor($\hat{\pi}_{t+j}$, $\log Y_t^s$)	0.744	0.814	0.850	0.867	0.649	0.550	0.469
cor($\hat{\pi}_{t+j}$, $\log Y_t^d$)	0.596	0.667	0.675	0.643	0.483	0.400	0.311

Y: real output, $\hat{\pi}$: rate of inflation, Y^p: trend component of real output, Y^s: stationary component of real output, Y^r: component of real output that is affected by only permanent shocks, Y^d: component of real output that is affected by only transitory shocks.

previous period's growth rate of M1 to estimate the money supply process[6] given by

$$\log \omega_t = \underset{(0.00064)}{-0.00003} + \underset{(0.063)}{0.603} \log \omega_{t-1} + \underset{(0.00814)}{\xi_{M,t}}, \tag{36}$$

where the numbers in parentheses denote standard errors.

[6] The data on M1 in the post-war U.S.A. is obtained from CITIBASE (1959–1987:FM1) and from Survey of Current Business (1947–1959).

On the other hand, when it is not exogenous, the money supply process is as follows:

$$\hat{\omega}_t = \sum_{j=1}^{k_1} v_{\omega,j}\hat{\omega}_{t-j} + \sum_{j=0}^{k_2} v_{A,j}\hat{\gamma}_{t-j} + \sum_{j=0}^{k_3} v_{M,j}\varepsilon_{M,t-j}. \tag{37}$$

In this case, one can estimate the parameters in Eq. (37) using the bivariate vector autoregression described in Section 2. In particular, note that the growth rate of nominal GNP derived from models can be written as $\Delta Y_t^{N,p} = u_A(L;v)\hat{\gamma}_t + u_M(L;v)\varepsilon_{M,t}$, where $u_A(L;v)$ and $u_M(L;v)$ are ratios of polynomials in the lag operator, L, and v is the vector of parameters in Eq. (37). Besides, the estimated growth rate of nominal GNP can be written as $\Delta Y_t^{N,e} = e_A(L;\hat{v})\Delta Y_t^p + e_M(L;\hat{v})\xi_{M,t}$, where $e_A(L;\hat{v})$ and $e_M(L;\hat{v})$ are ratios of polynomials in the lag operator and $\hat{v}$ is the vector of estimated coefficients of the vector autoregression in Section 2. An endogenous money supply process then can be estimated by calculating a vector v to solve the following equations for v, given L:

$$u_A(L;v) = e_A(L;\hat{v}) \quad \text{and} \quad u_M(L;v) = e_M(L;\hat{v}). \tag{38}$$

This implies that the endogenous money supply process[7] is calculated by setting the model's impulse response function of nominal GNP to equal the estimated impulse response function of nominal GNP.

4.2. Numerical results

This section presents some quantitative properties derived from numerical solutions for the model economies described in Section 3.

Figs. 2 and 3 show impulse responses of output and inflation in flexible and sticky price models with exogenous money supply respectively. Fig. 2 demonstrates the small effect of a monetary shock on output in the flexible price model, whereas in Fig. 3, with sticky prices, an exogenous expansion in the money supply leads to a gradual increase in the price level and a temporary increase in output. Besides, in both Figs. 2 and 3, a positive technology shock induces gradual decreases in the price level to a long-run level while it also increases output in the long run. Hence, when the permanent shock in Section 2 corresponds to an exogenous labor-augmenting technology shock and the temporary shock corresponds to an exogenous change in the growth rate of money supply, these figures

[7] The impulse responses of the endogenous money supply processes for flexible and sticky price models are presented in Fig. 4. Technical appendix on the calculation of the endogenous money supply processes is available from the author upon request.

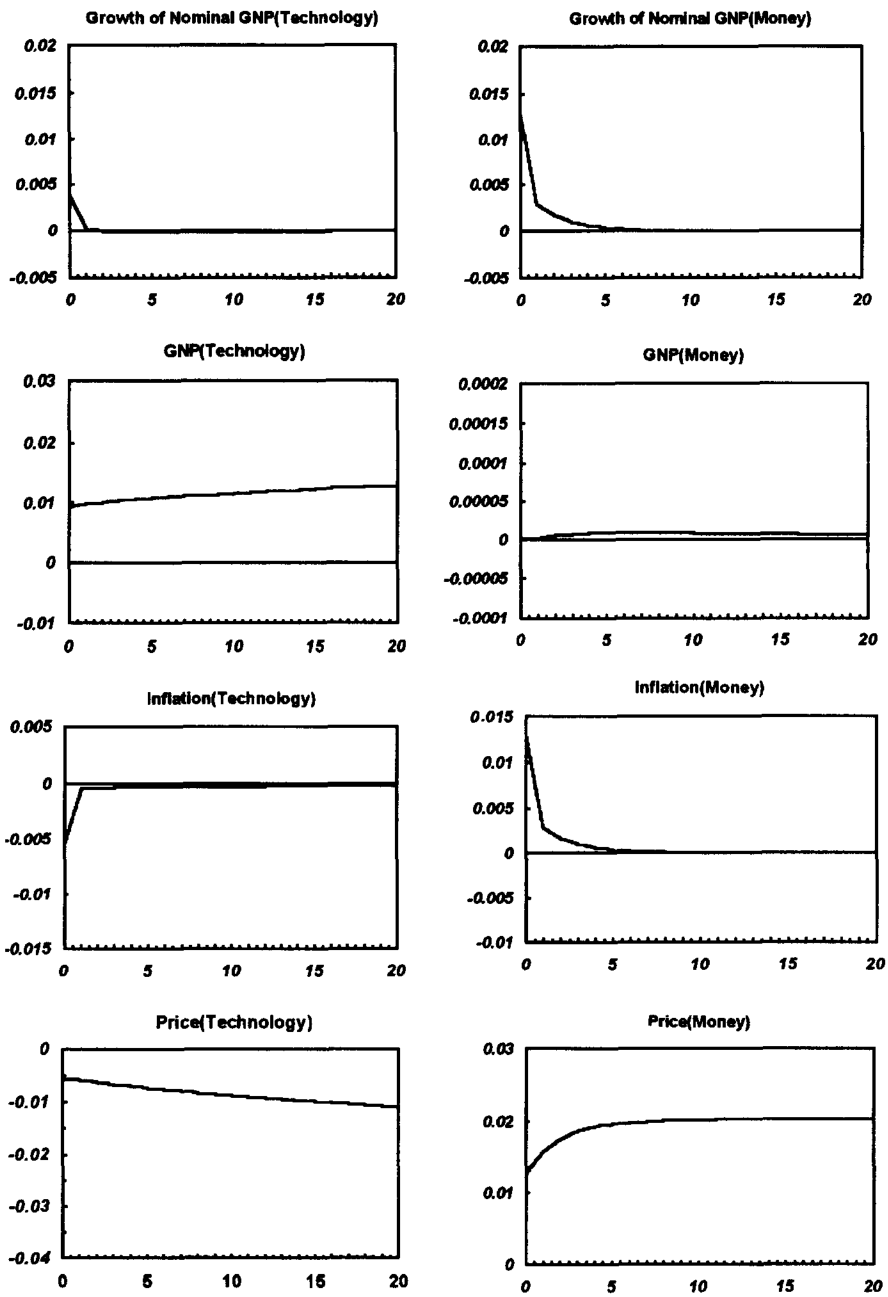

Fig. 2. Flexible price model with exogenous money supply.

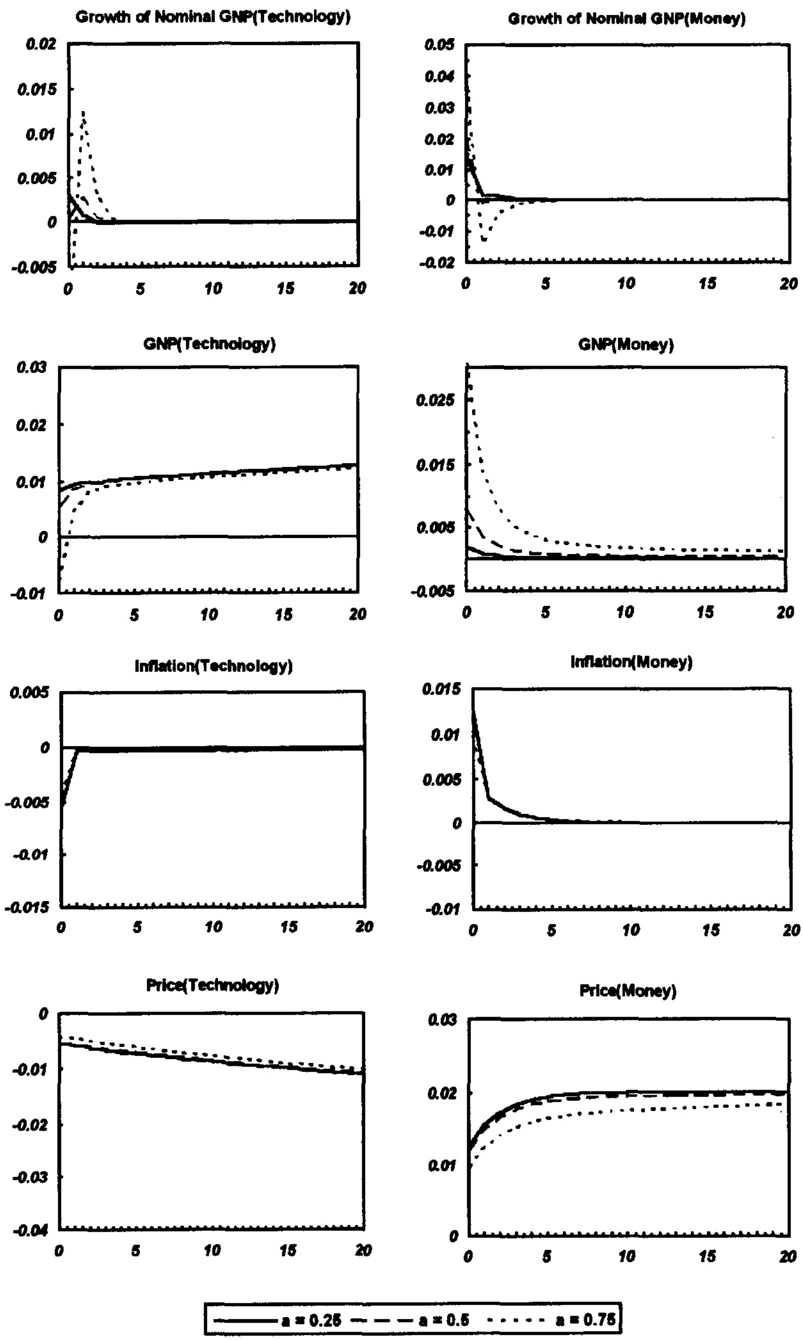

Fig. 3. Nominal price rigidity model with exogenous money supply.

imply that sticky price models fit the empirical evidence presented in Section 2 better than flexible price models. In particular, the difference between flexible and sticky price models in terms of the real effect of money supply shocks is associated with the response of the labor demand schedule to a monetary shock in sticky price models. The sluggish price adjustment of the type considered here causes positive variations of real marginal cost in response to a positive monetary shock. They shift up the labor demand curve in the initial period given predetermined capital, and then raise output by stimulating equilibrium employment. Note here that to achieve an increase in both real wage and employment involves a relatively weaker wealth effect to the extent that the shift-up of the labor supply curve induced by the wealth effect does not offset the variation of labor demand due to the marginal cost. In addition, the marginal cost becomes more variable as nominal price rigidity rises. Fig. 3 also shows that the initial effect of a technology shock on output decreases as the degree of nominal rigidity increases. A reason for it is that technological improvements decrease marginal cost, so these negative movements of marginal cost offset increases in equilibrium employment due to positive technology shocks. Moreover, the magnitude of this adverse effect increases as the degree of nominal price rigidity grows.

Furthermore, Fig. 4 presents the impulse responses of the endogenous money supply processes in both flexible and sticky price models that are calculated as described in Section 4.1. Given these endogenous money supply processes, Figs. 5 and 6 respectively display the impulse responses of output and inflation in flexible and sticky price models. The introduction of endogeneity in the money supply by itself does not make a significant difference in terms of the real effect of a monetary shock in flexible and sticky price models, as Figs. 5 and 6 are compared with Figs. 2 and 3, respectively. Besides, in Figs. 5 and 6, a positive technology shock induces gradual decreases in the price level to a long-run level while it also increases output in the long run. Hence these figures imply that, even with the endogenous money supply processes in Fig. 4, sticky price models fit the empirical evidence presented in Section 2 better than flexible price models.

The standard deviations of output measures and inflation in numerical models are reported in Table 3 in which the standard deviation of the differenced trend component of log output in model economies is set to equal the estimated one. Table 3 also shows small effects of monetary shocks in flexible price models with exogenous and endogenous money supply. Also, an increase in nominal price rigidity leads to larger standard deviations of output measures but less volatile inflation. The dynamic correlations of inflation and output measures are then reported in Tables 4 and 5. According to these tables, with sticky prices, the rate of inflation is positively correlated with two measures of stationary components of output ($\log Y_t^s$ and $\log Y_t^d$) but negatively with two measures of output containing permanent shocks ($\log Y_t^p$ and $\log Y_t^r$). On the other hand, flexible price models display negative cross-correlations of inflation with the

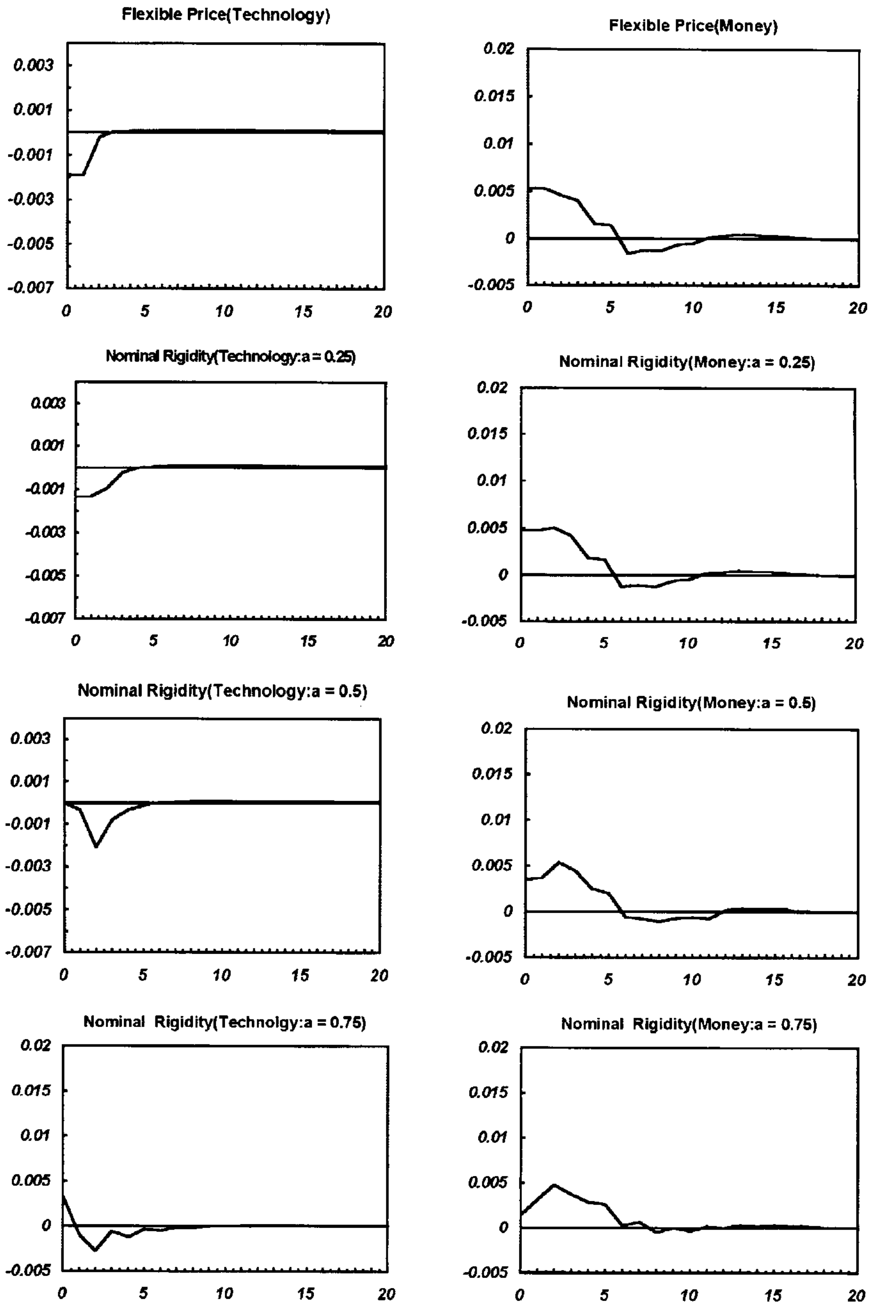

Fig. 4. Impulse responses of money supply growth rate in endogenous money supply models.

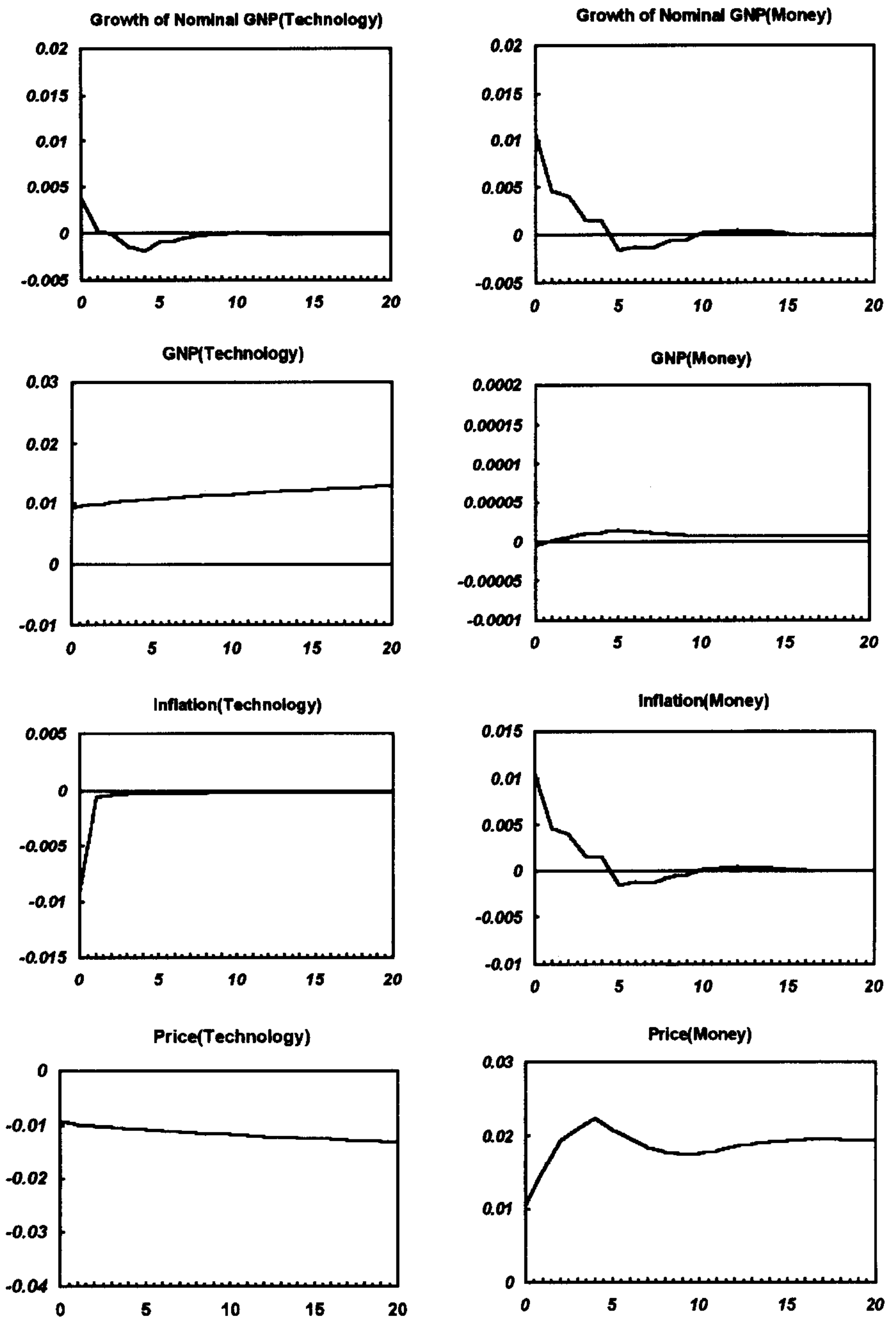

Fig. 5. Flexible price model with endogenous money supply.

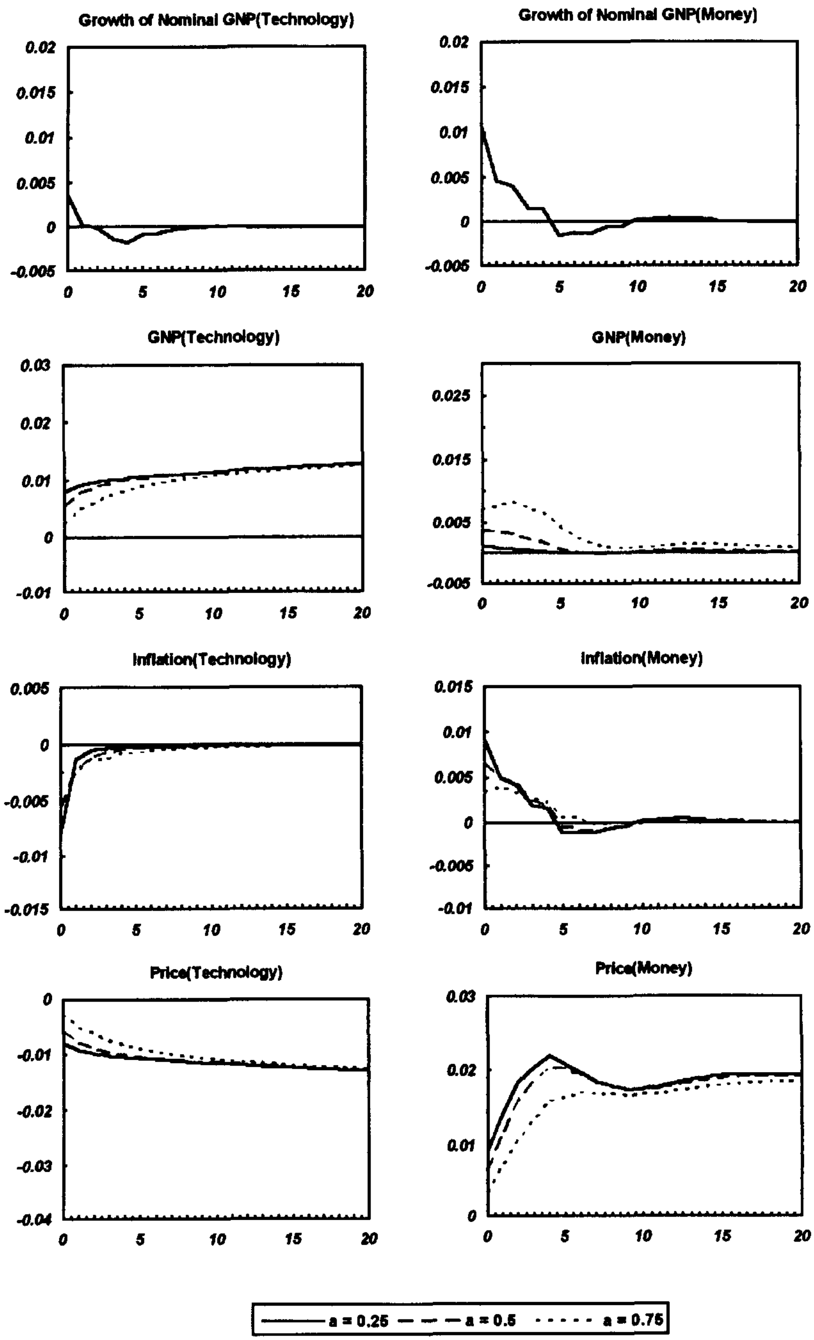

Fig. 6. Nominal price rigidity model with endogenous money supply.

Table 3
Standard deviations of inflation and output measures

Panel 1. Exogenous money supply

Percentage (quarter)	$\Delta \log Y$	$\Delta \log Y^p$	$\Delta \log Y^r$	$\log Y^s$	$\log Y^d$	$\hat{\pi}$
Exogenous money and $\alpha = 0$	0.927	1.595	0.927	2.374	0.004	1.459
Exogenous money and $\alpha = 0.25$	0.878	1.595	0.852	2.435	0.224	1.440
Exogenous money and $\alpha = 0.5$	1.105	1.595	0.657	2.764	0.922	1.379
Exogenous money and $\alpha = 0.75$	3.873	1.595	1.523	5.186	3.628	1.135

Panel 2. Endogenous money supply

Percentage (quarter)	$\Delta \log Y$	$\Delta \log Y^p$	$\Delta \log Y^r$	$\log Y^s$	$\log Y^d$	$\hat{\pi}$
Endogenous money and $\alpha = 0$	0.928	1.595	0.928	2.374	0.005	1.573
Endogenous money and $\alpha = 0.25$	0.832	1.595	0.820	2.450	0.198	1.440
Endogenous money and $\alpha = 0.5$	0.756	1.595	0.620	2.750	0.708	1.180
Endogenous money and $\alpha = 0.75$	0.905	1.595	0.425	3.723	1.835	0.847

Y: real output, $\hat{\pi}$: rate of inflation, Y^p: trend component of real output, Y^s: stationary component of real output, Y^r: component of real output that is affected by only permanent shocks, Y^d: component of real output that is affected by only transitory shocks.

component of GNP only with temporary shocks ($\log Y_t^d$) for some lags or leads of inflation.

5. Conclusion

This paper has considered whether nominal price rigidity is consistent with the positive co-movement of inflation and output observed in the U.S. economy. The various kinds of criteria used here for this purpose lead one to conclude that nominal price rigidity models can provide a better understanding of the observed associations between output and inflation than flexible price models. However, it should be noted that this conclusion depends critically on the degree of nominal price rigidity.

Furthermore, the quantitative results in this paper do not mean that money supply shocks are the only nominal disturbances that matter. For example, when the monetary authority accommodates fluctuations in aggregate money demand, aggregate demand disturbances affecting the money demand can be propagated

Table 4
Cross-correlations of inflation and output measures with exogenous money supply

	−3	−2	−1	0	1	2	3
Panel 1. Exogenous money and flexible price							
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t$)	−0.019	−0.020	−0.031	0.378	−0.035	−0.034	−0.033
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t^p$)	0	0	0	−0.378	−0.033	−0.035	−0.024
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t^r$)	−0.017	−0.021	−0.032	−0.378	−0.035	−0.034	−0.033
cor($\hat{\pi}_{t+j}$, $\log Y_t^s$)	0.172	0.179	0.187	0.199	0.098	0.094	0.091
cor($\hat{\pi}_{t+j}$, $\log Y_t^d$)	0.274	0.223	0.134	−0.008	0.022	0.013	0.008
Panel 2. Exogenous money and $\alpha = 0.25$							
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t$)	−0.042	−0.073	−0.168	−0.209	−0.012	−0.021	−0.026
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t^p$)	0	0	0	−0.371	−0.025	−0.025	−0.025
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t^r$)	−0.021	−0.030	−0.060	−0.379	−0.038	−0.038	−0.037
cor($\hat{\pi}_{t+j}$, $\log Y_t^s$)	0.187	0.212	0.228	0.289	0.122	0.109	0.104
cor($\hat{\pi}_{t+j}$, $\log Y_t^d$)	0.183	0.266	0.440	0.870	0.248	0.150	0.091
Panel 3. Exogenous money and $\alpha = 0.5$							
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t$)	−0.091	−0.187	−0.477	0.306	0.053	0.021	−0.001
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t^p$)	0	0	0	−0.374	−0.025	−0.026	−0.026
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t^r$)	−0.036	−0.069	−0.191	−0.351	−0.050	−0.051	−0.049
cor($\hat{\pi}_{t+j}$, $\log Y_t^s$)	0.220	0.256	0.363	0.522	0.184	0.148	0.125
cor($\hat{\pi}_{t+j}$, $\log Y_t^d$)	0.181	0.264	0.439	0.876	0.259	0.159	0.098
Panel 4. Exogenous money and $\alpha = 0.75$							
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t$)	−0.088	−0.196	−0.553	0.601	0.093	0.055	0.031
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t^p$)	0	0	0	−0.370	−0.025	−0.032	−0.033
cor($\hat{\pi}_{t+j}$, $\Delta \log Y_t^r$)	−0.031	−0.088	−0.323	0.150	−0.305	−0.027	−0.026
cor($\hat{\pi}_{t+j}$, $\log Y_t^s$)	0.243	0.308	0.455	0.867	0.305	0.228	0.177
cor($\hat{\pi}_{t+j}$, $\log Y_t^d$)	0.187	0.267	0.440	0.894	0.316	0.228	0.133

Y: real output, $\hat{\pi}$: rate of inflation, Y^p: trend component of real output, Y^s: stationary component of real output, Y^r: component of real output that is affected by only permanent shocks, Y^d: component of real output that is affected by only transitory shocks.

through this kind of accommodation. However, the incorporation of these kinds of demand disturbances into a model requires more developed identification schemes for the various possible nominal disturbances in order to estimate an endogenous money supply decision rule responding to these disturbances. Thus, developing models with nominal disturbances other than money supply shocks as well as such identification schemes may be future research subjects.

Table 5
Cross-correlations of inflation and output measures with endogenous money supply

Panel 1. Endogenous money and flexible price							
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t)$	−0.020	−0.024	−0.041	−0.586	−0.041	−0.025	−0.022
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t^p)$	0	0	0	−0.582	−0.036	−0.020	−0.016
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t^r)$	−0.020	−0.025	−0.042	−0.586	−0.042	−0.025	−0.021
$\mathrm{cor}(\hat{\pi}_{t+j}, \log Y_t^s)$	0.193	0.200	0.210	0.226	0.063	0.055	0.052
$\mathrm{cor}(\hat{\pi}_{t+j}, \log Y_t^d)$	0.325	0.228	0.115	−0.027	−0.044	−0.064	−0.047
Panel 2. Endogenous money and $\alpha = 0.25$							
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t)$	−0.074	−0.084	−0.148	−0.416	−0.058	−0.003	−0.009
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t^p)$	0	0	0	−0.553	−0.099	−0.040	−0.024
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t^r)$	−0.036	−0.060	−0.118	−0.584	−0.118	−0.060	−0.038
$\mathrm{cor}(\hat{\pi}_{t+j}, \log Y_t^s)$	0.240	0.278	0.323	0.395	0.160	0.108	0.071
$\mathrm{cor}(\hat{\pi}_{t+j}, \log Y_t^d)$	0.198	0.397	0.578	0.787	0.471	0.296	0.092
Panel 3. Endogenous money and $\alpha = 0.5$							
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t)$	−0.243	−0.451	−0.321	−0.195	0.002	0.093	0.058
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t^p)$	0	0	0	−0.462	−0.192	−0.101	−0.060
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t^r)$	−0.082	−0.130	−0.312	−0.520	−0.2345	−0.132	−0.085
$\mathrm{cor}(\hat{\pi}_{t+j}, \log Y_t^s)$	0.317	0.384	0.453	0.816	0.327	0.215	0.131
$\mathrm{cor}(\hat{\pi}_{t+j}, \log Y_t^d)$	0.335	0.523	0.677	0.816	0.569	0.361	0.146
Panel 4. Endogenous money and $\alpha = 0.75$							
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t)$	−0.397	−0.339	−0.285	−0.058	0.197	0.230	0.164
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t^p)$	0	0	0	−0.286	−0.298	−0.143	−0.158
$\mathrm{cor}(\hat{\pi}_{t+j}, \Delta \log Y_t^r)$	−0.226	−0.273	−0.383	−0.500	−0.388	−0.277	−0.232
$\mathrm{cor}(\hat{\pi}_{t+j}, \log Y_t^s)$	0.529	0.626	0.708	0.778	0.641	0.465	0.349
$\mathrm{cor}(\hat{\pi}_{t+j}, \log Y_t^d)$	0.518	0.662	0.766	0.818	0.671	0.486	0.308

Y: real output, $\hat{\pi}$: rate of inflation, Y^p: trend component of real output, Y^s: stationary component of real output, Y^r: component of real output that is affected by only permanent shocks, Y^d: component of real output that is affected by only transitory shocks.

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