Hump-shaped Behavior of Inflation and Dynamic Externality

Takayuki Tsuruga[*] [†]

This version: June 21, 2004

JOB MARKET PAPER

Abstract

This paper develops a model which can explain the hump-shaped impulse response of inflation to a monetary shock. A standard New Keynesian (NK) model is augmented so as to include dynamic externality with sticky wages and variable capital utilization. In our analysis, we assume *purely forward-looking* nominal rigidities in nominal prices and wages á la Calvo (1983). Nevertheless, we can show that inflation is hump-shaped under a reasonable range of parameters. It will be also shown that, in order for inflation to be hump-shaped, sticky wages and variable capital utilization are important as well as dynamic externalities.

[*]Correspondence: Department of Economics, The Ohio State University, 410 Arps Hall, 1945 N. High Street, Columbus, OH, 43210; email: tsuruga.1@osu.edu.

[†]I would like to thank Paul Evans for his invaluable advice; Bill Dupor, Joseph Kobaski, Pok-sang Lam, and Masao Ogaki at the Ohio State University for helpful discussions and suggestions; Ryo Kato at Bank of Japan for many helpful discussions and comments as well as supplying me with MATLAB code; Takuji Kawamoto at University of Michigan for his comments on the draft. All errors are my own.

JEL classification: E31; E32; E52

Keywords: Inflation; New Keynesian Phillips curve; Sticky-price model; Sticky wages; Variable capital utilization; Dynamic Externality

1 Introduction

Sticky prices are one of the most important elements in the New Keynesian model (NK model) and the policy analysis based upon it. Under nominal rigidities á la Calvo (1983) or á la Rotemberg (1982), an expression for inflation can be obtained in a very simple form called the New Keynesian Phillips Curve(NKPC). It has been one of the fundamental equations for the analysis of the monetary policy as discussed in Clarida, Gali, and Gertler (1999).

The NKPC is theoretically appealing because it can be derived from a rational expectation model with staggered price contracts and gives us intuitive descriptions of the supply side in the economy. Despite its theoretical appeal, however, the NKPC has been subject to criticism due to its counterfactual predictions. For example, Fuhrer and Moore (1995) and Fuhrer (1997) point out that NKPC predicts the expected change in inflation must decrease when the output gap is positive. Nelson (1998) concluded that standard Calvo (1983) type staggered price setting cannot generate the hump-shaped impulse response function (IRF hereafter) that estimated VARs characterize[1]. Mankiw and Reis (2002) report similar results: The sticky price model generates implausible responses to monetary policy shocks:

[1]Delayed responses of inflation to a monetary policy shock can be seen from VAR literature. Stock and Watson (2001) ran simple VAR with inflation rate, unemployment rate and FF rate, and concluded the responses of inflation to FF rate shock is delayed. Gali (1992) estimated a structural VAR with long-run and short-run restrictions. His IRF of inflation to M1 shock is hump-shaped and its peak is 8th period after monetary policy shock.

The effect of monetary policy on inflation is immediate in the sticky price model[2].

In general, the literature has considered two ways of extending the NKPC to generate a hump-shaped IRF for inflation to monetary policy shocks. First, the inclusion of lagged inflation in the equation can yield hump-shaped IRF for inflation. Fuhrer and Moore (1995) propose relative contract wage setting, which allows inflation to be a function of the lagged inflation[3]. Roberts (1997), Roberts (2001) and Ball (2000) stress the importance of less than perfectly rational economic agents who expect the future inflation by univariate forecasting with the lagged inflation. Gali and Gertler (1999) and Gali, Gertler, and Lopez-Salido (2001) estimated a hybrid NKPC, which assumes that a fraction of the firms determines its price according to a backward looking rule of thumb. Woodford (2003, Chap. 3) proposes an explanation for the hybrid NKPC, using backward looking indexation. However, these efforts to include the lagged inflation are hard to defend and less than convincing, because they have no clear theory explaining why the economic agents expect the future inflation by a univariate forecasting rule, why there is a fraction of non-rational economic agents and why the monopolistically competitive firm follows the backward indexation rule specified in Woodford (2003).

Second, serially correlated errors in the NKPC can generate a hump-shaped response of inflation to monetary policy shocks. Rotemberg (1997) first proposed this direction. He introduces an AR(1) error term in the NKPC and shows that the inflation is hump-shaped in the IRF to a cost push shock. Although the introduction of the AR(1) error itself is ad hoc,

[2]In some exceptional cases, Taylor (1980) type nominal rigidities seem to be able to generate hump-shaped impulse response. For example, Erceg (1997) uses Taylor type staggered *wages* and flexible prices to show that inflation can be hump-shaped in response to a monetary shock, although the reason hasn't been explored clearly.

[3]Nelson (1998) reports this Fuhrer and Moore (1995)'s expression for inflation is the only model in which the inflation response could be hump-shaped.

this direction has been extended to recent literature that emphasizes Kalman filtering or learning. Erceg and Levin (2003) focus on the imperfect information between private sectors and the central bank. They model serially correlated forecast errors with learning. Although Erceg and Levin (2003) did not show a hump-shaped IRF for inflation, Keen (2003), following the same idea as Erceg and Levin (2003), showed the inflation is hump-shaped in response to a monetary shock when imperfect information exists between private sectors and the central bank.

This paper explores another possible explanation for hump-shaped response of inflation. Throughout the paper, I do *not* take the assumptions - less than perfectly rational agents, hybrid NKPC, backward indexation, nor even Kalman filtering - discussed above. However, I do assume a propagation mechanism: Dynamic externality through a production spillover in which the stock of organizational capital accumulates over time according to the level of aggregate output. This kind of dynamic externalities plays an important role for generating a hump-shaped IRF for inflation in response to a monetary shock, if they are combined with *staggered wage contracts* and *variable capital utilization.*

In RBC literature, a number of papers have analyzed the effect of organizational capital as a propagation mechanism. For example, Cooper and Johri (1997) focused on dynamic complementarities which are external to an individual firm. Similarly, Cooper and Johri (2002) and Chang, Gomes, and Schorfheide (2002) study the effect of learning-by-doing as a propagation mechanism in RBC. In their analysis, the learning-by-doing is assumed to be internal rather than external. However, the dynamics of organizational capital are extremely similar to our case in that organizational capital (or human capital in their context) accumulates over time according to the level of production activity. In any case, the role of organizational capital is found to be powerful as an endogenous propagation mechanism in RBC models.

In a NK model, organizational capital may play more important role for inflation than for output, because changes in organizational capital directly affect firms' marginal costs via changes in the productivity. When an expansionary monetary shock occurs and output increases, organizational capital is accumulated through production activity, leading to high productivity and low marginal cost. Low marginal cost turns out to be a disincentive to pricing high in response to an expansionary monetary shock.

I emphasize the combined effect of the dynamic externality with sticky wages and variable capital utilization: The effect of the organizational capital on inflation appears significantly only when dynamic externalities are combined with both sticky wages and variable capital utilization. I found that, under flexible wages or constant capital utilization, the incentive to price higher owing to higher factor prices overpowers the disincentive resulting from the dynamic externality.

This paper contributes by showing that a thoroughgoing NK model can explain the observed behavior of inflation. Necessary ingredients besides sticky prices are dynamic externalities, sticky wages, and variable capital utilization. The NK model augmented by these features can fix the problem of inflation persistence unsolved in a standard NK model which incorporates only sticky prices.

The rest of the paper is organized as follows. In section 2, I present the specific model used in the simulations. The section 3 shows that the IRFs of inflation to a money growth shock is hump-shaped and explains the mechanism underlying that shape. The model therefore replicates the stylized facts on the estimated IRF qualitatively. Moreover, the model can explain the observed IRF of the marginal cost behavior as well. The section 4 discusses that the hybrid NKPC generates quite questionable prediction, given the estimated IRF of marginal costs which will be proxied by the unit labor cost, although the hybrid NKPC can generate the observed hump-shaped behavior of inflation. The section 5 concludes the paper.

2 The Model

In this section, we describe the model economy. We assume monopolistic competition in both the goods and labor markets as in Erceg, Henderson, and Levin (2000) and Christiano, Eichenbaum, and Evans (2003). The model consists of a representative goods aggregator, a representative labor aggregator and a government as well as monopolistic competitive firms and monopolistic competitive households. To include sticky prices and wages, we assume that the nominal price and wage adjustments are possible only at some constant hazard rate. This Calvo (1983)-style timing of nominal rigidity can reduce the number of state variables in the model and give us a NKPC for both price and wage inflation.

2.1 Firms

Following the literature, we introduce an output aggregator and monopolistic competitive firms with constant-returns to scale technology of the Dixit-Stiglitz form. An output aggregator produces a final good Y_t for household's consumption and investment in the perfect competitive market. The final good is transformed from a continuum of differentiated goods, each of which is produced by monopolistic firms. Under these assumptions, the demand function for intermediate goods takes the following form:

$$Y_t(f) = \left[\frac{P_t(f)}{P_t}\right]^{-\epsilon_p} Y_t, \tag{1}$$

where $Y_t(f)$ denotes a differentiated good and $P_t(f)$ is its price. P_t is the aggregate price index. f is the index for intermediate good firms distributed uniformly on [0,1]. $\epsilon_p > 1$ is the elasticity of substitution between the differentiated goods.

We assume Calvo type staggered price setting so that each firm is allowed to change its price only with a probability. Instead of deriving it, we simply start with the NKPC that is derived from that assumption. Let π_t denote the gross inflation rate $\pi_t = P_t/P_{t-1}$ and $\hat{\pi}_t = \log(\pi_t) - \log(\pi)$, where π is the steady state value of the gross rate of inflation. Then, the NKPC is given by

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \Psi_p \hat{mc}_t, \tag{2}$$

where Ψ_p and β are parameters satisfying $\Psi_p > 0$ and $0 < \beta < 1$ and $\hat{mc}_t$ is the log-deviation of marginal cost from the steady state value.

The intermediate good firm faces perfectly competitive factor markets for the *effective* capital input(defined below) $\tilde{K}_t(f)$ and the labor input $L_t(f)$, which it rents in competitive factor markets[4]. For this reason, each intermediate good firm takes the rental price of effective capital, R_t^k, and the aggregate wage index, W_t, as given.

Suppose that the production function for firm f is Cobb-Douglas in effective capital and

[4]It is not a contradiction to the assumption of monopolistic competitive households in their labor market. The households sell the labor to the labor aggregator in monopolistic competitive markets, but the labor aggregator sells its aggregate labor to the intermediate good firms in a competitive market. For this reason, we may assume the intermediate goods firm face a competitive labor market.

labor:

$$Y_t(f) = \tilde{K}_t(f)^{\alpha} L_t(f)^{1-\alpha} X_t^{\phi}, \tag{3}$$

where $\alpha \in (0,1)$ and X_t is external organizational capital. The steady state value of X is assumed to be one, so that production function converges to constant returns to scale technology in the long run.

Organizational capital accumulates through production activity. The law of motion of X is specified as follows:

$$\log\left(\frac{X_t}{X}\right) = \gamma \log\left(\frac{X_{t-1}}{X}\right) + \eta \log\left(\frac{Y_t}{Y}\right), \tag{4}$$

where $\gamma \in (0,1)$ captures the persistence of the external effect and $\eta > 0$ captures the effect of current aggregate output on individual production. Y is the steady state level of aggregate output. Thus, there is a spillover effect in the production process.

Given the production function and the assumption of perfectly competitive factor markets, the real marginal cost function mc_t and the marginal rate of substitution between inputs from the static cost minimization problem take the form:

$$mc_t = (1-\alpha)^{-(1-\alpha)} \alpha^{-\alpha} w_t^{1-\alpha} (r_t^k)^{\alpha} X_t^{-\phi}, \tag{5}$$

$$\frac{w_t}{r_t^k} = \frac{1-\alpha}{\alpha} \frac{\tilde{K}_t}{L_t}, \tag{6}$$

where w_t is real wage rate (i.e. $w_t = W_t/P_t$) and r_t^k is real rental cost of effective capital (i.e. $r_t^k = R_t^k/P_t$). Note that the index f is dropped because all intermediate firms face identical factor prices.

2.2 Households

Each household, indexed by $h \in (0,1)$, is assumed to supply a differentiated labor service to firms. As in Erceg, Henderson, and Levin (2000), we assume a representative labor aggregator which buys households' differentiated labor supply $L_t(h)$ to produce a single composite labor service L_t which it sells to intermediate good firms. It is simply parallel to the output aggregator in its formulation. Hence, we get the demand function for the differentiated labor:

$$L_t(h) = \left[\frac{W_t(h)}{W_t}\right]^{-\epsilon_w} L_t, \tag{7}$$

where $\epsilon_w > 1$ is the elasticity of substitution between the differentiated labor. $W_t(h)$ is the nominal wage for differentiated labor.

We set up the household's maximization problem. We assume the following expected utility function of the money-in-utility form with habit persistence:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t(h) - bC_{t-1}(h))^{1-\sigma_c}}{1-\sigma_c} - \frac{L_t(h)^{1+\sigma_L}}{1+\sigma_L} + \log\left(\frac{M_t(h)}{P_t}\right)\right], \tag{8}$$

where $C_t(h)$ is the consumption and $M_t(h)$ is the end-of-period money holding. We assume $b > 0$ which allows habit persistence.

Next, let us consider the household's budget constraint. It is given by

$$\begin{aligned} & W_t(h)L_t(h) + R_t^k \tilde{K}_t(h) + \Gamma_t(h) + T_t(h) && (9) \\ = \quad & P_t \left[C_t(h) + I_t(h) + \frac{\phi_k}{2} \left(\frac{I_t(h)}{K_t(h)} - \delta \right)^2 K_t(h) \right] + B_t(h) - R_{t-1}B_{t-1}(h) + M_t(h) - M_{t-1}(h). \end{aligned}$$

For the income side, his source of income is labor income $W_t(h)L_t(h)$, returns from effective capital service $R_t^k \tilde{K}_t(h)$, the sum of the profits from firms in the economy $\Gamma_t(h)$, and a lump-sum transfer from the government to the household $T_t(h)$. To analyze the effect of capital utilization, effective capital is defined as the product of the actual capital stock $K_t(h)$ and capital utilization $U_t(h)$:

$$\tilde{K}_t(h) = U_t(h)K_t(h). \tag{10}$$

The actual capital stock evolves according to

$$K_{t+1}(h) = (1 - \delta U_t(h)^{\zeta})K_t(h) + I_t(h), \tag{11}$$

where $\zeta > 1$ and $I_t(h)$ denotes the investment. In this equation, the depreciation rate is increasing function in $U_t(h)$. This dependence of the depreciation rate on utilization makes the optimal utilization rate variable. We assume that capital utilization rate in the steady state is equal to one. Thus, the law of motion for capital becomes standard only in the long-run.

For the spending side of the budget constraint, the household purchases the final goods for consumption and investment. In making the investment, the household loses final goods in the form of the capital adjustment cost[5] defined as $\frac{\phi_k}{2}\left(\frac{I_t(h)}{K_t(h)} - \delta\right)^2 K_t(h)$. This adjustment cost is zero when the investment-capital ratio is equal to the steady state value δ.[6] Finally, he spends his income for financial assets in the form of the net increase in money $(M_t(h) - M_{t-1}(h))$ and government bonds $(B_t - R_{t-1}B_{t-1}(h))$.

We assume that every household faces the same initial conditions and that the contingent markets are complete. Then, we have the symmetric equilibrium value for control variables except for $W_t(h)$. These assumptions allow us to drop the household index h for $C_t(h)$, $I_t(h)$, $U_t(h)$, $M_t(h)$, $B_t(h)$, and $K_{t+1}(h)$.

In order to make a decision for these variables, the household maximizes his expected utility function (8) subject to (9), (10), (11). The first order conditions are as follows:

[5] Christiano, Eichenbaum, and Evans (2003) uses the adjustment cost of *investment* rather than the adjustment cost of *capital*. In our case, I use much more standard capital adjustment cost, because the adjustment cost of investment adds a new state variable to the model, and investment exhibits a hump shape in its IRF. We avoid using investment adjustment cost function because such a new state variable not only complicates the model, but also makes the effect of the dynamic externality on inflation and output gap less clear.

[6] We may specify the adjustment cost of capital as $\frac{\phi_k}{2}\left(\frac{I_t(h)}{K_t(h)} - \delta U^{\zeta}\right)^2 K_t(h)$ with the steady state value of utilization different from zero. However, we can normalize the steady state value of the capital utilization to 1 without loss of generality by adjusting δ. Therefore, the two specifications are equivalent.

$$
\begin{aligned}
1 &= \beta E_t \left[\left(\frac{\lambda_{t+1}}{\lambda_t} \right) \frac{R_t}{\pi_{t+1}} \right], && (12) \\
m_t &= E_t \left[\frac{R_t}{R_t - 1} \frac{1}{\lambda_t} \right], && (13) \\
\frac{Q_t}{\lambda_t} - 1 &= \phi_k \left(\frac{I_t}{K_t} - \delta \right), && (14) \\
\lambda_t r_t^k &= \delta \zeta Q_t U_t^{\zeta - 1}, && (15) \\
Q_t &= \beta E_t \left[\lambda_{t+1} r_{t+1}^k U_{t+1} \right] \\
&\quad + \beta E_t \left[\lambda_{t+1} \phi_k \left(\frac{I_{t+1}}{K_{t+1}} - \delta \right) \frac{I_{t+1}}{K_{t+1}} - \lambda_{t+1} \frac{\phi_k}{2} \left(\frac{I_{t+1}}{K_{t+1}} - \delta \right)^2 \right] && (16) \\
&\quad + \beta E_t \left[(1 - \delta U_{t+1}^{\zeta}) Q_{t+1} \right],
\end{aligned}
$$

where $m_t \equiv M_t/P_t$ is real money holding at the end of the period t. Q_t is Lagrange multiplier for the capital accumulation equation (11) and λ_t is the marginal utility for current consumption:

$$
\lambda_t = (C_t - bC_{t-1})^{-\sigma_c} - \beta b E_t (C_{t+1} - bC_t)^{-\sigma_c}. \tag{17}
$$

These first order conditions are quite standard. The equation (12) is a standard Euler equation for consumption. It equates the marginal utility of consumption today with the discounted marginal utility of consumption tomorrow. The equation (13) is the money demand function: Real money holding are positively correlated with marginal utility and negatively correlated with the opportunity cost of holding money. The equation (14) is the first order condition for investment. Under our specification of the adjustment cost of capital, the investment-capital rate is linearly related to the marginal q in terms of the marginal utility. The equation (15) is the marginal condition for variable capital utilization.

The marginal benefit of capital utilization is equalized to the marginal cost of it: Marginal depreciation costs. The equation (16) determines the shadow price of investment. By solving the equation forward, Q_t is expressed as the present discounted value of net marginal benefits of actual capital stock.

2.2.1 Wage Setting

We go to the wage setting behavior. We assume that the nominal wage contracts are analogous to the price setting behavior. In each period, the household is allowed to reoptimize its nominal wages with a probability. As in Erceg, Henderson, and Levin (2000), Calvo type staggered wage setting gives us the following wage NKPC to a first order approximation:

$$\hat{\pi}_t^w = \beta E_t \hat{\pi}_{t+1}^w + \Psi_w \left[\sigma_L \hat{L}_t - \hat{\lambda}_t - \hat{w}_t \right], \quad \Psi_w > 0 \tag{18}$$

where $\hat{\pi}_t^w$ is the log-deviation of wage inflation from the steady state value. That is, $\hat{\pi}_t^w = \log(\pi_t^w) - \log(\pi^w)$, where $\pi_t^w = W_t/W_{t-1}$ and π^w is the gross rate of wage inflation in the steady state. Similarly, $\hat{\lambda}_t$ and $\hat{w}_t$ are the log-deviation from the steady state of marginal utility of consumption and real wages, respectively. Finally, Ψ_w is a parameter. The first two terms inside the bracket are the log-deviation of marginal rate of substitution between labor supply and consumption from the steady state. Thus, the difference between the marginal rate of substitution and the real wage affects the wage inflation rate.

2.3 Closing the model

To close the model, we specify the government budget constraint, monetary policy and market clearing condition. The government budget is balanced every period (i.e. $(M_t - M_{t-1}) + (B_t - R_{t-1}B_{t-1}) = T_t$, for all t). Its total lump-sum transfer is set equal to seignorage revenue.

We specify the monetary policy by the growth rate of money supply. The gross growth rate of money supply $g_t \equiv M_t/M_{t-1}$ is given by AR(1) process in logarithm:

$$\log(g_{t+1}) = (1-\rho)\log(g) + \rho_m \log(g_t) + e_{t+1}, \quad e_t \sim N(0, \sigma_e^2), \tag{19}$$

where $0 < \rho_m < 1$, $\sigma_e > 0$ and g is the steady state value of money growth rate.

Market clearing condition is given by

$$Y_t = C_t + I_t + \frac{\phi_k}{2}\left(\frac{I_t}{K_t} - \delta\right)^2 K_t. \tag{20}$$

We also have two model identities for real wage rate and real balance:

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

$$m_t = \frac{g_t m_{t-1}}{\pi_t}. \tag{22}$$

2.4 Model Solution and Parameters

2.4.1 Model Solution

The log-linearized model is used to analyze the solution to the model. Since some of the equations such as (2) and (18) are already log-linearized, we take log-linearizations of other Euler equations and several model identities around the steady state. There are 16 equations to be log-linearized: (3)-(6), (10)-(17), (19)-(22). Therefore, we obtain 18 log-linearized equations. On the other hand, we have 18 unknowns. $\hat{Y}_t$, $\hat{\pi}_t$, $\hat{\pi}_t^w$, $\hat{r}_t^k$, $\hat{R}_t$, $\hat{mc}_t$, $\hat{L}_t$, $\hat{U}_t$, $\hat{\bar{K}}_t$, $\hat{I}_t$, $\hat{Q}_t$, $\hat{\lambda}_t$, $\hat{C}_{t-1}$, $\hat{X}_{t-1}$, $\hat{K}_t$, $\hat{w}_{t-1}$, $\hat{m}_{t-1}$, $\hat{g}_t$. The last 6 variables in the list of the variables are the state variables in the model. That is, lagged consumption, lagged organizational capital, capital stock, lagged real wages, lagged real balance, and money growth rate are predetermined or exogenous. Finally, the log-linearized system of equations has a unique equilibrium at the model parameters calibrated below.

2.4.2 Parameterization

We have parameters to be specified from outside the model. Since the model is calibrated at a quarterly frequency, we assume that $\beta = 0.99$. The preference parameters in the utility function follows the literature: $\sigma_C = 1$ and $\sigma_L = 2$. The habit parameter is set to $b = 0.65$[7]. The elasticities of demand functions are $\epsilon_p = \epsilon_w = 11$, which implies 10% mark-up in the long-run. The parameters Ψ_p and Ψ_w in two NKPCs are given in a standard way[8]:

[7] This calibrated value of habit parameter is the same as Christiano, Eichenbaum, and Evans (2003).

[8] In the literature of the NK model, for example Gali (2002), Ψ_p is a function of β and the probability that firms can reoptimize their nominal price. Letting $1-\xi_p$ be the probability, the parameter Ψ_p is given by $\frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p}$. $\Psi_p = 0.0858$ is standard, because $\xi_p = 0.75$ gives $\Psi_p = 0.0858$. Similarly, letting $1-\xi_w$ be the probability that households can change their nominal wage, Ψ_w is given by $\frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p(1+\epsilon_w\sigma_L)}$. The values of $\xi_w = 0.75$, $\sigma_L = 2$ and $\epsilon_w = 11$ gives $\Psi_w = 0.0037$.

$\Psi_p = 0.0858$ and $\Psi_w = 0.0037$.

I assume $\delta = 0.025$, which implies 10% depreciation in a year in the steady state. This parameterization also implies the convex cost structure on variable capital utilization. In this parameterization of δ, ζ will be found to be 1.404[9].

As for the production side, we need to assign calibrated values of ϕ, γ, η, and α. I take a relatively wide range of calibrated values of ϕ: $\phi \in [0, 0.4]$ for simulation[10]. I take $\phi = 1/3$ as a baseline and check different values of ϕ in sensitivity analysis. On the other hand, I follow Cooper and Johri (2002) in calibrating γ and η, that is, $\gamma = \eta = 0.5$. Finally, I assume that the total cost share of effective capital inputs is 0.36 (i.e. $\alpha = 0.36$).

For the adjustment cost of capital, we set $\phi_k = 3.0$. In the empirical literature on investment, the estimates of the adjustment cost parameter differ depending on the estimation methods. Eberly (1997) estimated that ϕ_k lies between 5.6 and 11.1 using linear q-equations, while Whited (1992) found that it ranges from 0.54 to 2.05, using Euler equation approach.

---

[9]To see this, note that the first order condition (16) in the steady state becomes

$$Q = \lambda r^k + \beta Q(1 - \delta),$$

where a variable without time subscript is the steady state value. Because $Q/\lambda = 1$ from (14),

$$1 = \frac{\beta}{1 - \beta(1 - \delta)} r^k.$$

However, the equation (15) implies that $r^k = \delta\zeta$. By substitution of this equation, we get

$$\zeta = \frac{1 - \beta}{\beta\delta} + 1.$$

Thus, given β and δ, the value of ζ has to be determined uniquely. Substituting $\beta = 0.99$ and $\delta = 0.025$, ζ turns out to be 1.404. See Burnside and Eichenbaum (1996) for the details.

[10]The calibrated values assigned here are controversial. For example, Burnside, Eichenbaum, and Rebelo (1995), Basu (1996), Sbordone (1996) and others argue against external increasing returns to scale proposed by Caballero and Lyons (1992) and Bartelsman, Caballero, and Lyons (1994). On the other hand, Harrison (2003) found externalities in both consumption and investment sector, although she consider static externalities. Cooper and Johri (1997) and Cooper and Johri (2002) found evidence for the effect of macro-level organizational capital from the production function estimation.

Our calibrated value of ϕ_k approximately takes the middle of their estimates: ϕ_k is 3.0.

The monetary policy parameter ρ_m is assumed to be 0.5, as suggested as Christiano, Eichenbaum, and Evans (1998). The value of ρ does not affect qualitative results for IRF analysis. The steady state value of money growth rate is set to 1.005, which implies 2% money growth rate per year if the economy is in the steady state.

Table 1 summarizes the calibrated parameters.

Preference Parameters	
σ	1
ψ	2
b	0.65
β	0.99
Real Rigidities	
ϵ_p	11
ϵ_w	11
Nominal Rigidities	
Ψ_p	0.0858
Ψ_w	0.0037
Capital Accumulation Technology	
δ	0.025
ζ	1.404
ϕ_k	3.0
Technology in the production function	
α	0.36
ϕ	0.33
γ	0.5
η	0.5
Money Supply	
g	1.005
ρ_m	0.5

Table 1: Calibrated Parameters in the model

3 Effects of a Money Growth Rate Shock

3.1 Stylized Facts and Unit Labor Costs

To confirm the stylized facts in the VAR literature, I run a simple VAR similar to Walsh (2002)'s. He ran a three variable-VAR (output, inflation and the money growth rate) to generate some stylized facts about the IRFs of inflation and the output gap. Into this simple VAR, I add unit labor cost as a proxy for marginal cost, because the behavior of the marginal cost is critically important in our analysis[11].

Fig 1 shows the resulting IRFs to one standard deviation shock to money growth rate[12]. The number of lags was selected to be three on the basis of AIC. As shown in Fig. 1, inflation and the output gap have hump-shaped IRFs: The peak for inflation occurs at the eighth quarter while the peak for the output gap occurs at the fifth quarter.

In certain circumstances, unit labor cost proxies well for marginal cost[13]. The data therefore suggests that the IRF of marginal cost is reduced for seven quarters after a money growth rate shock and increased only after eight quarters.

[11]We could have run a much larger VAR to confirm the stylized facts as Christiano, Eichenbaum, and Evans (2003) did. However, a VAR with many variables usually has large standard error bands and often lacks robust IRFs. For our purposes, it will be enough just to confirm the stylized facts about inflation and the output gap and to generate stylized facts about marginal cost.

[12]I HP filtered the logarithm of real GDP and unit labor cost to get the output gap and the marginal cost gap. I used log-difference CPI and M2 to obtain the inflation rate and the money growth rate. The order of the variables in the VAR is output gap, marginal cost gap, the inflation rate and the money growth rate.

[13]In order for this relation to hold, we need to assume Cobb-Douglas technology and free mobility of labor input.

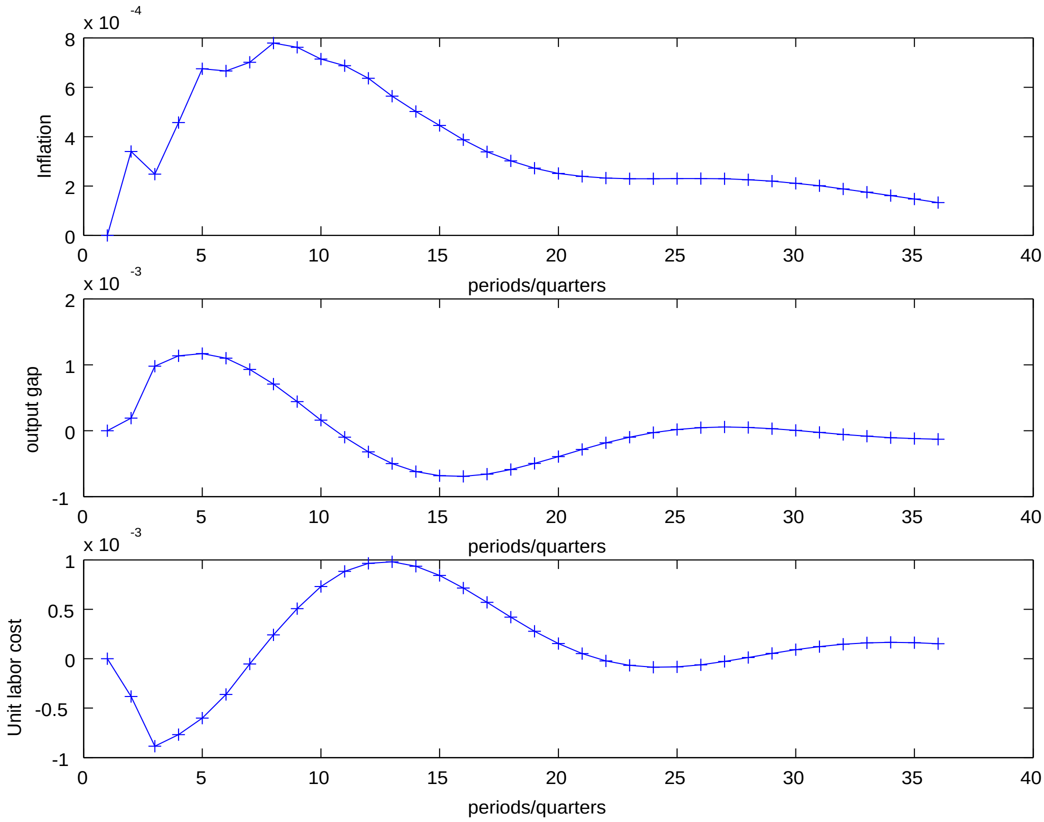

Figure 1: **Estimated IRFs of inflation, the output gap and unit labor cost in response to one standard deviation shock in money growth rate shock**: The sample is from 1965:1 to 2002:4. The IRFs are estimated 4 variable VAR with lag 3.

3.2 The Role of Dynamic Externality

Fig 2 and 3 implied by our model show several IRFs for increase of the 1% in money growth rate in the benchmark case.

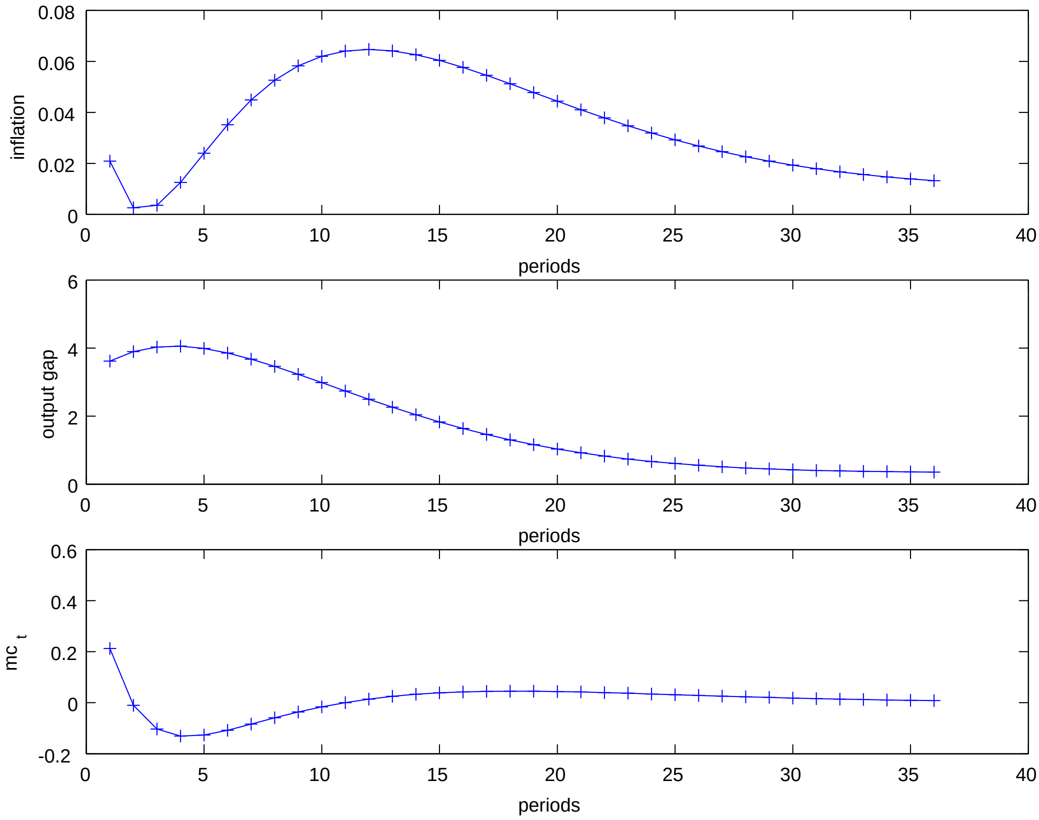

Figure 2: **With Dynamic Externality**:IRF of inflation, output gap and marginal cost in response to 1% of money growth rate shock

As the first two panels of Fig 2 shows, inflation and output are hump-shaped. The response of inflation peaks in the 12th period after a monetary shock. This shape is qualitatively similar to our IRF shown in Fig 1, although the peak is faster than the model's prediction. It is also similar to the IRF with many variables estimated by Christiano, Eichenbaum, and Evans (2003) except that our inflation response shows a positive response in the initial period of the expansionary monetary shock. Similarly, the output gap peaks in the

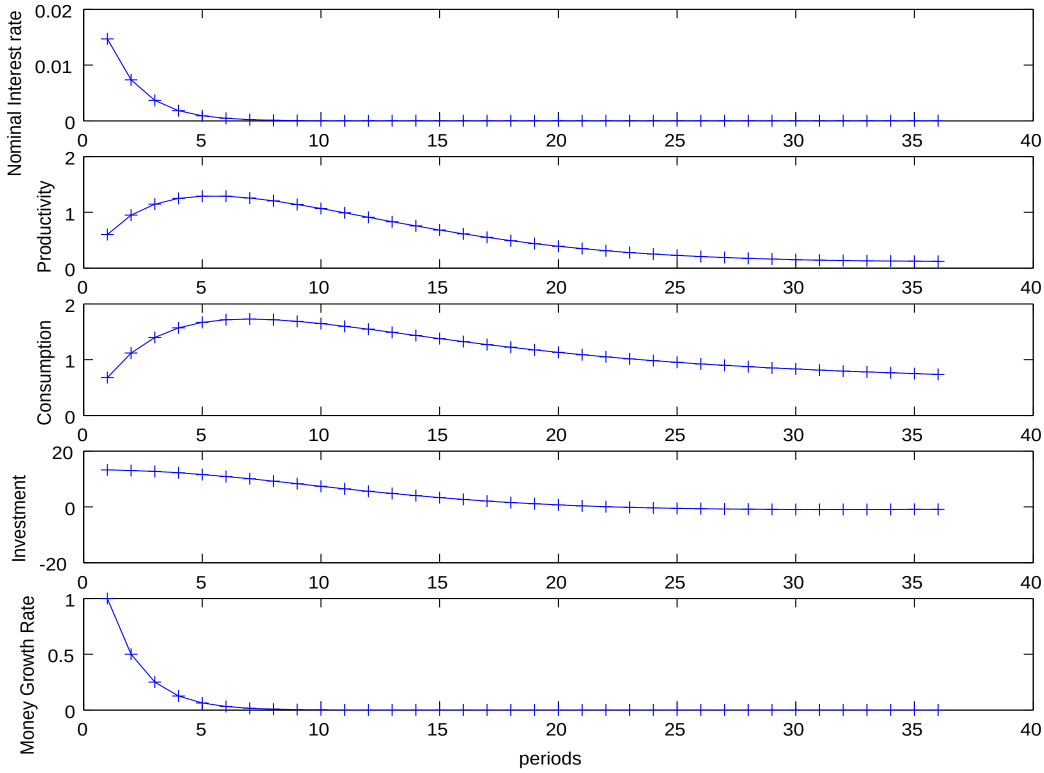

Figure 3: **With Dynamic Externality**:IRF of other variables of interest in response to 1% of money growth rate shock

4th period after the shock. This is also consistent with our finding from the VAR analysis and Christiano, Eichenbaum, and Evans (2003)'s VAR. Finally, the marginal cost in the benchmark case behaves interestingly. The log-deviation of marginal cost jumps up initially but becomes negative from the second through the 11th period, returning to positive values only after the 12th period. This behavior of the marginal cost is quite similar to our VAR in Fig. 1.

The IRF of other variables of interest are shown in Fig. 3. As in standard NK models, we encounter the lack of a liquidity effect in the first panel in Fig. 3. Due to the dynamic externality, productivity shows strong procyclical response to an expansionary monetary shock. Obviously, consumption shows hump-shape in its IRF, because we assume habit formation. Investment jumps up at the first period and decays to the steady state level.

To get the intuition behind hump-shaped IRF for inflation, consider IRF of marginal cost first. The real marginal cost at each period is decomposed into three effects, as shown in (5).

1. The effect of the real wage : Marginal cost is higher, the higher the real wage.
2. The effect of the rental cost of effective capital: Marginal cost is higher, the higher the rental cost of capital.
3. The effect of productivity through the dynamic externality: the higher the externality X_t, the lower marginal cost.

When the money growth rate increases, increased real balances cause real interest rate to decrease, which in turn causes marginal utility to decrease from (12)[14]. To meet decreased

[14]To see this, we solve the log-linearized equation of (12) forward. Because the marginal utility positively

marginal utility, the consumption must increase, which in turn raises the demand for goods. To meet more demand for goods, an individual firm needs to hire more labor and capital. Thus, the real wages and rental cost of capital will increase. The increase in factor prices gives the firm the incentive to price high. However, in our model, the organizational capital is accumulated due to the increased consumption and investment. For an individual firm, the increase in the organizational capital raises firm's productivity, because this effect is external to the firm. The higher productivity gives the firm the incentive to price low. Because the effects of the productivity and the factor prices are canceling each other, the marginal costs may increase or decrease, depending on the dynamic structure of these three elements above. In the simulation, the marginal cost after a monetary shock increases at first, then decreases for several periods and then increase again.

Now, the reason for hump-shaped IRF for inflation is straightforward. As a first approximation, let $\beta = 1$. Then, (2) becomes

$$E_t \hat{\pi}_{t+1} - \hat{\pi}_t = -\Psi_p \hat{mc}_t. \tag{23}$$

In our simulation shown in Fig. 2, $\hat{mc}_t$ is *negative* from the second to the eleventh quarter after a monetary shock. Thus, inflation is expected to increase and actually increases rather than decreasing over time, even though the output gap during these periods is *positive*. After 12 quarters, $\hat{mc}_t$ becomes *positive* until it converges to its steady state level of zero, implying that inflation decreases over time. *Inflation increases as long as $\hat{mc}_t$ is negative and decreases as long as $\hat{mc}_t$ is positive.* This generates the hump-shaped response of inflation.

depends on the sum of short-term real interest rate, the decrease in real interest rate causes the marginal utility to decrease.

This relationship between marginal cost and inflation is surprisingly consistent with our impulse response analysis. The marginal cost in Fig 1 takes a negative value from the second to the seventh period and then becomes positive. On the other hand, the peak of inflation is the eighth quarter in Fig 1. In other words, the estimated IRFs show the same pattern as the model's prediction: inflation is increasing over time while the marginal cost is negative and inflation is decreasing over time after mc becomes positive!

The hump-shaped IRF for inflation can be interpreted as follows. After an unexpected monetary shock, a firm observes higher demand for its goods and needs to set the price of its goods in response to higher demand. When it is possible to reset the price, the firm will predict that the marginal cost will be high in the future but will be low for several periods before it increases. Since inflation is determined in purely forward-looking manner, the firm will take the low marginal costs in the short-run and the high marginal costs in the intermediate-run into consideration for the determination of its price. Therefore, the firm will hesitate to price high while the marginal cost is low in the short-run. However, $\hat{mc}$ is increasing over time, as the externalities weaken and factor prices increase. When it is possible to reset the price again, the forward looking firm no longer has such a low marginal cost. At this point, the incentive to price low created by externalities has become small, leading the forward looking firm to set its price higher. Thus, inflation response is hump-shaped *not because firms are backward-looking, but because they are forward-looking.*

In our simulation results, the IRF for the output gap is also hump-shaped. This hump-shaped response of the output gap largely reflects habit formation in consumption. However, the dynamic externality plays a role of an amplification mechanism. We will discuss dynamic externalities as an amplification mechanism in a different subsection.

A natural question is what happens if the extent of externalities is different from the benchmark case. Fig. 4 and 5 are IRF when $\phi = 0$. Inflation and output gap are front loaded as shown in Fig. 4. As in the standard NK model, the log-deviation of the marginal cost jumps up and then decays to the steady state level. It does not become negative. The reason that inflation doesn't exhibit a hump shape is simple. Without dynamic externalities, productivity does not change in response to the increase in the production (the second panel of Fig. 5). Marginal cost increases because of higher factor prices. Therefore, $\hat{mc}$ is uniformly positive and inflation is decreasing over time as (23) suggests.

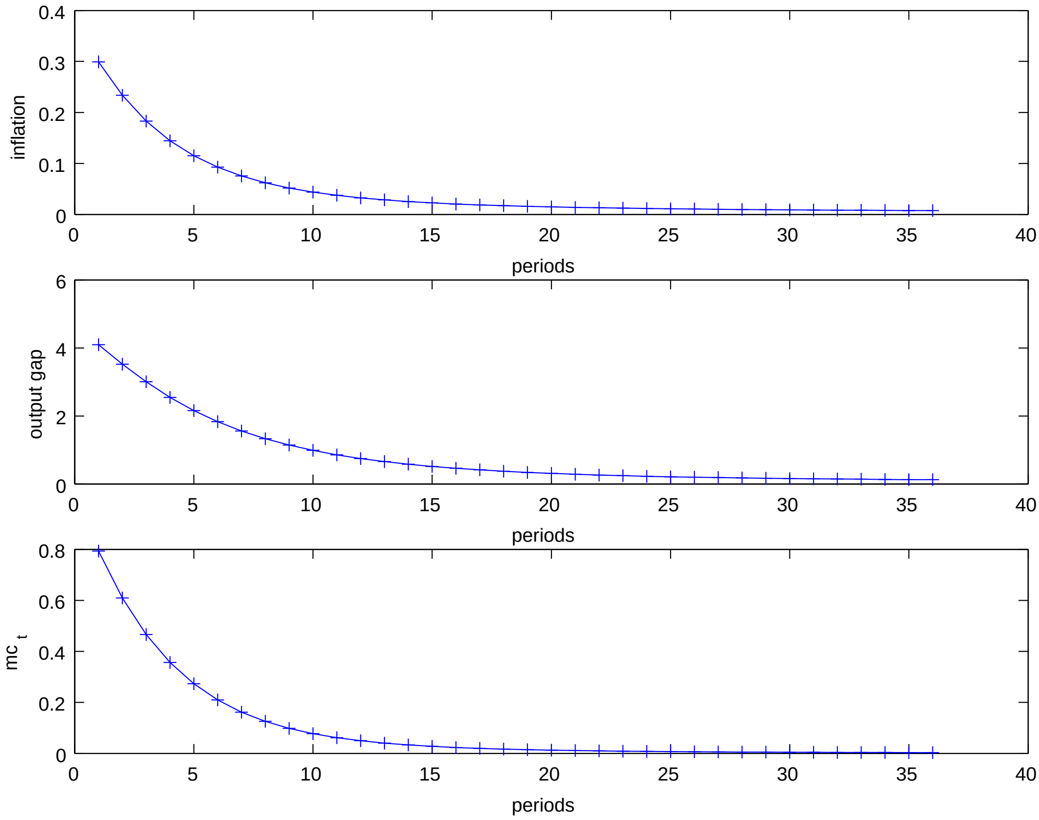

Figure 4: **No Dynamic Externality**:IRF of inflation, output gap and the marginal cost in response to 1% of money growth rate shock

Fig. 6 shows the simulation results when $\phi = 0.4$. In this case, inflation starts from a

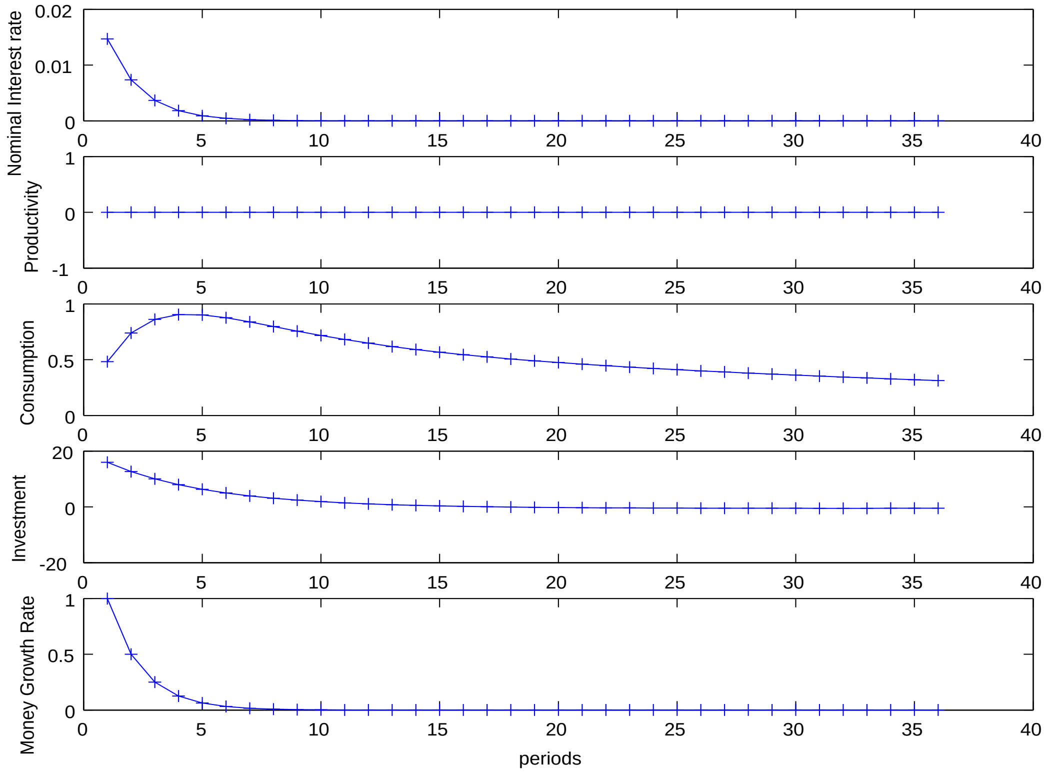

Figure 5: **No Dynamic Externality**:IRF of other variables of interest in response to 1% of money growth rate shock

negative value, implying a decrease in the price level in response to a monetary shock. In other words, the price puzzle that is apparently found in data results when there are large externalities. The reason for the price puzzle is also straightforward: The productivity effect in the short-run is so great that it is optimal for firms to price low in the short-run.

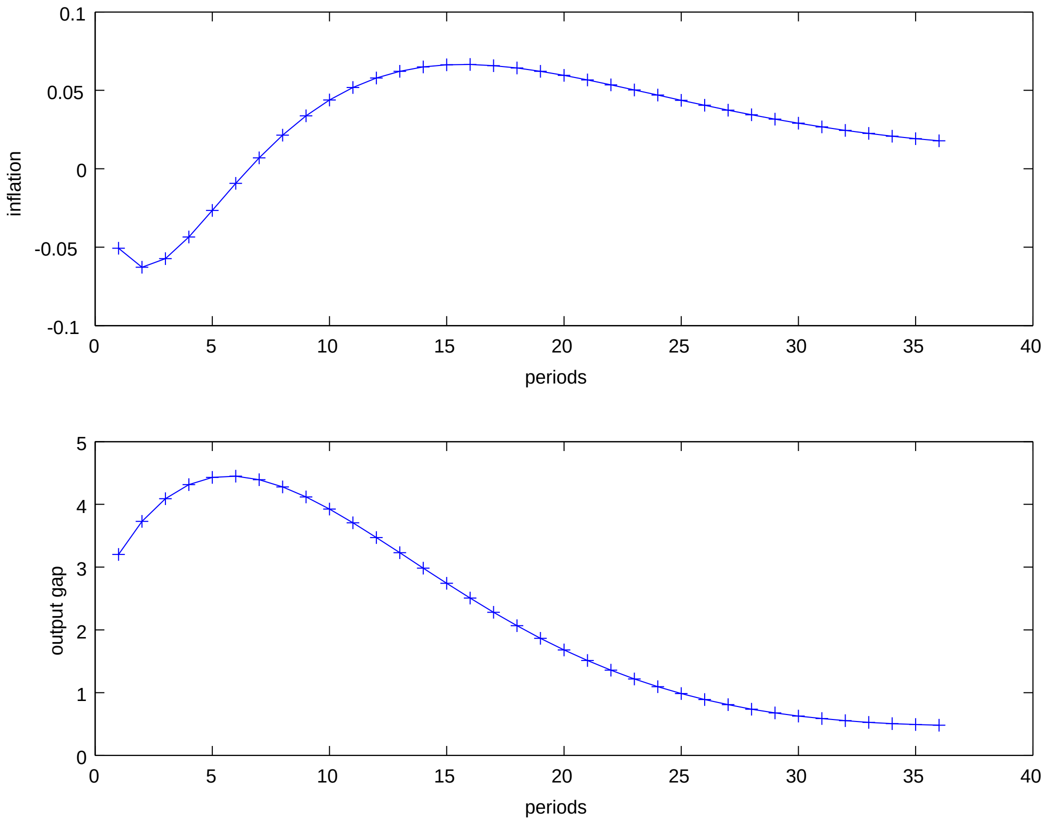

Figure 6: **Large Dynamic Externality**:IRF of inflation and output gap in response to 1% of money growth rate shock

3.3 The Role of Sticky Wages and Variable Capital Utilization

In this subsection, we discuss the role of sticky wages and variable capital utilization. In the analysis in the previous subsection, we found that the behavior of marginal cost is important: When the log-deviation of the marginal cost takes negative values in the short-run and positive values in the intermediate-run, the inflation can be hump-shaped. It will be shown that sticky wages and variable capital utilization are important for generating such a behavior of the marginal cost and that dynamic externalities alone cannot generate a hump shape in inflation. That is, the hump-shaped IRF for inflation is obtained only when dynamic externalities are combined with sticky wages and variable capital utilization.

To analyze the effect of sticky wages and variable capital utilization, we use (5) to take the log-linearization of the marginal cost around the steady state:

$$\hat{mc}_t = \hat{P}_t^f - \phi \hat{X}_t,$$

where $\hat{P}_t^f \equiv (1-\alpha)\hat{w}_t + \alpha \hat{r}_t^k$. In other words, $\hat{P}_t^f$ is the weighted average of real wages and rental cost of effective capital. The second term in the equation $\phi \hat{X}_t$ shows the log-deviation of the productivity through dynamic externality.

Fig. 7 makes the effect of sticky wages and capital utilization clearer. At each panel of the figure, the IRFs of factor prices $\hat{P}_t^f$ and productivity $\phi \hat{X}_t$ to a monetary shock are shown. The upper left panel of the figure is the benchmark case while the lower right panel of the figure is the case of flexible wages and constant capital utilization. In the off-diagonal panels of the figure are the case in which either of sticky wages or variable capital utilization is missing in the simulation.

Note that only in the upper left panel does the productivity exceed the factor prices in the response for several periods and then reverse after those periods. Thus, $\hat{mc}$ is first negative and then positive. As shown in the previous subsection, inflation is hump-shaped due to this negative response of $\hat{mc}$. On the other hand, the factor prices in the other panels

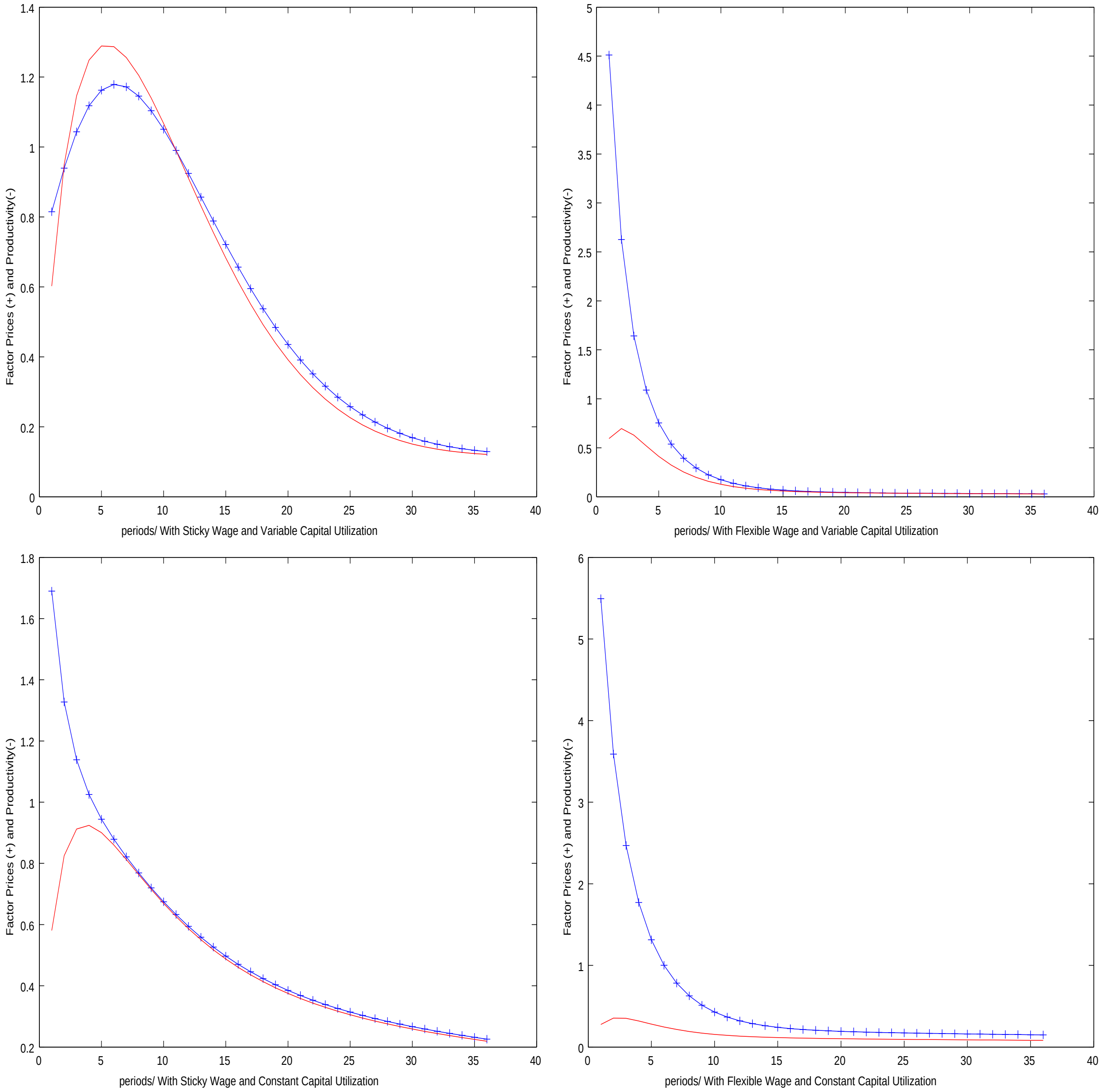

Figure 7: **Factor Prices and Productivity**:The line with (+) is the log-deviation of factor prices from the steady state value $\hat{P}_t^f$ and the line with (-) is productivity. The factor price minus productivity is the log-deviation of the marginal cost.

of the figure are *always* larger than productivity in the log-deviation response, which implies that $\hat{mc}$ always takes positive values in response to a monetary shock. Therefore, inflation is never hump-shaped.

We can see that both sticky wages and variable capital utilization are important. In the upper right panel of the figure, capital utilization is variable but real wages are flexible. In this case, the factor price effect overwhelms the productivity effect in its magnitude, because real wages is adjusted upward quickly. In the lower left panel, real wages are sticky but capital utilization is constant. As a result, the rental cost of effective capital is adjusted upward so much that factor prices exceed productivity, although the magnitude of factor prices shifts down closer to that of productivity[15]. Finally, under flexible wages and constant capital utilization, the effect of factor prices is so strong that the productivity effect is almost negligible.

3.4 Dynamic Externality as an Amplification Mechanism

As pointed out, the hump-shaped dynamics of output gap largely rely on the assumption of habit formation in consumption. Nevertheless, when $\phi = 0$, the output gap was front loaded as shown in the second panel of Fig 4[16].

The intuition for hump-shaped output under $\phi = 1/3$ is straightforward. The increased

[15]Although real wages $\hat{w}$ show a hump shape in its response, $\hat{P}^f$ does not. This is because $\hat{P}^f$ is the weighted average of real wages and rental cost of capital and the response of $\hat{r}^k$ is much larger in its magnitude than in the case of variable capital utilization. While real wages are hump-shaped, the rental cost of capital is not only front loaded but also jumps up to a large extent. Because of the large front loaded rental cost, $\hat{P}^f$ as the weighted average doesn't exhibit hump-shaped behavior in its IRF.

[16]It is easily shown that output can be hump-shaped even without dynamic externality, when we assume the investment adjustment cost rather than capital adjustment cost. However, the point here is to stress the importance of dynamic externality as an amplification mechanism. For expositional purpose, it will be easier to understand the amplification mechanism if it is shown that the output gap is front loaded under $\phi = 0$ but the output gap becomes hump-shaped under the degree of externality different from zero.

demand for goods raises productivity. The price for goods is lower when there are externalities than otherwise due to increased productivity. Because of the lower price of goods, the increase in the demand for goods is larger. Thus, externalities *amplify* the effect of habit persistence. In fact, the response of the consumption in the third panel of Fig. 3 are larger than that in Fig. 5. As a result, the output response becomes more similar to the consumption response[17].

Another natural question we may ask is whether habit formation is important for inflation and output dynamics. Fuhrer (2000) included habit formation in his general equilibrium model and concluded inflation with habit formation in consumption is more persistent than otherwise[18]. On the other hand, Christiano, Eichenbaum, and Evans (2003) which uses NKPC with backward looking indexation concluded that sticky wages and variable capital utilization are important for generating inflation inertia, but habit formation is not so important for inflation inertia and output behavior.

From perspective of IRF, we can show that the role of habit formation is consistent with Christiano, Eichenbaum, and Evans (2003). Fig 8 shows IRFs of inflation, and output gap with $b = 0$, holding other parameters at the benchmark values. Inflation still exhibits a pronounced hump shape, even without habit formation in consumption. This result is consistent with Christiano, Eichenbaum, and Evans (2003)'s conclusion[19]: Habit formation

[17]This interpretation is consistent with the fact that the response of the output gap in Fig. 6 exhibits a more pronounced hump shape than in Fig. 3. When there are larger externalities, the response of the consumption are more amplified. As a result, the output gap is more hump-shaped.

[18]Strictly speaking, he uses the relative contracting model for inflation instead of NKPC. Because his inflation equation has lagged inflation, we may expect a different behavior of inflation.

[19]In Christiano, Eichenbaum, and Evans (2003), a policy shock generates a larger initial response in *both* output and inflation without habit formation in consumption. However, in our case, it generates a smaller initial response in inflation and a larger initial response in output. This is because an initially larger response in output makes an initial larger response in productivity. Indeed, current productivity depends on the current output gap through (4). The more the current output, the higher the productivity, implying

is not so important for inflation inertia.

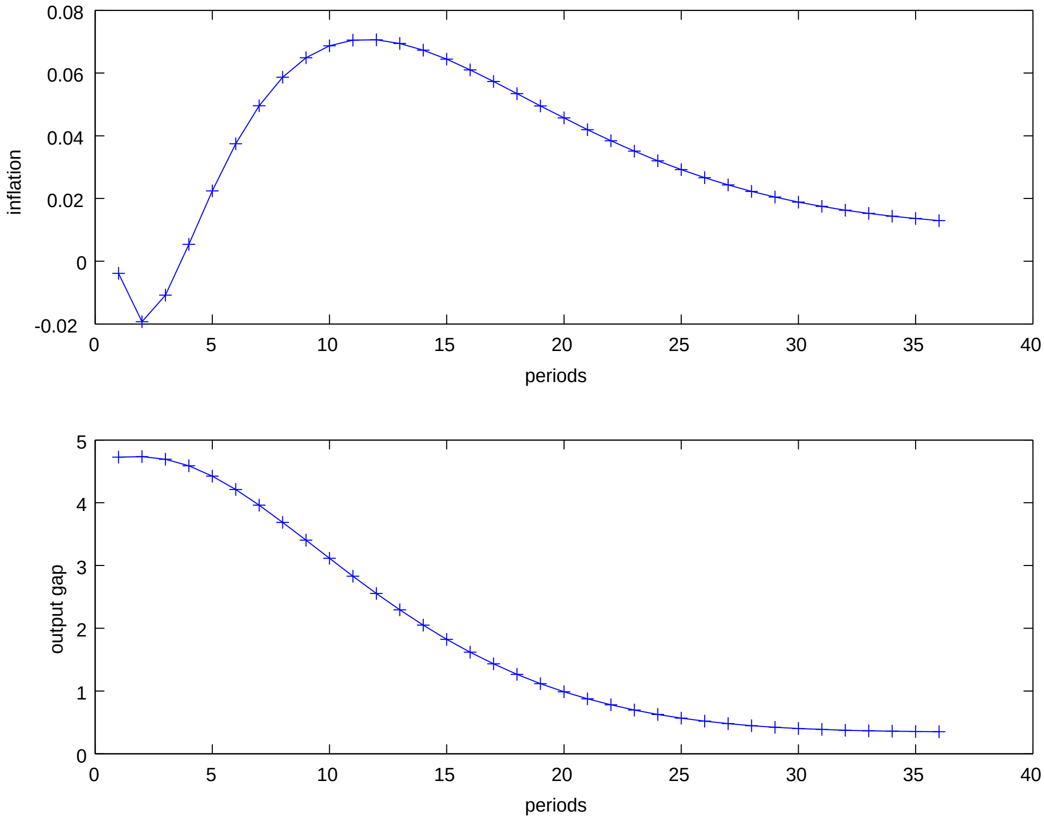

Figure 8: **No Habit Formation in Consumption**:IRF of inflation, and output gap in response to 1% of money growth rate Shock

As for the output gap, we obtained a bit different conclusion from Christiano, Eichenbaum, and Evans (2003). The output gap is only weakly hump-shaped. Because consumption without habit formation is front loaded, the amplification mechanism of the dynamic externality is too weak to get qualitatively plausible output behavior[20].

firm's stronger incentive to price low.

[20]When dynamic externality is large enough such as $\phi = 0.4$, we found that output, consumption, and investment are all hump-shaped. Therefore, dynamic externality itself can generate hump-shaped dynamics of real variables. In this sense, Chang, Gomes, and Schorfheide (2002)'s conjecture that learning by doing may work in a NK model as a propagation mechanism seems to be correct. However, I employ external propagation mechanism rather than internal, and the calibration value of $\phi = 0.4$ may be too strong empirically. Thus, it is better to say that the validity of their conjecture is still an open question.

4 Can the Hybrid NKPC be Consistent with Marginal Cost Behavior?

In the preceeding section, I showed that a dynamic externality can generate a hump-shaped IRF for inflation without backward-looking rule-of-thumb firms. However, it is a conventional wisdom that the hybrid NKPC improves the empirical fit of models and that it can generate a hump-shaped IRF for inflation. Therefore, the hybrid NKPC has been used even though it doesn't have a clear microfoundation. In this section, however, I will show that the hybrid NKPC is not consistent with the observed marginal cost behavior.

Suppose that a researcher wants to use the hybrid NKPC. For example, Christiano, Eichenbaum, and Evans (2003) derived the following hybrid NKPC.

$$\hat{\pi}_t = \frac{1}{1+\beta}\hat{\pi}_{t-1} + \frac{\beta}{1+\beta}E_t\hat{\pi}_{t+1} + \frac{\Psi_p}{1+\beta}\hat{mc}_t. \tag{24}$$

Multiplying both sides by $1+\beta$, rearranging and assuming $\beta \simeq 1$, we get

$$E_t(\hat{\pi}_{t+1} - \hat{\pi}_t) - (\hat{\pi}_t - \hat{\pi}_{t-1}) = -\Psi_p\hat{mc}_t.$$

Thus, the *change* of inflation must be increasing while $\hat{mc}$ is negative, implying that IRF must be a convex function in time over which mc takes a negative value. Intuitively, the hybrid NKPC predicts that inflation accelerates while mc is negative. Even when mc becomes positive after several periods, the inflation is still increasing. Finally, when mc converges to zero, inflation stops increasing. Inflation never returns to the level before the shock of money growth rate.

In order for the hybrid NKPC to be compatible with the observed behavior of inflation, the log-deviation of the marginal cost must be positive from the period of a money growth rate shock. However, we don't observe this kind of behavior of marginal costs from the data.

This inconsistency of the hybrid NKPC with marginal cost can be also confirmed from simple regressions. From (2), the empirical version of purely forward-looking NKPC is

$$\beta\pi_{t+1} - \pi_t = -\Psi_p \hat{mc}_t + \text{error}_t \tag{25}$$

The empirical version of hybrid NKPC (24) is

$$\beta\Delta\pi_{t+1} - \Delta\pi_t = -\Psi_p \hat{mc}_t + \text{error}_t \tag{26}$$

where Ψ_p is expected to be positive.

Table 2 reports GMM estimates of the purely forward-looking NKPC and the hybrid NKPC (β is set to 0.99.). The Panel A of Table 2 shows that the estimate of Ψ_p is positive and significant under the purely forward-looking NKPC. On the other hand, the estimate of Ψ_p in the hybrid NKPC is negatively related with marginal costs and the coefficient is insignificant. This finding seems to be inconsistent with the theory of backward-looking rule of thumb behavior.

From these points of view, I conclude that hybrid NKPC's performance is quite questionable, given the marginal cost behavior proxied by unit labor cost. Moreover, this conclusion strengthens our conclusion in the simulations. Inflation is hump-shaped not because firms

Panel A (Purely forward-looking NKPC)	
Dependent Var: $\beta\pi_{t+1} - \pi_t$	
Estimates of Ψ_p	Overidentification Restriction ($\chi^2(7)$)
0.059	5.366
(0.026)	0.615 (p-value)
Panel B (Hybrid NKPC)	
Dependent Var: $\beta\Delta\pi_{t+1} - \Delta\pi_t$	
Estimates of Ψ_p	Overidentification Restriction ($\chi^2(7)$)
-0.005	9.260
(0.038)	0.235 (p-value)

Table 2: **Regressions on Purely Forward-looking NKPC and Hybrid NKPC**: The number in parenthesizes in the first column is a standard error of a coefficient. The constant term is suppressed. the log-differenced CPI is used for inflation rate π_t. The log-deviation of the marginal cost is calculated by HP-detrended series of unit labor cost. The sample period is from 1965:1 to 2002:4. Instruments includes the four lags of marginal costs and money growth rate.

are backward-looking but because firms are forward-looking in their price setting.

5 Conclusion

This paper provides a dynamic general equilibrium model which includes no irrational economic agents and symmetric information between private agents and a central bank, but can explain the hump-shaped response for inflation to money growth shocks. The key assumptions for the hump-shaped IRF for inflation are a dynamic externality, sticky wages, and variable capital utilization. Dynamic externalities give firms an incentive to price low because productivity is high in the short-run. However, because real wage increases slowly, it gives firms the incentive to price high in the intermediate-run. Variable capital utilization helps marginal cost to be damped in its magnitude. By combining these three elements, marginal cost can decrease for several periods but increase in the end. Given this dynamic behavior of marginal cost, forward-looking firms raise their prices only moderately for several periods and the response of inflation to a monetary shock can be hump-shaped for a reasonable range of parameters.

When the dynamic externality is large enough, even a price puzzle can emerge. In this case, the degree of externalities is perhaps too great empirically. But, it could be a possible explanation for the price puzzle, if the degree of externalities can be reduced by adding other elements to our model.

The dynamic externality also serves as an amplification mechanism for output. In our simulation, the output gap under dynamic externalities is hump-shaped, while the output gap without externalities is not. Dynamic externalities amplify the consumption IRF characterized by habit formation in consumption. As a result, IRF of the output gap becomes more similar to consumption IRF.

Given the observed dynamics of marginal cost, the hybrid NKPC generates a quite questionable prediction. Rather, the purely forward-looking NKPC seems to be more consistent with the data than the hybrid one, unlike a conventional wisdom.

References

Ball, L., 2000, "Near-Rationality and Inflation in Two Monetary Regime," *NBER Working Paper.*

Bartelsman, E. J., R. J. Caballero, and R. K. Lyons, 1994, "Customer- and Supplier- Driven Externalities," *American Economic Review*, 84, 1075–1084.

Basu, S., 1996, “Procyclical Productivity: Increasing returns to scale or Cyclical Utilization?,” *Quarterly Journal of Economics*, 111, 719–751.

Burnside, C., and M. Eichenbaum, 1996, “Factor Hoarding and the Propagation of Business Cycle Shocks,” *American Economic Review*, 86, 1154–1174.

Burnside, C., M. Eichenbaum, and S. Rebelo, 1995, “Capital Utilization and Returns to Scale,” NBER Working Paper.

Caballero, R. J., and R. K. Lyons, 1992, “External Effect in U.S. Procyclical Productivity,” *Journal of Monetary Economics*, 29, 209–225.

Calvo, G., 1983, “Staggered Prices in a Utility Maximizing Framework,” *Journal of Monetary Economics*, 12, 383–398.

Chang, Y., J. F. Gomes, and F. Schorfheide, 2002, “Learnig-by-Doing as a Propagation Mechanism,” *American Economic Review*, 92, 1498–1520.

Christiano, L. J., M. Eichenbaum, and C. L. Evans, 1998, “Modeling Money,” NBER Working Paper.

Christiano, L. J., M. Eichenbaum, and C. L. Evans, 2003, “Nominal Rigidities and the Dynamic Effect of a Shock to Monetary Policy,” Forthcoming in Journal of Political Economy.

Clarida, R., J. Gali, and M. Gertler, 1999, “The Science of Monetary Policy: A New Keynesian Perspective,” *Journal of Economic Literature*, 37, 1661–1707.

Cooper, R. W., and A. Johri, 1997, "Dynamic Complementarities: A Quantitative Analysis," *Journal of Monetary Economics*, 40, 97–119.

Cooper, R. W., and A. Johri, 2002, "Learning-by-Doing and Aggregate Fluctuations," *Journal of Monetary Economics*, 49, 1539–1566.

Eberly, J. C., 1997, "International Evidence on Investment and Fundamentals," *European Economic Review*, 41, 1055–1078.

Erceg, C. J., 1997, "Nominal Wage Rigidities and the Propagation of Moneytary Disturbances," Board of Governors of the the Federal Reserve System International Finance Discussion Papers.

Erceg, C. J., D. W. Henderson, and A. T. Levin, 2000, "Optimal Monetary Policy with Staggered Wage and Price Contracts," *Journal of Monetary Economics*, 46, 281–313.

Erceg, C. J., and A. Levin, 2003, "Imperfect Credibility and Inflation Persistence," *Journal of Monetary Economics*, 50, 915–944.

Fuhrer, J., and G. Moore, 1995, "Inflation Persistence," *Quarterly Journal of Economics*, 110, 127–159.

Fuhrer, J. C., 1997, "(Un)Importance of Forward Looking Behavior in Price Setting," *Journal of Money, Credit and Banking*, 29, 338–350.

Fuhrer, J. C., 2000, "Habit Formation in Consumption and Its Implication for Monetary Policy Models," *American Economic Review*, 90, 367–390.

Gali, J., 1992, "How Well Does the IS-LM Model Fit Postwar U.S. Data?," *Quarterly Journal of Economics*, 107, 709–738.

Gali, J., 2002, "New Perspective on Monetary Policy, Inflation and the Business Cycle," in M. Dewatripont L. P. Hansen, and S. Turnovsky (ed.), *Advances in Economic Theory*, Cambridge University Press, forthcoming.

Gali, J., and M. Gertler, 1999, "Inflation Dynamics: A Structural Econometric Analysis," *Journal of Monetary Economics*, 44, 195–222.

Gali, J., M. Gertler, and J. D. Lopez-Salido, 2001, "European Inflation Dynamics," *European Economic Review*, 45, 1237–1270.

Harrison, S. G., 2003, "Returns to Scale and Externalities in the Consumption and Investment Sectors," *Review of Economic Dynamics*, 6, 963–976.

Keen, B. D., 2003, "The Signal Extraction Problem Revisited: Its Impact on a Model of Monetary Policy," mimeo.

Mankiw, N. G., and R. Reis, 2002, "Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve," *Quarterly Journal of Economics*, 117, 1295–1328.

Nelson, E., 1998, "Sluggish Inflation and Optimizing Models of the Business Cycle," *Journal of Monetary Economics*, 42, 302–322.

Roberts, J. M., 1997, "Is Inflation Sticky?," *Journal of Monetary Economics*, 39, 173–196.

Roberts, J. M., 2001, "How Well Does the New Keynesian Sticky - Price Model Fit the Data?," Board of Governers of the Federal Reserve System Working Paper.

Rotemberg, J. J., 1982, "Sticky Prices in the United States," *Journal of Political Economy*, 90, 1187–1211.

Rotemberg, J. J., 1997, "Toward a Compact, Empirically-verified Rational Expectations Model for Monetary Policy Analysis: A Comment," *Carnegie Rochester Conference Series on Public Policy*, 47, 231–241.

Sbordone, A. M., 1996, "Cyclical Productivity in a Model of Labor Hoarding," *Journal of Monetary Economics*, 38, 331–361.

Stock, J. H., and M. W. Watson, 2001, "Vector Autoregressions," *Journal of Economic Perspective*, 15, 101–115.

Taylor, J. B., 1980, "Aggregate Dynamics and Staggered Contracts," *Journal of Political Economy*, 88, 1–23.

Walsh, C. E., 2002, "Labor Market Search and Monetary Shocks," Prepared for Elements of Dynamic Macroeconomic Analysis, S. Altug, J. Chadha, and C Nolan(ed.).

Whited, T. M., 1992, "Debt, Liquidity Constraints, and Corporate Investment: Evidence from Panel Data," *Journal of Finance*, 47, 1425–1460.

Woodford, M., 2003, *Interest and Prices: Foundations of a Theory of Monetary Policy*, Princeton University Press.