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Comment on Monetary Non-Neutrality and Inflation Dynamics

by

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Abstract

In this paper we show that the highly persistent inflation dynamics and its lead-lag relationship with output can be explained by a standard flexible price RBC model augmented with endogenous monetary policy. Endogenous monetary policy acting upon the illusion that price is sticky and money is effective can create price movements that appear to indicate price stickiness, although there is none in the economy.

Keywords: Inflation Dynamics, Sticky Price, New Phillips Curve, Taylor Rule, Endogenous Monetary Policy.

JEL classification: E31; E32; E52

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1 Introduction

Is the business cycle a real or a monetary phenomenon? The answer seemed clear after the seminal work of Kydland and Prescott (1982) and Long and Plosser (1983), but only for a while. Along side with some well known criticisms of standard RBC models, such as the lack of strong propagation mechanisms, a serious challenge to the RBC paradigm is to explain fluctuations in nominal variables, such as the highly persistent inflation dynamics and its correlations with output. A large literature has therefore emerged recently in general equilibrium modeling of the business cycle with a renewed focus on stick price and money.[1] At stake, among other things, is the issue of monetary non-neutrality and what should be the appropriate conduct of monetary policy (see, e.g., Goodfriend and King, 1997, for a comprehensive survey).

A defining feature of this recent literature is a more sophisticated way of modeling sticky price. Based on early work of Taylor (1980), Calvo (1983) and others, this new literature attempts to explain the business cycle from a monetary point of view by casting firms' price setting decisions within an explicit individual optimization framework. A chief success of this literature is the theoretical derivation of the so-called "new Phillips curve" that links inflation to expected future inflation and some measure of overall real activity, such as the marginal cost of production. The empirical evidence so far appears to support the new Phillips curve (see, e.g., Robert, 1995; Gali and Gertler, 1999) . Hence, progress seems have been made towards understanding the nature of the business cycle beyond the real-business-cycle theory. Namely, the business cycle may be better understood in models where monetary shocks and price setting behavior play a central role. Or is it so?

Recently, Ireland (2003) estimates a sticky-price business cycle model with endogenous monetary policy that nests the flexible-price DSGE model as a special case (in this paper, "RBC" model and "flexible price DSGE" model are used interchangeably). Important findings include that monetary shocks seem to have not played a significant role in explaining the real side of economic fluctuations, and that the flexible-price model does quite well in explaining some important features of the nominal business cycle. For example, Ireland finds that the flexible price model performs better than the sticky price model in explaining the volatility of inflation and the degree of inflation persistence. But Ireland also finds evidence in support of the sticky price model,

[1] See e.g., Rotemberg and Woodford (1992), King and Watson (1996), King and Wolman (1996), and Yun (1996), among others.

especially with respect to the lead-lag relationship among output, inflation and interest rate.

This comment attempts to provide a theoretical analysis and explanation for Ireland's (2003) empirical findings. We show that sticky price is not the only way to derive the new Phillips curve; the new Phillips curve can also be a consequence of endogenous monetary policy. In other words, the new Phillips curve can also be derived from standard, flexible-price DSGE models where money is a veil but is endogenously determined by other economic variables. In this type of models, it is the conduct of monetary policy – e.g., the Taylor rule – that gives rise to a relationship linking current inflation to expected and lagged inflation as well as some measure of real activity. We calibrate such an DSGE model and we show that with standard parameter values the model can perform very well in explaining some important features of the nominal business cycle, which includes not only the volatility of inflation relative to output and the degree of inflation persistence (in consistence with Ireland, 2003), but also the lead-lag relationships among output, inflation and interest rate (in sharp contrast to Ireland, 2003).

Because the structure of RBC models is well understood in the literature and it is much simpler than that of sticky price models, we are able to reveal the precise conditions under which a monetary model can generate persistent and hump-shaped inflation dynamics. Thus, we are able to resolve a number of long standing puzzles in the sticky price literature. In particular, we can explain: 1) why the aggregate price level is counter-cyclical; 2) why it is difficult to generate highly persistent or hump-shaped inflation dynamics under monetary shocks; and 3) why sticky price does not help resolving the lack of propagation mechanism in standard RBC models.

Since by design money is neutral in our model, our analysis implies that not only in the long-run but also in the short-run inflation can be purely a monetary phenomenon. Hence, the highly persistent price movements and inflation dynamics may provide no additional clue for the nature of the business cycle beyond what the real business cycle theory predicts. Our analysis supports the view that monetary policies operating under the illusion that price is sticky (i.e., money has real effect) can produce price movements that appear to indicate price stickiness, although in fact price is flexible and money is completely neutral.

In this paper we also conduct a Monte Carlo analysis that may be of independent interest to the literature. Many people have argued that monetary policy is endogenous. If money is truly endogenous, or if money is completely neutral, then it is impossible to use VAR analysis to identify the effects of monetary shocks. But how come the existing literature often finds that money shocks has real effects?[2] We conjecture that the empirical evidence may not be conclusive

[2] See e.g., Sims (1971, 1980, 1992), Christiano et al. (1995), and Strongin (1995).

because the reported statistics is subject to large sampling, estimation, and identification errors. One of the most likely source of identification error is the fact that there may be far more shocks in the economy than the number of variables included in a typical VAR analysis. Hence each type of identified shocks potentially reflects a group of other unobservable shocks, making the labeling of these "identified" shocks highly misleading. To offer an example supporting our conjecture, we simulate our flexible price DSGE model in which money is a veil, and we apply standard econometric tools used in the literature to our model generated samples to identify the effects of the so called "monetary shocks". We find: 1) Using the Choleski decomposition (short run restriction), negative shocks to nominal interest rate tend to increase output in a manner similar to what is found in the data; and 2) Using the Blanchard-Quah (1989) decomposition (long-run restriction), positive shocks to inflation rate tend to increase output in a manner similar to what is found in the data. Although money is completely neutral in our model, but standard econometric analysis based on the model generated finite samples tends to indicate monetary non-neutrality.[3]

Our work can also be viewed as related to the recent work of Benhabib et al. (2001), and Chari et al. (2000). Benhabib et al. (2001) argue that endogenous monetary policy in the form of Taylor rule can be dangerous in that it can lead to multiple equilibrium and expectations driven business cycles. Hence endogenous policies can be destabilizing rather than stabilizing. Our finding is that endogenous monetary policy can also be dangerous in that it can lead to inflation persistence, a phenomenon that falsely indicates the existence of sticky price which monetary authority relies on to justify the use of active monetary policy. This is another example where the intention of monetary policy can be self-fulfilling: the very conduct of policy creates a phenomenon – the illusion of sticky price – that is in turn used to justify the use of such policy.

Chari et al. (2000) show that sticky price by itself cannot enhance the propagation mechanism of a DSGE model with respect to output fluctuations.[4] Their analysis thus suggests that real frictions are perhaps more important than nominal frictions in understanding the business cycle. Our analysis reinforces the analysis of Chari et al. (2000). Here we show that sticky price is not even necessary for understanding the nominal business cycle such as the price movements, since it is entirely possible to construct a real business cycle model with endogenous monetary policy to explain short-run inflation dynamics without resorting to sticky price.[5]

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[3] We do not think our results on this issue are conclusive, but they do offer some foods for thought.

[4] Also see Ball and Romer (1990).

[5] Using individual consumer prices, Bills and Klenow (2003) also find that the joint hypothesis of sticky-price models and popular monetary policy identification schemes are rejected by the data.

2 The Basic Model

The model is a prototype DSGE model with money in the utility and Taylor rule, which is also a simplified flexible price version of the model studied by Ireland (2003). A representative agent in this model chooses consumption (c), real money balance ($\frac{M}{p}$), labor supply (n), savings in terms of either bond or capital stock (B, k) to solve

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \log(c_t - \eta_t) + \gamma_m \log(\frac{M_t}{p_t}) - \gamma_n \frac{n_t^{1+\gamma}}{1+\gamma} \right\}$$

subject to

$$c_t + g_t + k_{t+1} - (1-\delta)k_t + \frac{M_t + B_t/R_t}{p_t} = A_t k_t^{\alpha} n_t^{1-\alpha} + \frac{M_{t-1} + T_t + B_{t-1}}{p_t};$$

where η denotes preference shocks (see e.g., Baxter and King, 1991), g government spending shocks, and A technology shocks. Denoting λ as the Lagrangian multiplier, the first order conditions are:

$$\frac{1}{c_t - \eta_t} = \lambda_t \tag{1}$$

$$\gamma_n n_t^{\gamma} = \lambda_t (1-\alpha) A_t k_t^{\alpha} n_t^{-\alpha} \tag{2}$$

$$\lambda_t = \beta E_t \left\{ \lambda_{t+1} \left[\alpha A_{t+1} k_{t+1}^{\alpha-1} n_{t+1}^{1-\alpha} + 1 - \delta \right] \right\} \tag{3}$$

$$\gamma_m \left(\frac{M_t}{p_t} \right)^{-1} - \lambda_t + \beta E_t \left[\lambda_{t+1} \frac{p_t}{p_{t+1}} \right] = 0 \tag{4}$$

$$\frac{\lambda_t}{R_t} = \beta E_t \left[\lambda_{t+1} \frac{p_t}{p_{t+1}} \right] \tag{5}$$

plus three market-clearing conditions for the goods market, the money market and the bond market:

$$c_t + g_t + k_{t+1} - (1-\delta)k_t = A_t k_t^{\alpha} n_t^{1-\alpha}, \tag{6}$$

$$M_t = M_{t-1} + T_t \tag{7}$$

$$B_t = B_{t-1} = 0. \tag{8}$$

An endogenous monetary policy rule (the Taylor rule) is specified as:

$$\log R_t = \delta_y \log y_t + \delta_\pi \log \pi_t + \log i_t \tag{9}$$

where i_t is a policy shock variable. All shocks are assumed to follow AR(1) processes in log:

$$\begin{aligned}
\log \eta_t &= (1-\rho_\eta)\bar{\eta} + \rho_\eta \log \eta_{t-1} + \varepsilon_{\eta t} \\
\log A_t &= (1-\rho_\eta)\bar{A} + \rho_a \log A_{t-1} + \varepsilon_{at} \\
\log g_t &= (1-\rho_\eta)\bar{g} + \rho_g \log g_{t-1} + \varepsilon_{gt} \\
\log i_t &= (1-\rho_\eta)\bar{i} + \rho_i \log i_{t-1} + \varepsilon_{it}.
\end{aligned}$$

Since money is a veil and the utility function is separable, this economy exhibits the classical feature of "dichotomy" in which a subset of equations (i.e., equations 1-3 plus equation 6) determine the values of all real variables with the level of money supply playing no role in determining the equilibrium value of any real variable. Hence the values of all real variables, such as output, consumption, capital stock and employment, are determined by the real sectors in the model economy (the labor and the goods markets), and the values of nominal variables are then determined subsequently by the nominal sectors (the money and bond markets) and monetary policy. For example, the nominal interest rate is determined by the Taylor rule (7), the inflation rate is determined by the bond demand equation (5), and the endogenous money supply level is determined by the money demand equation (4). Hence, the model has two parts, a "real" part that behaves just like a RBC model without money (equations 1-3 plus 6) and a "nominal" part that determines all the nominal variables once the real variable are determined.[6]

Notice that compared to Ireland (2003), we do not have adjustment costs in capital; and most importantly we do not have intermediate goods and the associated monopolistic competition. However, it can be shown that this model is equivalent to Ireland's model with flexible price. In our model the real wage is given by $\frac{w}{p} = (1-\alpha)\frac{y}{n}$. In Ireland's model with flexible price, the real wage is given by $\frac{w}{p} = mc(1-\alpha)\frac{y}{n}$, where the marginal cost (mc) is a constant that reflects the level of markup.[7] Hence, regarding log-linear dynamics, our model is equivalent to Ireland's model with flexible price.

Since in this model all real variable behave exactly like they do in a RBC model, we can represent the equilibrium of the real part of the model as a set of log-linear decision rules identical to an RBC model (circumflex denote log-linearized values),

$$\hat{s}_t = M\hat{s}_{t-1} + G\varepsilon_t$$

$$\begin{pmatrix} \hat{z}_{1t} \\ \hat{z}_{2t} \end{pmatrix} = \begin{pmatrix} H_1 & 0 \\ H_2 & H_3 \end{pmatrix} \begin{pmatrix} \hat{s}_t \\ \hat{\imath}_t \end{pmatrix}$$

where s is a vector of non-monetary state variables including capital (k) and other real shocks to the economy (η, A, g), ε is a vector of innovations to the real shocks, z_1 is a vector of non-monetary flow variables (such as output, consumption, real wage, real interest rate, and employment) that is a function of the real state (s) only, and z_2 is a vector of monetary flow variables (such as price,

[6]Under the Cash-In-Advance constraint or none-separable utility function, money can have certain real effect even under flexible prices, such as the inflation tax effect (see e.g., Cooley and Hansen 19??). We choose to work with a model where such effects are completely absent in order to highlight our point and to present our argument in a most stark environment.

[7]The marginal cost is no longer constant if price is sticky.

inflation rate, nominal interest rate, real money demand) that is a function of both the real state (s) and the nominal state (i.e., shocks to monetary policy, i_t). The "dichotomy" of the model is reflected by that fact the coefficient matrix for the flow variables is lower triangular and the fact that the real state variables (s) evolve separately from nominal state variables.

To derive the new Phillips curve, note that the log-linearized version of equation (5) and equation (7) are given by

$$E_t(\hat{\lambda}_{t+1} - \hat{\lambda}_t) = \hat{R}_t - E\hat{\pi}_{t+1}$$

$$\hat{R}_t = \delta_y \hat{y}_t + \delta_\pi \hat{\pi}_t + \hat{\imath}_t$$

which implies

$$\hat{\pi}_t = \frac{1}{\delta_\pi} E_t \hat{\pi}_{t+1} + x_t - \frac{1}{\delta_\pi} \hat{\imath}_t$$

where x_t is a linear combination of real variables $\left\{\hat{\lambda}_{t+1}, \hat{\lambda}_t, \hat{y}_t\right\}$. Since in a RBC model all real variables have solutions as functions of the real state, s_t, the above equation can be expressed as

$$\hat{\pi}_t = \frac{1}{\delta_\pi} E_t \hat{\pi}_{t+1} + \phi \hat{s}_t - \frac{1}{\delta_\pi} \hat{\imath}_t. \tag{10}$$

Thus, like the new Phillips curve derived from a typical sticky price model, here the current inflation is linked to the expected future inflation and some measure of real activity, s_t. Given that $\delta_\pi > 1$ according to an active Taylor rule, we can iterate this equation forward to get

$$\begin{aligned}
\hat{\pi}_t &= \phi E_t \sum_{j=0}^{\infty} \left(\frac{1}{\delta_\pi}\right)^j \hat{s}_{t+j} - \frac{1}{\delta_\pi} E_t \sum_{j=0}^{\infty} \left(\frac{1}{\delta_\pi}\right)^j \hat{\imath}_{t+j} \\
&= \phi \left[I - \frac{1}{\delta_\pi} M\right]^{-1} \hat{s}_t - \frac{1}{\delta_\pi - \rho_i} \hat{\imath}_t,
\end{aligned}$$

which can be represented more compactly as

$$\hat{\pi}_t \equiv \begin{pmatrix} \phi_1 & \phi_2 & \phi_3 \end{pmatrix} \begin{pmatrix} \hat{k}_t \\ x_t \\ \hat{\imath}_t \end{pmatrix},$$

where the state vector s_t is partitioned into capital stock (k) and a vector of real shocks (x), and the coefficients $\{\phi_1, \phi_2, \phi_3\}$ are elasticities.

Therefore, it becomes clear at this point that inflation behaves either like the capital stock if ϕ_1 is large, or like the exogenous shocks if the elements in ϕ_2 or ϕ_3 are large. Since in a standard RBC model the capital stock is hump-shaped and the shocks are assumed to follow persistent AR(1) processes, we can see the possibility for inflation rate to be either hump-shaped or persistent AR(1) process. However, a hump-shaped inflation is possible only when the shocks originate from real sectors in this model. To see this, note that monetary policy has no real effect in this model, hence it has no effect on the capital stock, consequently it is impossible for monetary policy shocks (i) to generate hump-shaped impulse dynamics of inflation in this model. In other words, under monetary policy shocks inflation behaves exactly like i_t since $\hat{k}_t = 0$ for all t. However, under real shocks inflation may be hump-shaped if ϕ_1 dominates ϕ_2 so that inflation behaves like capital stock.

Equation (10) has another interesting implication. Since in a standard RBC model the endogenous state variable $\hat{k}_t$ follows the equilibrium law of motion,

$$\hat{k}_t = \phi_{kk}\hat{k}_{t-1} + \phi_{kx}x_{t-1},$$

where $\phi_{kk} \in (0,1)$, equation (10) can also be expressed as (assuming $i_t = 0$ for simplicity)

$$\begin{aligned}\hat{\pi}_t &= \frac{1}{\delta_\pi}E_t\hat{\pi}_{t+1} + \phi_{\pi k}\hat{k}_t + \phi_{\pi x}x_t \\ &= \frac{1}{\delta_\pi}E_t\hat{\pi}_{t+1} + \frac{\phi_{\pi k}\phi_{kx}}{1-\phi_{kk}L}x_{t-1} + \phi_{\pi x}x_t,\end{aligned}$$

which implies

$$\hat{\pi}_t = \phi_{kk}\hat{\pi}_{t-1} + \frac{1}{\delta_\pi}E_t\hat{\pi}_{t+1} - \frac{\phi_{kk}}{\delta_\pi}E_{t-1}\hat{\pi}_t + \phi_{\pi x}x_t + (\phi_{\pi k}\phi_{kx} - \phi_{\pi x}\phi_{kk})\,x_{t-1}. \quad (11)$$

This is a second order difference equation in expected inflation, $E_{t-1}\hat{\pi}_t$. It can be shown that one of the roots of this equation lies outside the unit circle and the other lies inside the unit circle. Hence solving the explosive root forward can give us the solution,

$$E_{t-1}\hat{\pi}_t = \xi_{\pi\pi}\hat{\pi}_{t-1} + \xi_{\pi x}x_{t-1},$$

where $\xi_{\pi\pi}$ is the smaller root and is hence less than one in absolute value. Substituting this into equation (11) gives

$$\hat{\pi}_t = \psi_1\hat{\pi}_{t-1} + \frac{1}{\delta_\pi}E_t\hat{\pi}_{t+1} + \phi_{\pi x}x_t + \psi_2 x_{t-1}, \quad (12)$$

where $\psi_1 = \phi_{kk}\left(1 - \frac{\xi_{\pi\pi}}{\delta_\pi}\right), \psi_2 = \left(\phi_{\pi k}\phi_{kx} - \phi_{\pi x}\phi_{kk} - \frac{\phi_{kk}\xi_{\pi x}}{\delta_\pi}\right)$. Note that $\psi_1 > 0$, since $\xi_{\pi\pi} < 1$, $\delta_\pi > 1$, $\phi_{kk} > 0$. Hence equation (12) looks very similar to the hybrid Phillips curve discussed by Gali and Gertler (1999).

Notice that without the Taylor rule, then money supply is exogenous, hence the quantity theory (money in the utility gives rise to a relationship between money and consumption similar to the CIA constraint) implies that the price level is as persistent as output in this model under real shocks. Since output in a standard RBC model behaves like exogenous shocks (see Cogley and Nason, 1995; and Wen, 1995), price therefore follows an AR(1) process like output, hence the inflation rate, as a first difference of an AR(1) process (price), will have little persistence in it. This shows that endogenous monetary policy is the chief culprit of inflation persistence in the model.

3 Impulse Responses

This section examines the impulse responses of inflation and output to several shocks: technology shock, preference shock, government spending shock, and monetary policy shock. We show that under either technology shocks or policy shocks, inflation is monotonic and negatively correlated or uncorrelated with output, while under real demand shocks inflation can be hump-shaped and positively correlated with output with lags. We calibrate the parameters as follows. We set the time interval of the model as a quarter, the time discounting factor $\beta = 0.99$, the rate of capital depreciation $\delta = 0.025$, the capital elasticity of output $\alpha = 0.36$, the inverse labor supply elasticity parameter $\gamma = 1$, the steady-state government spending to output ratio $\frac{g}{y} = 0.2$, the steady-state consumption shock ratio $\frac{\bar{\eta}}{c} = 0.1$, and the shock persistence parameters $\rho_a = \rho_\eta = \rho_g = \rho_i = 0.9$ (unless otherwise indicated). In setting the Taylor rule parameter, we set $\delta_\pi = 1.35$ and $\delta_y = 0$ (the broad pattern of the model's dynamics is not sensitive to the coefficients in the Taylor rule as long as $\delta_\pi > 1$; we set $\delta_y = 0$ since empirical studies, e.g., Gali and Gertler, 1999, and Ireland 2000, typically find δ_y to be very small; also, making $\delta_y \neq 0$ has no significant effect on our results).[8]

Figure 1 shows the impulse responses of output and inflation rate to a demand shock and a technology shock respectively (since preference shocks and government spending shocks generate exactly the same pattern of impulse responses, we report only the results for preference shocks and technology shocks in Figure 1). It is seen in Figure 1 that inflation (upper right window) is highly persistent and hump-shaped under real demand shocks, and it is inversely hump-shaped under technology shocks (the lower right window). Under demand shocks (the top two windows), inflation and output are positively (weakly) correlated contemporaneously, but with inflation lagging output. Under technology shocks (the bottom two windows), inflation and output are nearly negatively correlated with inflation leading output.

[8] Even when δ_y is relatively large, we are still able to generate almost exactly the same results by slightly adjusting the other parameters in the model.

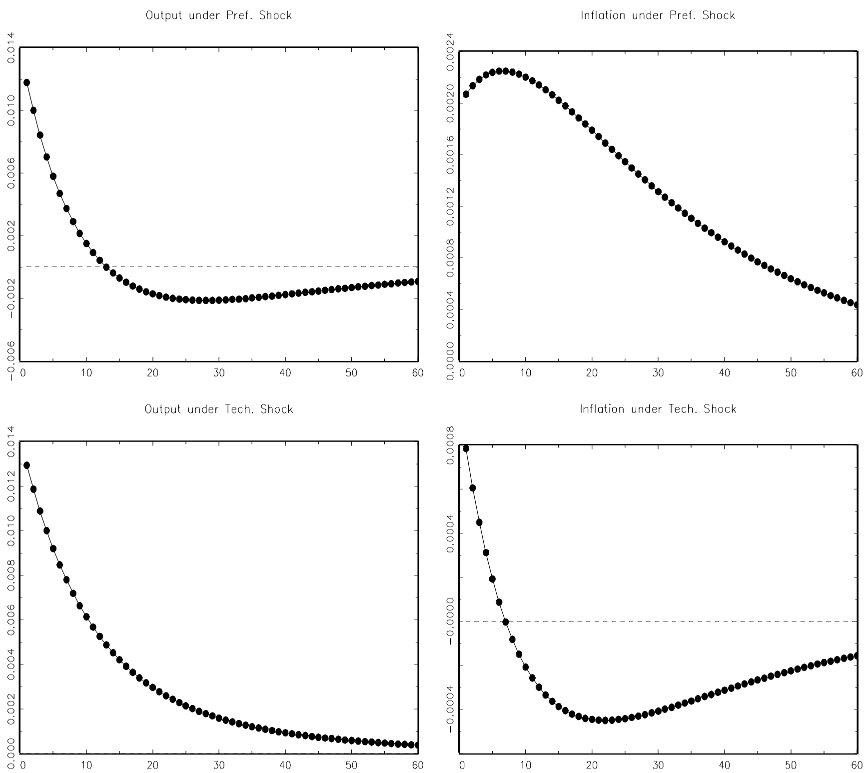

Figure 1. Impulse Responses of Flexible Price Model.

Table 1 reports the standard deviation of inflation relative to output (second column), the contemporaneous correlation of inflation with output, and the autocorrelations of output and inflation respectively (the last two columns). It is seen that the model under either preference shocks or government spending shocks matches the data quite well. In particular, similar to the data, the model predicts that inflation and output are positively correlated contemporaneously, and inflation is more persistent than output in terms of autocorrelations (the last two columns).[9] The predicted volatility relative to output also matches the data well. Technology shocks, on the other hand, cannot explain the positive correlation between inflation and output and the relative volatility of inflation in the US data.

[9] Note that preference shocks and government shocks have exactly the same effects.

Table 1. Standard Moments of Output and Inflation ($x = y, \pi$)

		σ_x	σ_x/σ_y	$cor(x_t, y_t)$	$cor(x_t, x_{t-1})$	$cor(x_t, x_{t-2})$
US Data**						
	y	0.015	–	–	0.85	0.65
	π	0.006	0.41	0.09	0.90	0.85
Model						
η_t	y	0.015	–	–	0.87	0.75
	π	0.005	0.35	0.13	0.98	0.96
g_t	y	0.015	–	–	0.87	0.75
	π	0.005	0.35	0.13	0.98	0.96
a_t	y	0.015	–	–	0.92	0.85
	π	0.0009	0.06	0.01	0.94	0.88
Model 2 (η_t)						
($\alpha = 0.2$)	y	0.015	–	–	0.89	0.80
	π	0.004	0.27	0.84	0.98	0.95

** The sample period is 1959:1 - 2003:4. Output is H-P detrended real GDP, inflation is percentage chang in GDP deflator.

Table 2 reports the lead-lag relationship between output and inflation. The lead-lag relationship between inflation and output has been emphasized by Gali and Gertler (1999) as a key stylized fact for the US economy which any monetary business cycle models must explain. The top row in Table 2 shows that the US inflation rate is positively correlated with past output but negatively correlated with future output, and inflation lags output about four quarters. The middle panel in Table 2 shows that under real demand shocks the predicted inflation in the model is also positively correlated with past output and negatively correlated with future output; and the predicted inflation also lags output by about four quarters. The model matches the data almost exactly for the correlations of inflation with future output.[10] On the other hand, under technology shocks the model fails to mimic the cross correlation pattern of inflation and output found in the US data. In particular, under technology shocks the predicted inflation leads output instead of lagging output.

[10] Note again that preference shocks and government shocks have exactly the same effects.

Table 2. Correlations of Inflation (π_t) with Output ($y_{t\pm j}$)

	y_{t-4}	y_{t-3}	y_{t-2}	y_{t-1}	y_t	y_{t+1}	y_{t+2}	y_{t+3}	y_{t+4}
US Data**									
	0.29	0.27	0.23	0.17	0.09	0.03	-0.06	-0.13	-0.20
Model									
η_t	0.18	0.17	0.16	0.14	0.13	0.03	-0.06	-0.14	-0.20
g_t	0.18	0.17	0.16	0.14	0.13	0.02	-0.06	-0.14	-0.20
a_t	-0.40	-0.32	-0.22	-0.11	0.01	0.01	0.00	-0.01	-0.01
Model 2 (η_t)									
($\alpha = 0.2$)	0.79	0.81	0.82	0.83	0.84	0.75	0.66	0.59	0.53

** The sample period is 1959:1 - 2003:4. Output is H-P detrended real GDP, inflation is percentage chang in GDP deflator.

The reason for the model's success in replicating the lead-lag pattern of US inflation and output is clearly attributable to the fact that the model is able to generate highly persistent and hump-shaped inflation under real demand shocks. The intuition for inflation being hump-shaped under real demand shocks is as follows. Arbitrage between real assets (capital) and nominal assets (bond) implies that the real interest rate (gross marginal product of capital, $r_{t+1} \equiv 1 - \delta + \partial y_{t+1}/\partial k_{t+1}$) is related to the nominal rate and the expected inflation by

$$E_t \hat{r}_{t+1} = \hat{R}_t - E_t \hat{\pi}_{t+1}.$$

Under the Taylor rule (for simplicity, assume there is no monetary policy shock, $\hat{\imath}_t = 0$), this arbitrage condition becomes

$$\hat{\pi}_t = \frac{1}{\delta_\pi} E_t \hat{\pi}_{t+1} + \frac{1}{\delta_\pi} E_t \hat{r}_{t+1}. \tag{13}$$

Thus, the current inflation is linked to expected future inflation and the real interest rate. Hence the dynamics of inflation should mimic the dynamics of the real interest rate in the model. Figure 2 shows that the real interest rate in the model is hump-shaped under real demand shocks but monotone-shaped under technology shocks. This explains why inflation is hump-shaped only when the shocks are from real demand in the model.[11]

[11] By adjusting the parameter values of the model, the hump in the real interest rate and inflation rate can also be adjusted either forward or backward, or the hump can even disappear. Thus the model is flexible enough to explain other possible types of inflation-output relationships that exhibit either larger lag, smaller lag, or no lag at all. For example, across countries, some countries may exhibit stronger contemporaneous output-inflation correlations but weaker leads in output, and some others exhibit weaker contemporaneous correlations but stronger leads in output. The most crucial parameters in the model that control the hump-shaped real interest rate and inflation rate include the capital elasticity of output (α) and the inverse labor supply elasticity parameter (γ). For example, as α or γ

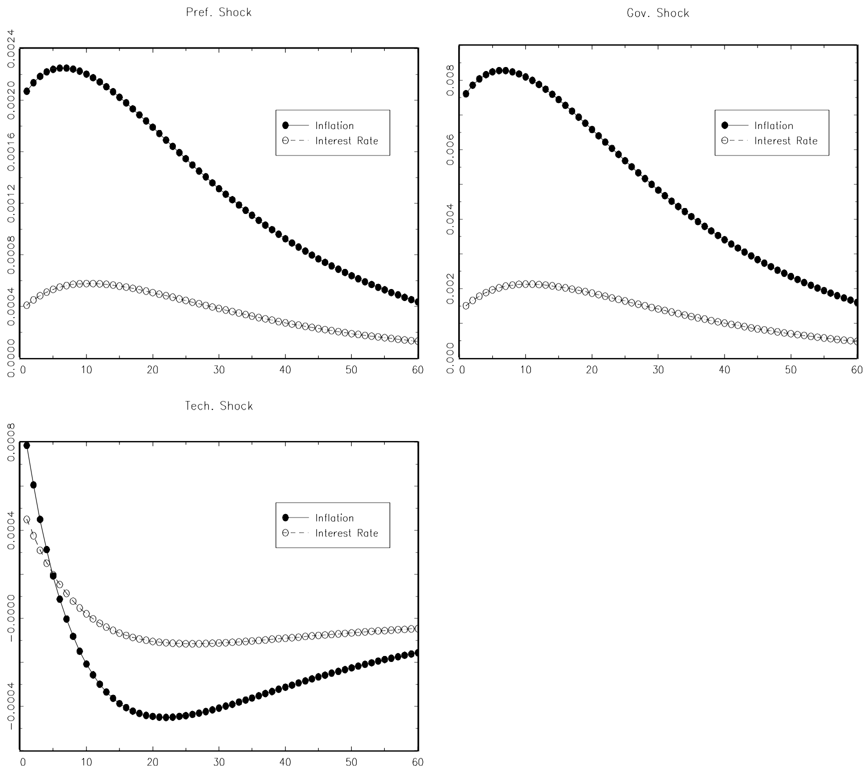

Figure 2. Impulse Responses of Inflation and Real Interest Rate.

Interestingly, there are strong empirical evidence supporting equation (13). Figure 3 shows that the US real interest rate and inflation rate are highly correlated and they synchronize strongly with each other at the business cycle frequency (8-40 quarters by band-pass filter). Given this strong relationship between inflation and the real interest rate in the data as well as in the model, it is not surprising that the model can match the data very well for the output-inflation relationship if the major source of business cycle shocks is from real demand.[12]

increases the hump becomes larger, making inflation lag output more; conversely as α or γ decreases the hump becomes smaller, making inflation to be more strongly correlated with output contemporaneously.

[12] The real interest rate is computed as nominal rate minus current inflation rate. The result does not change significantly if we use one-period ahead forecast of future inflation rate instead. Hence, we conjecture that similar econometric analysis to that used by Gali and Gertler (1999) will fare equation (13) well by empirical data.

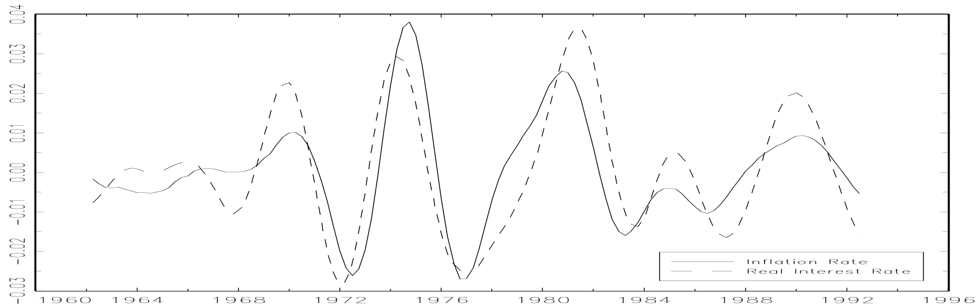

Figure 3. U.S. Inflation and Real Interest Rate at Business Cycle Frequency.

Introducing stick price into the current model has little effect on the dynamics of either output or inflation respect to their responses to real shocks. For example, Figure 4 shows that the volatilities of output, inflation and the real interest rate, as well as their cross correlations remain virtually unchanged under all three types of real shocks when price is sticky.[13] The only significant effect of sticky price is that money shocks can now move output. However, the persistence of output mimics the persistence of money shocks under sticky price, indicating that sticky price does not enhance the internal propagation mechanisms of the model. Our results thus reinforce the analysis of Chari, Kehoe, and McGrattan (2000) in that sticky price does not enhance RBC model's propagation mechanism under either real shocks or nominal shocks.[14]

[13]In the sticky price model the price-stickiness parameter is standard ($\theta = 0.75$), implying that only θ fraction of the firms can adjust their prices each period and that aggregate price is kept sticky for one year. Since government spending shocks and preference shocks have similar effects on output and inflation, only the impulse responses to preference shocks are plotted.

[14]Chari et al. (2000) only show that sticky price has no effect on the propagation mechanism of an RBC model under nominal shocks. Here we show that this is also true for real shocks.

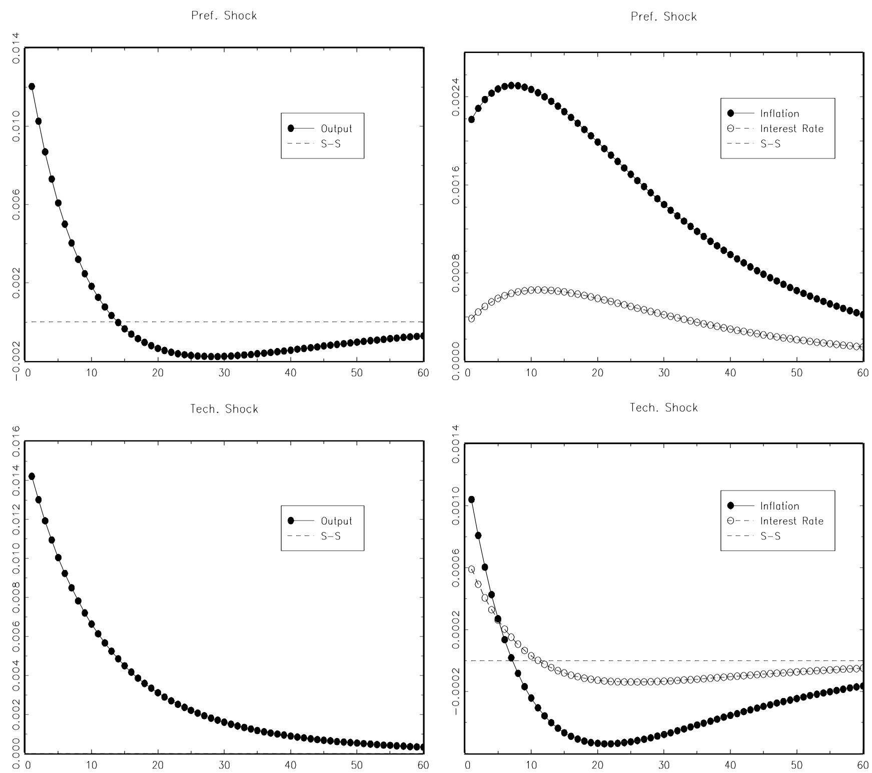

Figure 4. Impulse Responses under Sticky Price.

Some of the results reported here appear to contradict part of Ireland's (2000) empirical findings. According to Ireland (2003), with respect to output-inflation correlations, the sticky price model does much better than the flexible price model. This is not true here in our analysis. This inconsistence is the consequence of the fact that Ireland (2003) has in his model a very low capital elasticity of output in the production function (i.e., $\alpha = 0.2$). When we set $\alpha = 0.2$ in our model, we also obtain result similar to that of Ireland; namely, the performance of the flexible price model deteriorates substantially with respect to output-inflation correlations. This is reported in the lower panels in Table 1 and Table 2 under the title "Model 2", where only preference shocks (η) are considered to illustrate the point. It is seen there that the correct lead-lag relationship between output and inflation disappears when α is too small.

4 Resolving the Counter-Cyclical Price Puzzle

According to traditional sticky-price Keynesian theory (e.g., the IS-LM model), aggregate price level is expected to be procyclical when aggregate fluctuations are driven primarily by aggregate demand. However, the observed aggregate price level is strongly counter-cyclical (see e.g., Kydland and Prescott, 1990). This counter-cyclical price puzzle is related to the price reversal puzzle documented by Sims (1992). Sims (1992) shows that in a typical VAR analysis for aggregate data, price level is counter cyclical under interest rate shocks. Following an increase in the interest rate (representing a monetary contraction) there is a substantial decline in output but a prolonged increase in the price level. Sims (1992) argues that this puzzling phenomenon is inconsistent with traditional IS-LM models.

Kydland and Prescott (1990) argue that counter-cyclical price movement is consistent with flexible price RBC models driven by technology shocks. Although technology shocks can generate counter-cyclical price movements in a standard RBC model with money in the utility or under the cash-in-advance constraint, they also generate counter-cyclical inflation dynamics, contrary to what is observed in the data. When endogenous monetary policy is taken into consideration, technology shocks then imply procyclical price movements, which is also inconsistent with the data.

Here we show that if the main source of aggregate fluctuations originates from aggregate demand, then the observed counter-cyclical price movement is fully consistent with the prediction of a flexible price RBC model with endogenous monetary policy. The intuition is that under real demand shocks, inflation is procyclical but it lags output, as discussed previously. Hence when output enters the phase of a recession, inflation still remains positive, implying that the price level is counter cyclical. This is shown in Figure 5, where the impulse responses of price level and output to a preference shock are depicted. Government spending shocks also yield exactly the same predictions for output and price level.[15]

[15] Based on the analysis, we suspect that the interest rate shocks identified by Sims (1992) may largely reflect aggregate demand shocks, rather than monetary shocks. An interesting follow up work would be to replace the nominal interest rate by consumption or government spending in the VARs used by Sims (1992).

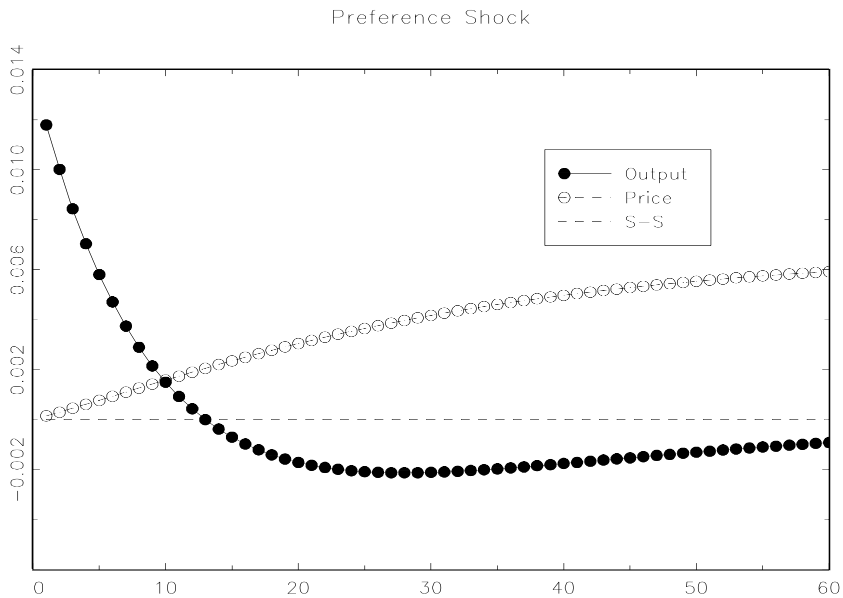

Figure 5. Impulse Responses of Price and Output.

Since the existing literature often documents the counter-cyclical price movements in the data by applying either the H-P filter or the band-pass filter, we also report in Table 3 the second moments of the US data and the model under both filters. The statistics of the model are based on 500 simulations, each simulation generates output and price series with sample length of 140 observations (roughly the length of the data). Since for each round of the simulation, a full set of moments can be computed, Table 3 reports the means of these moments based the 500 simulations. Since government spending shocks have the same effects as preference shocks on output and price level, we report only the statistics based on preference shocks. The top panel in Table 3 shows that in the US the volatility of price relative to GDP is around 0.6 regardless of the filter used, and the price level is negatively correlated with output contemporaneously under both filters. This negative correlation between price and output is intensified as we move towards future output (the right side of the table) but it lightens and even becomes positive as we move towards the past (the left side of the table), indicating that price level substantially lags GDP in the US such that it appears to be counter cyclical. The bottom panel in Table 3 shows that the flexible price model predicts price volatility relative to output to be around $0.5 \sim 0.7$, which is consistent with the data. Also, the model is able to predict the same pattern of price-output correlations under both filters. This is not surprising given that the model is able to predict the inflation dynamics well.

What is surprising is the fact that real demand shocks can generate counter-cyclical price movement with respect to output when monetary policy is endogenous. Allowing for sticky price in the model does not change these predictions. This is in sharp contrast to the predictions of traditional IS-LM model where monetary policy is exogenous.

Table 3. Correlations of Price (p_t) with Output ($y_{t\pm j}$) under Demand Shocks

	σ_p/σ_y	y_{t-4}	y_{t-3}	y_{t-2}	y_{t-1}	y_t	y_{t+1}	y_{t+2}	y_{t+3}	y_{t+4}
US Data										
H-P	0.57	0.10	0.05	-0.02	-0.14	-0.28	-0.39	-0.49	-0.54	-0.53
B-P	0.60	0.04	-0.07	-0.19	-0.30	-0.40	-0.50	-0.54	-0.53	-0.46
Model**										
H-P	0.54	0.19	0.11	-0.00	-0.15	-0.33	-0.54	-0.64	-0.65	-0.61
	(0.01)	(0.11)	(0.11)	(0.10)	(0.09)	(0.08)	(0.06)	(0.06)	(0.08)	(0.09)
B-P	0.67	0.24	0.14	-0.00	-0.18	-0.37	-0.54	-0.66	-0.71	-0.69
	(0.02)	(0.14)	(0.13)	(0.12)	(0.09)	(0.08)	(0.07)	(0.08)	(0.09)	(0.09)

** The statistics of the model are the means of moments based on 500 simulations (sample length = 140). Numbers in parentheses are standard errors.

5 Identifying Real Effects of "Monetary" Shocks

Although much empirical work has pointed out repeatedly that monetary shocks, compared to real shocks such as shocks to consumption demand and technology, are not quantitatively important in explaining output fluctuations (see e.g., Cochrane, 1994, Leeper et al., 1996, and Ireland, 2003), qualitatively speaking there do appear to exist evidence that money has real, despite small, effects on output in a way suggested by the standard Keynesian sticky price theory. Therefore, an extensive literature has been developed to identify and document such effects and to explain why such effects exist (see e.g., Sims, 1971, 1980, 1992; Christiano et al., 1995, 2003). In this section we offer a new interpretation to the literature's empirical findings about the effects of monetary shocks.

In a typical VAR analysis, the number of variables included is very limited, often less than five. But in the real world, the number of different shocks is likely to far exceeds the number of variables included in a typical VAR. Hence each identified shock in a VAR is likely to be a combination of many other shocks. If this is the case, then the so called "monetary shocks" identified using a finite variable VAR is likely to reflect a group of non-monetary shocks that may or may not act like monetary shocks. Hence, even if monetary shocks have no real effects, this identification problem associated with VAR analysis could attribute effects of other shocks to monetary shocks.

In what follows, we conduct a Monte Carlo analysis to illustrate this possibility. In the analysis we generate finite samples of artificial data from the flexible price RBC model and then apply standard econometric tools to the samples to see if we are able to identify any real effects of monetary shocks (in the model money has no real effects). We find that real effects of monetary shocks do appear to exist in our artificial samples, although they are not significant.

To make our point in a simplest way possible, we introduce three shocks in our model but we use only two-variable VARs to identify the shocks. The procedure of our analysis is as follows. We let the flexible price model be subject to three types of shocks: a permanent technology shock, a transitory AR(1) demand shock (to preference), and a transitory AR(1) money shock to the Taylor rule. Due to the existence of the third shock, monetary policy is not completely endogenous although it is completely neutral in the model. The parameters of the shock processes are set as follows: $\rho_a = 1.0$, $\rho_\eta = 0.9$, $\rho_i = 0.6$, $\sigma_a = 0.02$, $\sigma_\eta = 1$, $\sigma_i = 0.5$. Since we are simply trying to provide an example to illustrate our point, we do not calibrate these parameter values according to independent empirical studies. We choose the sample length of each simulation under independent draws of the three othorgonal shocks to be 140 quarters (roughly the US data length), and we repeat our simulation for 500 times. For each round of the simulation, we collect the samples for output, nominal interest rate, and inflation rate and we estimate a 2-variable VAR for each sample as follows.[16]

First, we estimate a 2-variable VAR for output and nominal interest rate with output ordered the first in the VAR, and then use the lower-triangular Choleski decomposition to identify the shock which has no contemporaneous effect on output as a monetary shock (see e.g., Christiano et al., 1995). We then compute the impulse response functions of output and interest rate to this monetary shock. We repeat this estimation procedure for all the 500 samples and we obtain 500 estimated impulse response functions for output and interest rate respectively. Figure 6 graphs the mean of the 500 estimated impulse response functions and the ± 0.2 standard error bands for output and interest rate.[17] It shows that although the effect of money shocks is small and insignificant, but the sign of the responses of output to a decrease in the nominal interest rate (representing a injection of money supply) is positive and hump-shaped. This is very similar to the liquidity effect the literature often finds in the US data (e.g., Christiano et al. 1995).

[16]3 lags are included in all the VARs.

[17]Since the standard error is very large as expected, we multiply the one standard deviation by 0.1. The monetary effect is not significant based on the two standard error bands.

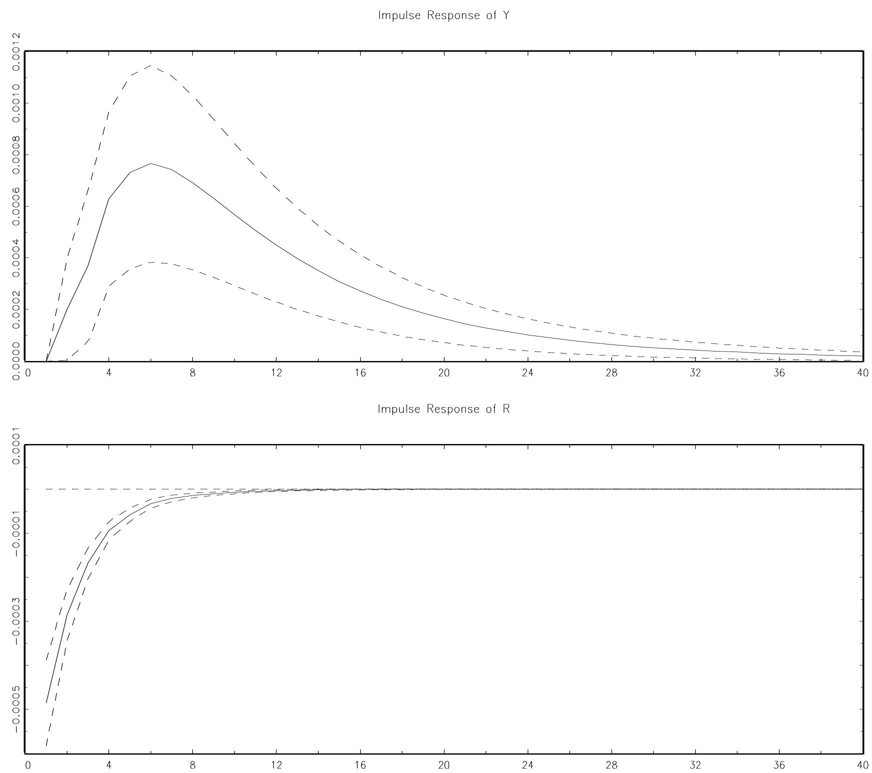

Figure 6. Impulse Responses to Interest Rate Shocks.

Second, we estimate a 2-variable VAR for output growth and inflation rate, and then apply a long-run restriction (Blanchard and Quah, 1989) to identify the effects of monetary police shocks. Following the existing literature (e.g., Yun, 1996; Ellison and Scott, 2000), the shock which has no long run effect on output but may have long-run effect on the price level is identified as monetary shock, and the shock which has long-run effect on output is identified as supply shock. The impulse response function of output and inflation to money shock is estimated by the Blanchard-Quah method for each sample generated, and this process is repeated for 500 times. Figure 7 graphs the mean and the ± 0.5 standard error bands of the estimated impulse response functions for output and inflation rate based on the 500 samples generated. It shows that the responses of both output and inflation to the monetary shock are positive, indicating that money has positive real effects on output. This is also consistent with what the literature finds in the US data.

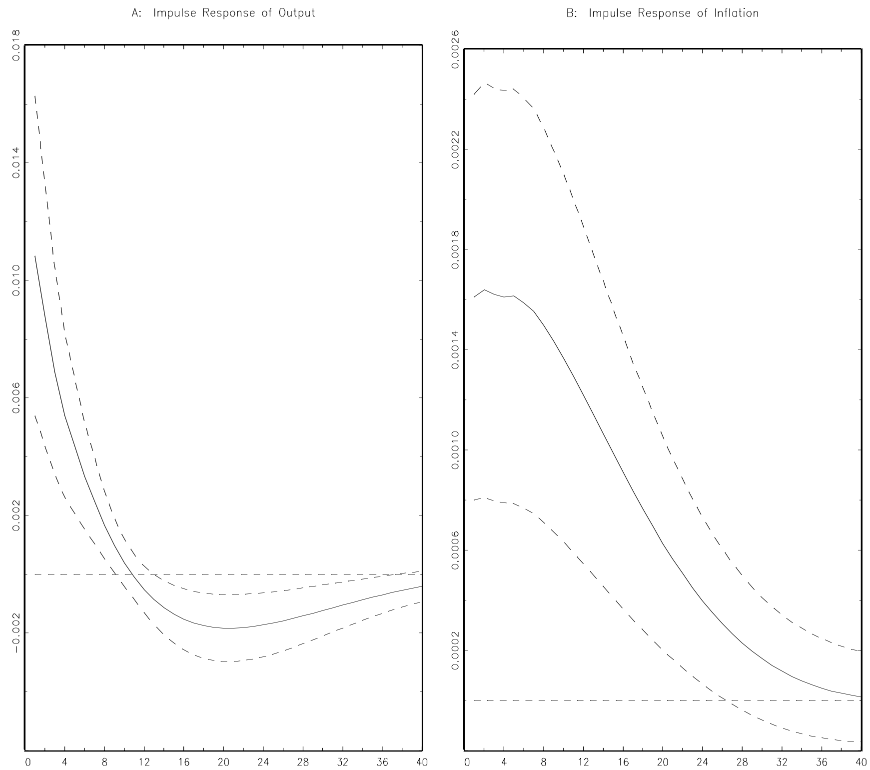

Figure 7. Impulse Responses to Inflation Shocks.

Since the samples are generated from a model in which money has no real effects, the apparent positive effects of money reported in figure 6 and figure 7 are clearly due to sampling and identification errors. What is interesting, however, is that the estimated signs of monetary effects on output are all consistent with the implication of the sticky price model. The reason, we think, is that the identified monetary shocks based on small samples are influenced by real demand and supply shocks, because neither the Choleski restriction nor the Blanchard-Quah restriction can effectively distinguish real shocks from monetary shocks. In the flexible price model a positive preference shock raises output and inflation, while a positive technology shock raises output and lowers nominal interest rate (because inflation rate decreases more than the real interest rate rises). These effects can not be unambiguously distinguished from monetary shocks in a finite VAR system when the sample size is small. Although our analysis on this issue is not conclusive, but we think the results are sufficiently interesting and suggestive to warrant further research and scrutiny on this issue.

6 Inspecting the Propagation Mechanism of Monetary Shocks

It is now a well known fact in the literature that nominal rigidity does not help enhance RBC model's internal propagation mechanism (see e.g., Ball and Romer, 1992; and Chari et al., 2000). But why this is the case is less clear in the literature. Since the structure of standard RBC models is much simpler than that of standard sticky price models, this section tempts to shed light on this issue by first revealing the necessary conditions needed to enrich the weak propagation mechanism of a standard RBC model, and then showing that sticky price does not meet the requirement of these necessary conditions.

In a standard RBC model, the impact of shocks on output is propagated through capital assimilation, because capital is the only endogenous state variable linking the current state to the future state. Schematically, the propagation mechanism is given by

$$shock \rightarrow Y_t \rightarrow I_t \rightarrow K_{t+1} \rightarrow Y_{t+1} \rightarrow ....$$

How long can the effect of the initial shock be propagated is measured by how much it can affect the future output, Y_{t+1}. This, however, depends crucially on how much effect it has on the current investment and hence the next period capital stock, K_{t+1}, assuming a fixed labor for a moment. When the rate of depreciation is small, then even if all the initial increase in output goes to investment, the percentage change of capital stock in the next period is going to be minimal, since capital is a stock variable and investment a flow variable. A big change in a flow variable can hardly bring about an equally big change in the stock of the variable. To see this quantitatively, log-linearize the law of motion for capital,

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

around a steady state, we have a relation linking the percentage change in capital to percentage change in investment:

$$\%K_{t+1} = (1 - \delta)\%K_t + \delta\%I_t.$$

Hence, a one percent increase in investment can lead only to at most δ percent increase in the capital stock. The rate of depreciation of capital is about 10 percent a year or $\delta = 0.025$ in a quarterly model, hence for each one percent initial increase in output can bring about at most 0.025 percent increase in the capital stock, which can increase output at most by 0.025 percent in the next period, assuming a linear production function.

Hence in the absence of other production factors, no shocks can be effectively transmitted to the next period in a standard RBC model. However, even if there are other production factors, such as labor and capital utilization, the situation remains basically the same. These other production factors can amplify the effect of the shocks in the impact period through income or substitution effects. But in the subsequent periods, since the capital stock has changed little, the optimal capital-labor ratio and other factor ratios will return back to the steady state. Hence they are not able to contribute much to output in the subsequent periods. Thus, in order to generate persistent movements in output, the shocks themselves must be highly persistent.

Clearly, in order to enrich the propagation mechanism of the model, we need to introduce new state variables that are serially dependent. But unlike capital stock, these variables must be flow variables, such that any change in the current values of these variables can continue to bring large changes in the future values of these variables. Furthermore, these new state variables must also be able to directly influence the other factors of production (i.e., labor or capital utilization) so as to impact on output. A good example is the dynamic employment adjustment cost model studied by Wen (1995). In Wen's model, lagged employment is a state variable and also a flow variable. In addition, employment enters directly into the production function. Hence any persistence in employment due to adjustment costs can cause persistent movements in output.

Although the price level is not a stock variable and it can become a state variable in sticky price models, it is however not closely linked to factors of production. In spite of sticky price, the optimal factor ratios in standard sticky price models (e.g., Yun, 1996) are still determined by their marginal products. This implies that sticky price per se does not affect the relative factor demand ratios. To see this, recall that the factor demand of labor and capital for a monopolistic firm (i) in a typical sticky price model are given by

$$w = mc\frac{\partial y(i)}{\partial n(i)},$$

$$r = mc\frac{\partial y(i)}{\partial k(i)};$$

where $\{w, r, mc\}$ denote the real wage, real interest rate and real marginal cost respectively. Firm's price setting behavior changes the dynamic behavior of the marginal cost by rendering the real marginal cost a function of other variables in the model, instead of being a constant as in a flexible price model. However, the ratio of marginal products,

$$\frac{\partial y(i)/\partial n(i)}{\partial y(i)/\partial k(i)} = \frac{w}{r},$$

is independent of the marginal cost function (mc). Since market clearing in the labor market and goods market equates the factor price ratio, $\frac{w}{r}$, to terms pertaining to marginal utilities, sticky price thus has no effect on the optimal factor ratios. If sticky price cannot cause stickiness in factor demand, then labor will return quickly to it steady state value after an initial shock if the capital stock changes little in the subsequent period. Hence, unless the shocks are highly persistent, the initial impact of a shock on output dies out quickly in the second period, regardless of price being sticky or not.

The above analysis reveals that sticky price alone cannot change the basic propagation mechanism of a DSGE model under either real shocks or monetary shocks. Sticky price can cause output to move at the impact period under a money shock, but the propagation of the shock still relies only on the channel of capital accumulation, not on price stickiness.

7 Conclusion

In this paper we try to provide a theoretical analysis on the issue of monetary non-neutrality in light of the recent empirical finding of Ireland (2003) that flexible price models are not necessarily inferior to sticky price models in matching the data. We show that real demand shocks combined with endogenous monetary policy is the key in explaining Ireland's finding, since endogenous policy can also give rise to the new Phillips curve that links the current inflation to expected future inflation and some measure of real activity. As a consequence of endogenous monetary policy, a standard flexible price DSGE model in which money is a veil has the potential to fully explain the short-run inflation dynamics without relying on sticky price. Since the structure of RBC models is simpler than that of sticky price models, we are able to reveal the precise mechanisms through which real shocks affect inflation and output and explain why sticky price is not effective in enhancing RBC models' propagation mechanisms. We also conduct Monte Carlo analysis to show that the so called monetary non-neutrality identified in the empirical literature could be due to estimation and identification errors based on finite samples and finite variable VARs. An implication of our analysis is that endogenous monetary policy could be far more important than monetary shocks in shaping the dynamic behavior of key macroeconomic variables in actual economies. This point has also been emphasized by previous authors, such as King and Plosser (1984), Sims (1992), Leeper et al. (1996), and McCallum (2001), among many others.

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