Structure from Shocks

Michael Dotsey

Arguments favoring Keynesian models that incorporate sticky prices over real business cycle models are often made on the grounds that the correlations and impulse response patterns found in the latter are inconsistent with the data. Critics further assert that these correlations and patterns are consistent with models that include price stickiness. Gali (1999) constitutes a prominent example of this reasoning. He observes empirically that conditional on a technology shock the contemporaneous correlation between labor effort and labor productivity is negative. He then makes the case that this observation implies that prices are sticky. Basu, Fernald, and Kimball (1998), using different identifying assumptions, also find this correlation in the data and make a similar assertion. Mankiw (1989) provides still another example of this type of reasoning. He argues that RBC models imply, counterfactually, that inflation and real activity are negatively correlated and so are inconsistent with the existence of a Phillips curve, which would not be the case in sticky price models.

But statements like those of Gali, Basu, Fernald, and Kimball, and Mankiw assume a certain characterization of monetary policy. This assumption is best demonstrated by Gali (1999), who uses intuition based on a money supply rule to persuade us that sticky prices are needed to generate a fall in employment in the presence of positive technology shocks. The fall in employment together with an increase in output produces the negative correlation between employment and labor productivity. However, under a monetary policy that employs the interest rate rule estimated in Clarida, Gali, and Gertler (1998), positive technology shocks produce an increase in both employment and labor productivity. Given the correct estimation of the rule, one must question the conclusion drawn by Gali (1999) and the assertions of Basu and Kimball

Vice President and Senior Economic Policy Advisor, Research Department, Federal Reserve Bank of Philadelphia. I wish to thank Margarida Duarte, Marvin Goodfriend, Andreas Hornstein, Tom Humphrey, Robert King, Pierre Sarte, and John Walter for a number of useful suggestions. I have also greatly benefitted from many helpful discussions with Alex Wolman. The views expressed herein are the author's and do not represent the views of the Federal Reserve Bank of Richmond or the Federal Reserve System.

(1998).[1] Furthermore, work by Christiano and Todd (1996) is able to generate within the confines of the RBC paradigm the labor-productivity correlation estimated by Gali. Thus, it is clear that discriminating among classes of models based on a few correlations is a perilous enterprise, especially when those correlations are sensitive to the nature of monetary policy.

Within the confines of a model similar to that used by Gali (1999), I show the importance of the specification of monetary policy for the dynamic behavior of the economy. The model includes the more realistic specification of staggered price-setting rather than one-period price rigidity and includes capital accumulation. In all other respects the model is true to Gali's original specification. One can see the effects of the systematic portion of policy by examining how the model economy reacts to a technology shock under different specifications of a monetary policy rule. As in Dotsey (1999a), the experiments show that, in the presence of significant linkages between real and nominal variables, the way shocks propagate through an economy is intimately linked to the systematic behavior of the monetary authority. Thus, even correlations among real variables may be influenced by policy. In particular, the justification put forth by both Gali and Basu and Kimball for favoring a sticky-price model over an RBC model no longer applies.

Also, the correlations between real and nominal variables are sensitive to the specification of the central bank's feedback rule. Depending on the form of the monetary policy rule, the model is capable of producing either positive or negative correlations between output and inflation irrespective of whether prices are sticky or flexible. Therefore, Mankiw's reasoning for favoring a sticky-price model over a flexible-price model is not persuasive.[2] These latter results are reminiscent of the arguments made by King and Plosser (1984) concerning the correlations between money balances and output. Their article shows that the positive correlation between money and output need not reflect a causal role for money in the behavior of output.

This is not to say that the methodology advocated by Gali or the idea that some form of price stickiness characterizes the economic environment is invalid. Understanding the nature of the price-setting process is of paramount importance for conducting appropriate monetary policy, and comparing model impulse response functions with those found in the data is a potentially valuable tool in helping to discriminate between flexible and sticky price models. Gali's emphasis on conditional correlations is a useful refinement of

[1] One may also question whether labor effort does in fact decline following a technology shock. For a more detailed investigation concerning the robustness of results in the face of varying identifying assumptions, see Sarte (1997). In this article I choose to take as given the correctness of the empirical results cited by Gali and others.

[2] Similar findings occur with respect to an autonomous shift in aggregate demand. That is, the monetary policy rule is as important in determining the effects of the demand shock as is the underlying model structure. In particular, for the types of rules considered in this article one cannot discriminate between a flexible and sticky price model based on the correlations typically emphasized. For more detail see Dotsey (1999b).

this methodology. However, his conclusions—that the particular impulse response functions and correlations emphasized are helpful in understanding price-setting behavior—are not robust to the specification of monetary policy.

Section 1 sketches the underlying model common to the analysis. A key feature of the model is the presence of price stickiness. Section 2 describes the various monetary policy rules under investigation. One is a simple money growth rule and the others fall into the general category of Taylor-type rules, in which the nominal interest rate responds to inflation and output. Section 3 analyzes the response of the model economy to a technology shock. The responses are quite different and depend on the rule employed by the monetary authority. Section 4 concludes.

1. THE MODEL

For the purpose of this investigation, I use a framework that embeds sticky prices into a dynamic stochastic model of the economy. The underlying model is similar to that of Gali (1999), but it is somewhat less stylized. There are two main differences in the model here, but these do not qualitatively affect the results. The first is that price rigidity is introduced through staggered contracts, and the second is that capital is included. Under flexible prices the underlying economy behaves as a classic real business cycle model. The model is, therefore, of the new neoclassical synthesis variety and displays features that are common to much of the current literature using sticky price models.[3] Agents have preferences over consumption, work effort, and leisure, and they own and rent productive factors to firms. For convenience, money is introduced via a demand function rather than entering directly in utility (as in Gali) or through a shopping time technology. Firms are monopolistically competitive and face a fixed schedule for changing prices. Specifically, one-quarter of the firms change their price each period, and each firm can change its price only once a year. This type of staggered time-dependent pricing behavior, referred to as a Taylor contract, is a common methodology for introducing price stickiness into an otherwise neo-classical model.

Consumers

Consumers maximize the following utility function:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t [\ln(C_t) - \chi_n n_t^{\zeta} - \chi_u U_t^{\eta}],$$

[3] Examples of this literature are Goodfriend and King (1998), Chari, Kehoe, and McGrattan (1998), and Dotsey, King, and Wolman (1999).

where $C = [\int_0^1 c(i)^{(\varepsilon-1)/\varepsilon} di]^{\varepsilon/(\varepsilon-1)}$ is an index of consumption, n is the fraction of time spent in employment, and U is labor effort. This is the preference specification used by Gali (1999), and I use it so that the experiments carried out below are not influenced by an alteration in household behavior.

Consumers also face the intertemporal budget constraint

$$P_t C_t + P_t I_t \leq W_t n_t + V_t U_t + r_t P_t K_t + D_t$$

and the capital accumulation equation

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

where $P = [\int_0^1 p(i)^{1-\varepsilon} di]^{1/(1-\varepsilon)}$ is the price index associated with both the aggregator C and an analogous investment aggregator I, W is the nominal wage for an hour of work, V is the nominal payment for a unit of effort, r is the rental rate on capital, δ is the rate at which capital, K, depreciates, and D is nominal profits remitted by firms to households. The function ϕ is concave and depicts the fact that capital is costly to adjust.[4]

The relevant first order conditions for the consumers' problem are given by

$$(W_t/P_t) = \chi_n \varsigma n_t^{\varsigma-1}, \tag{1a}$$

$$(V_t/P_t) = \chi_u \eta U_t^{\eta-1},$$

and

$$(1/C_t\phi'_t) = \beta E_t(1/C_{t+1}\phi'_{t+1})[r_{t+1}\phi'_{t+1} + (1-\delta) + \phi_{t+1} - \phi'_{t+1}(\frac{I_{t+1}}{K_{t+1}})]. \tag{1c}$$

Equation (1a) indicates that agents supply the number of labor hours that equate their marginal disutility of labor with the real wage. Similarly, equation (1b) indicates that agents exert a level of effort that equates their marginal disutility of effort with the payment on effort. Equation (1c) employs the shorthand notation ϕ_t and ϕ'_t to indicate the function and its first derivative evaluated at time t investment-to-capital ratios. The intertemporal condition is consistent with optimal capital accumulation. Agents invest up to the point where the marginal utility cost of sacrificing one unit of current consumption equals the marginal benefit of additional future consumption. The derivatives of the adjustment cost scale the utility cost because in this case the marginal utility of investment and consumption are not equal. Adjustment costs also affect the value of next period's capital and thus enter the bracketed expression

[4] Capital adjustment costs are included primarily for the purpose of making the impulse response functions smoother. As is typical in models with staggered price-setting, the impulse response functions can be rather choppy as firms cycle through the price adjustment process.

on the right-hand side of (1c). With no adjustment costs, $\phi(I/K) = I/K$ and $\phi' = 1$, (1c) would become the standard intertemporal first order condition.

The demand for money, M, posited rather than derived, is given by

$$\ln(M_t/P_t) = \ln Y_t - \eta_R R_t. \tag{2}$$

The nominal interest rate is denoted R, and η_R is the interest semi-elasticity of money demand. One could derive the money demand curve from a shopping time technology without affecting the results in the article.

Firms

There is a continuum of firms indexed by j that produce goods, $y(j)$, using a Cobb-Douglas technology that combines labor and capital according to

$$y(j) = a_t k(j)^{\alpha} l(j)^{1-\alpha}, \tag{3}$$

where a is a technology shock that is the same for all firms and l is effective labor, which is a function of hours and effort given by $l_t = n_t^{\theta} U_t^{1-\theta}$. Each firm rents capital and hires labor and labor effort in economywide competitive factor markets. The cost-minimizing demands for each factor are given by

$$\psi_t a_t (1-\alpha)\theta (k_t(j)/l_t(j))^{\alpha} (U_t/n_t)^{1-\theta} = W_t/P_t, \tag{4a}$$

$$\psi_t a_t (1-\alpha)(1-\theta)(k_t(j)/l_t(j))^{\alpha} (U_t/n_t)^{-\theta} = V_t/P_t, \tag{4b}$$

and

$$\psi_t a_t \alpha (l_t(j)/k_t(j))^{1-\alpha} = r_t, \tag{4c}$$

where ψ is real marginal cost. Equation (4a) equates the marginal product of labor with the real wage, and (4b) indicates that firms pay for effort until the marginal product on increased effort equals the payment for effort. In equation (4c), cost minimization implies that the marginal product of capital equals the rental rate. The above conditions also imply that capital-labor ratios and employment-effort ratios are equal across firms and that $U/n = ((1-\theta)/\theta)(W/V)$. Using the latter relationship and equations (1a) and (1b) yields the reduced form production function $y(j) = a_t A k(j)^{\alpha} n(j)^{\varphi}$, where $\varphi = \theta(1-\alpha) + (\psi/\eta)(1-\theta)(1-\alpha)$ and A is a function of the parameters θ, χ_n, χ_u, ψ, and η.

Although firms are competitors in factor markets, they possess some monopoly power over their own product and face downward-sloping demand curves of $y(j) = (p(j)/P)^{-\varepsilon} Y$, where $p(j)$ is the price that firm j charges for its product. This demand curve results when individuals minimize the cost of purchasing the consumption and investment indices represented by C and I. Thus $Y = C + I$. Firms are allowed to adjust their price once every four periods, and they may choose a price that will maximize the expected value of the discounted stream of profits over that period. Specifically, a firm that sets its price in period t has the objective

$$\max_{p_t(j)} E_t \sum_{\tau=t}^{t+3} (\lambda_\tau/\lambda_t)\omega_\tau(j),$$

where real profits at time τ, $\omega_\tau(j)$, are given by $[p_t^*(j)y_\tau(j) - \psi_\tau P_\tau y_\tau(j)]/P_\tau$, and λ is the multiplier associated with the consumer's budget constraint.

As a result of this maximization, an adjusting firm's price is given by

$$p_t^*(j) = \frac{\varepsilon}{\varepsilon - 1} \frac{\sum_{h=0}^{3} \beta^h E_t\{(\lambda_{t+h}/\lambda_t)\psi_{t+h}(P_{t+h})^{1+\varepsilon} Y_{t+h}\}}{\sum_{h=0}^{3} \beta^h E_t\{(\lambda_{t+h}/\lambda_t)(P_{t+h})^{\varepsilon} Y_{t+h}\}}. \tag{5}$$

Further, the symmetric nature of the economic environment implies that all adjusting firms will choose the same price. One can see from equation (5) that, in a regime of zero inflation and constant marginal costs, firms would set their relative price $p^*(j)/P$ as a constant markup over marginal cost of $\frac{\varepsilon}{\varepsilon-1}$. In general, a firm's pricing decision depends on future marginal costs, the future aggregate price level, future aggregate demand, and future discount rates. For example, if a firm expects marginal costs to rise in the future, or if it expects higher rates of inflation, it will choose a relatively higher current price for its product.

The aggregate price level for the economy will depend on the prices charged by the various firms. Since all adjusting firms choose the same price, there will be four different prices charged for the various individual goods. The aggregate price level is, therefore, given by

$$P_t = [\sum_{h=0}^{3} (1/4)(p_{t-h}^*)^{1-\varepsilon}]^{(1/(1-\varepsilon))}. \tag{6}$$

Steady State and Calibration

An equilibrium in this economy is a vector of prices p_{t-h}^*, wages, rental rates, and quantities that solves the firm's maximization problem and solves the consumer's optimization problem, such that the goods, capital, and labor markets clear. Furthermore, the pricing decisions of firms must be consistent with both the aggregate pricing relationship (6) and the behavior of the monetary authority described in the next section. In an examination of how the economy behaves when the central bank changes its policy rule, the above description of the private sector will remain invariant across policy rules and experiments.

The steady state is solved for the following parametrization. Labor's share, $1 - \alpha$, is set at 2/3, $\zeta = 9/5$, $\beta = 0.984$, $\varepsilon = 10$, $\delta = 0.025$, $\eta_R = 0$, and agents spend 20 percent of their time working. These parameter values imply a steady state ratio of I/Y of 18 percent, and a value of $\chi = 18.47$. The choice of $\zeta = 9/5$ implies a labor supply elasticity of 1.25, which complies with recent work by Mulligan (1998). A value of $\varepsilon = 10$ implies a steady state markup of 11 percent, which is consistent with the empirical work in Basu and Fernald (1997) and Basu and Kimball (1997). The interest sensitivity of money demand is set at zero. The demand for money is generally acknowledged to be fairly interest insensitive in the short run, with zero being the extreme case. Since the ensuing analysis concentrates on interest rate rules, the value of this parameter is unimportant. The adjustment cost function is parameterized so that the elasticity of the investment capital ratio with respect to Tobin's q is 0.25. This value is consistent with the estimate provided in Jermann (1998). The remaining parameter of importance is φ. Gali claims that a reasonable value for the parameter lies between 1 and 2, implying increasing returns to employment. Since the general nature of the results presented in Section 3 is not sensitive to this parameter, I set it to 1.5. Finally, the economy is buffeted by a random-walk shock to technology.

2. MONETARY POLICY

To study the effects of the systematic part of monetary policy on the transmission of technology shocks to the economy, I shall investigate the model economy's behavior under three types of policy rules. The first is a simple money growth rule, parameterized so that the economy experiences a steady state inflation rate of 2 percent. This inflation rate is held constant across all three rules.

The other two rules employ an interest rate instrument, thus falling into the category broadly labeled Taylor-type rules (Taylor 1993). The first rule allows the monetary authority to respond both to expected deviations of inflation from target and expected deviations of current output from its steady state or potential level. Because shocks are assumed to be contemporaneously observed in this model, the specification allows policy to respond to current movements in output. This rule is parameterized based on the estimations carried out in Clarida, Gali, and Gertler (1998) for the Volcker-Greenspan period.[5] Their estimation also implies that the Fed is concerned with smoothing the behavior of the nominal interest rate; that behavior is incorporated into the following specification,

$$R_t = \overline{r} + \pi^* + 0.7R_{t-1} + 0.59(E_t\pi_{t+1} - \pi^*) + 0.04(Y_t - \overline{Y_t}). \quad (7)$$

The second rule is backward looking and allows the Fed to respond to deviations of inflation from target and of output levels from the steady state level of output. Specifically, I use the parameters in Taylor (1993),

$$R_t = \overline{r} + \pi^* + 1.5(\overline{\pi}_t - \pi^*) + 0.5(Y_t - \overline{Y_t}), \quad (8)$$

[5] This specification is taken from their Table 3b.

where $\overline{\pi}_t$ is the average rate of inflation over the last four quarters, π^* is the inflation target of 2 percent, and $\overline{Y}_t$ is the steady state level of output. Under this rule, when inflation is running above target or output is above trend, monetary policy is tightened and the nominal interest is raised. It is worth noting that because the coefficient on the output gap term is so small in the Clarida, Gali, and Gertler specification (7), there is no perceptible difference between impulse response functions generated in a model that omits this term entirely.

The experiments in the ensuing section show how the model economy's response to a technology shock depends on the specification of the systematic portion of monetary policy. Depending on the monetary rule in place, conditional correlations between output and productivity can vary both in magnitude and sign. In general, one can say nothing about the underlying structure of price setting—sticky or flexible—from these correlations.[6]

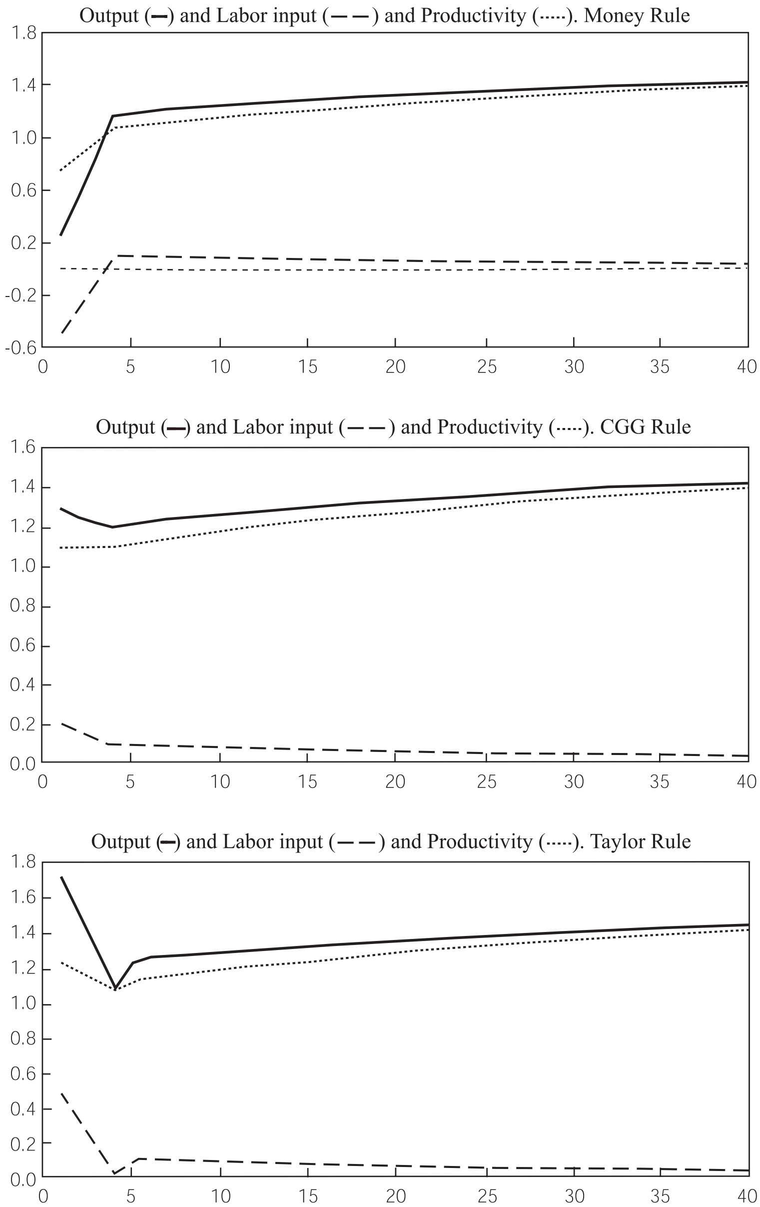
3. A COMPARISON OF THE POLICY RULES

I will next demonstrate how the model economy reacts to a technology shock. The underlying specification of the private sector is invariant in all experiments; only the specification of monetary policy is changed. As is conventional in modern macroeconomics, the model's behavioral equations are linearized and the resulting system of expectational difference equations is solved numerically using the procedures outlined in King and Watson (1998).

The response of the model economy to technology shocks is given in Figures 1 and 2. Figure 1 displays the response of hours, output, and average productivity, while Figure 2 examines the relationship between inflation and output. The differences across policy rules are striking. When money growth is held fixed, employment initially falls in response to a permanent change in productivity. With no deviation in money from steady state, there can be no deviation in nominal output from steady state. Because prices are sticky, they do not decline significantly. Therefore, the increase in output is not as great as the increase in productivity, and it takes less labor to produce the necessary output. This mechanism is stressed by Gali (1999). On the other hand, if the central bank follows the rule estimated by either Clarida, Gali, and Gertler (1997) or by Taylor (1993), monetary policy is very accommodative of the technology shock, so much so that the price level increases and output actually overshoots its new steady state level. The large increase in output requires additional labor, implying that labor productivity and labor hours are positively correlated, as they are in a simple RBC model. Thus, under

[6] As shown in Dotsey (1999b) a similar message applies to demand shocks. The article's concentration on the sensitivity of the economy's responses to shocks under different policies makes it similar to recent papers by McCallum (1999) and Christiano and Gust (1999).

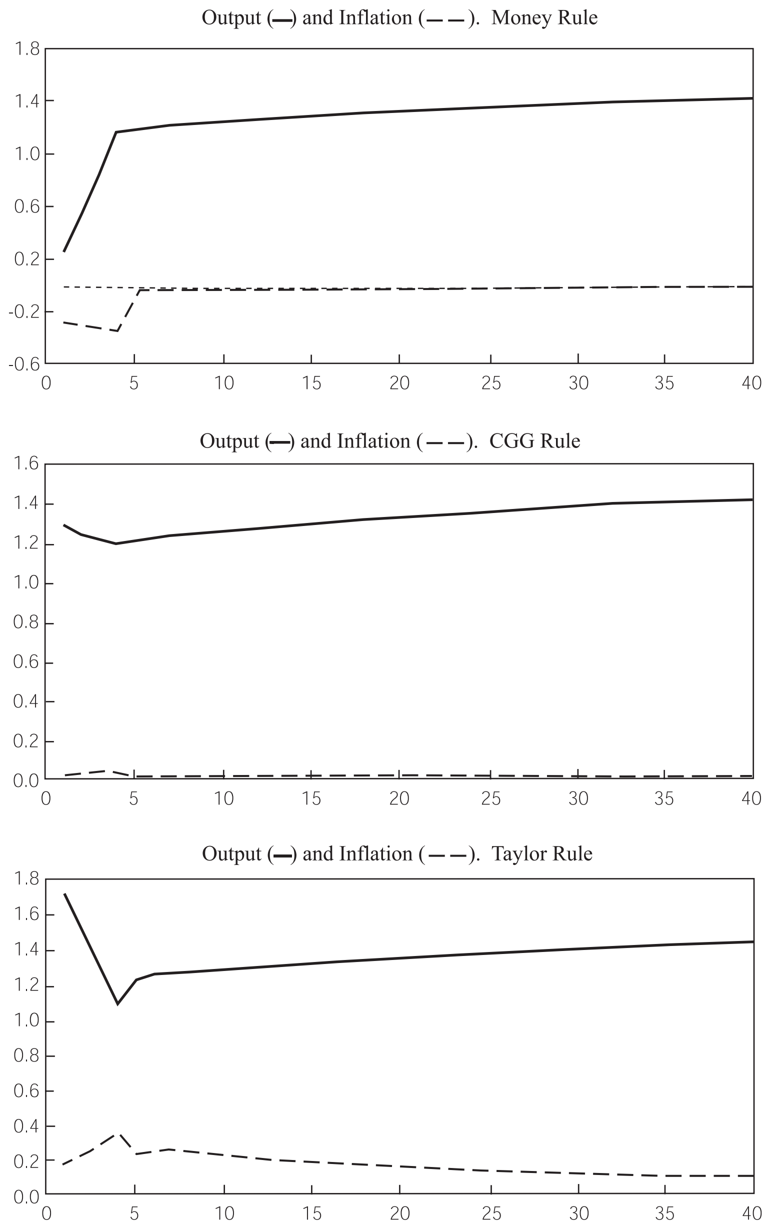
Figure 1



reasonably specified monetary policy rules, one cannot infer the price-setting behavior of firms from the conditional correlation emphasized in Gali.[7]

[7] McGrattan (1999) finds in a model with a CGG interest rate rule and two period overlapping Taylor-type contracts, in which prices are set a period in advance, that labor input declines on

Figure 2



impact in response to a technology shock. Her technology shock is stationary and potential output

To muddy the waters further, Christiano and Todd (1996) are able to generate a negative conditional correlation between employment and labor productivity in an RBC model that is augmented with a time-to-plan investment technology. Thus, one must conclude that this particular correlation is not very informative in identifying the feature of the economy that Gali seeks to uncover.

The impulse responses in Figure 2 show that inflation-output correlations are also sensitive to the specification of monetary policy. In both the Clarida, Gali, and Gertler and Taylor specifications, inflation is positively correlated with output. By contrast, in the constant money growth rule inflation is negatively correlated with output. The same relationships hold in a flexible-price model. Therefore, Mankiw's (1989) appeal to Phillips curve relationships as means to identify pricing behavior is problematic.

4. CONCLUSION

There are a number of points established by the analysis presented in this article. First and foremost is that the systematic component of monetary policy is important in determining the economy's reaction to shocks. In fact, the behavior of the model economy can differ so drastically across policies that forming some intuition about the underlying behavior of the private sector, such as whether prices adjust flexibly or are sticky, cannot be divorced from one's assumption about central bank behavior. In the limit, if the central bank were following the optimal policy prescribed in King and Wolman (1999), the bank's policy response to a technology shock would produce real behavior identical to that of the underlying real business cycle model.

Of more relevance to my analysis is the observation that a standard real business cycle model produces a positive correlation between labor productivity and hours, a result that is inconsistent with the data. Yet the same is true for a sticky-price model when the monetary authority follows either the rule estimated by Clarida, Gali, and Gertler (1999) or the rule estimated by Taylor (1993). The apparent inconsistency between model and data is, therefore, a poor reason to favor one type of model over the other, even though under a money stock rule the sticky-price model produces a negative correlation. The fact is, the Fed has probably never followed a money stock rule, so intuition drawn under such a rule may be of little value. In light of the results presented

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does not respond to the shock as it does here when the technology shock is permanent. However, it is the presetting of prices that delivers the response of labor in her model. If prices were not preset, then labor would increase on impact as it does in experiments performed above.

above, discriminating among models based on impulse response functions is a subtle exercise that requires an accurate depiction of monetary policy.

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