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SUPPLY SHOCKS AND OPTIMAL MONETARY POLICY

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ABSTRACT

This paper demonstrates that if current shocks are observed instantaneously, output can be stabilized perfectly for completely general supply disturbances, using simple monetary rules based only on: (i) the current shock, (ii) the previous forecast of the current shock, (iii) the forecast for just one period ahead. The optimal rule can be expressed in an infinite number of ways and various alternatives are considered. With optimal wage indexation, the monetary rule is even simpler. If current shocks are not observed instantaneously, but are inferred from other signals, the optimal rules are of the same form, with the current perceived disturbance replacing the actual.

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1. INTRODUCTION

The sharp increases in the price of oil during 1973-74 focused attention on the question of the appropriate monetary response in the face of supply disturbances. Should monetary policy be accommodative and finance the higher level of prices or should it be contractionary to offset the inflationary effects of such disturbances? These issues have occupied the attention of macroeconomists for over a decade now; see, e.g., Gordon (1975, 1984), Phelps (1978), Blinder (1981), Aizenman and Frenkel (1986), Fischer (1985). With the current fall in oil prices, the topic promises to be relevant for some time, although the direction of the shocks has been reversed.

At this point, there does not seem to be any consensus as to what the appropriate monetary response should be. In his early study, Gordon argued for monetary accommodation in response to an adverse supply shock (higher oil price). On the other hand, Blinder (1981) argues that certain types of disturbances may require a monetary contraction. By contrast, Fischer (1985) argues that as long as there is no real wage resistance by workers, supply shocks by themselves should require no monetary response. However, his results depend upon very specific assumptions regarding the form of the money demand function. Marston and Turnovsky (1985a) show how the macroeconomic effects of supply disturbances depend crucially upon wages policy, while Aizenman and Frenkel (1985) stress how this in turn is important in determining the role of monetary policy.

This paper analyzes the optimal monetary response to supply disturbances, taking up several issues which have thus far not been addressed in the literature. First, while several authors note the distinctions between: (i) permanent and transitory shocks on the one hand, and (ii) unanticipated and anticipated shocks on the other, and recognize that the required response to each type of disturbance will be different, a systematic general treatment of these different disturbances is thus far lacking. Secondly, the policy rules typically considered specify the adjustment of the money stock to *current* disturbances in supply.[1] Yet it is also possible and reasonable for the monetary authorities to respond to *anticipations* of both current and future supply shocks. Indeed, an important result of our analysis is that more general policy rules of this kind turn out to require less information about the nature of the supply disturbances than do 'simpler' rules based only on information about current shocks. They are therefore likely to lead to improved stabilization performance. Thirdly, the existing literature assumes that the monetary authorities observe and respond to the current supply disturbance instantaneously.[2] This may not always be a plausible assumption. We therefore also investigate the case where the stochastic disturbances impinging on the economy are not observed instantaneously, but must be inferred from the movements of other variables, such as the price level and the interest rate, which are likely to be observed with greater frequency. It turns out that the optimal monetary response to a supply shock is virtually identical to that under complete information. The only difference is that the actual disturbance is replaced by the perceived disturbance determined by solving the appropriate signal extraction problem.

The remainder of the paper is structured as follows. Sections 2 and 3 outline the framework and provide the general solution to the model. The next two sections then determine the optimal monetary response under the assumptions of full and imperfect information respectively. The main results are reviewed in the final section.

2. THE FRAMEWORK

Our analysis assumes a closed economy described by the following equations. These are expressed in deviation form about a stationary equilibrium so that all constants are suppressed.

$$Y_t = -d[r_t - (P^*_{t+1,t} - P_t)] + u_t \qquad d > 0 \tag{1a}$$

$$M_t - P_t = \alpha_1 Y_t - \alpha_2 r_t + w_t \qquad \alpha_1 > 0, \alpha_2 > 0 \tag{1b}$$

$$Y_t = \left(\frac{1-\theta}{\theta}\right)(1-\tau)(P_t - P^*_{t,t-1}) + \left(\frac{1-\theta}{\theta}\right)\left[E_t(v_t) - \frac{v^*_{t,t-1}}{1+n\theta}\right] + v_t \tag{1c}$$

$$0 < \theta < 1,\ 0 \leqq \tau < 1,\ n > 0$$

where

Y_t = real output, expressed in logarithms

r_t = nominal interest rate,

P_t = price level, expressed in logarithms

$P^*_{t+1,t}$ = forecast of P_{t+1}, formed at time t,

M_t = nominal money supply, expressed in logarithms,

u_t = stochastic disturbance in the demand for output,

w_t = stochastic disturbance in the demand for money,

v_t = stochastic disturbance in supply of output,

$v^*_{t,t-1}$ = forecast of v_t, formed at time $t-1$,

$E_t(x_t)$ = perception of disturbance x_t, formed at time t, $x = u, v, w$.

The model contains three stochastic disturbances u_t, v_t, and w_t, which in general need not be observed contemporaneously. While our main interest is in the supply shock v_t, the introduction of the two demand disturbances u_t, w_t, is required in order to generate a potential situation of imperfect information. If the only disturbance is v_t, its value can always be inferred precisely from movements in other variables such as the interest rate, which may more reasonably be observed instantaneously.

Equation (1a) is the economy's IS curve, expressed as a negative relationship between output and the real interest rate, while (1b) is the LM curve. Equation (1c) describes the aggregate supply function; being less familiar, it is derived in the Appendix. Basically, it incorporates a one-period Fischer-Gray wage contract model, in which the contract wage adjusts to expected price movements and expected supply shocks.[3] The current wage is then determined by indexation to unanticipated movements in the price level, with the rate of indexation being τ. As is clear from (A.2) in the Appendix, the aggregate supply shock v_t can be interpreted as a shock in productivity, while $(1 - \theta)$ is the exponent on labor in the underlying production function. The remaining parameter n is the elasticity of labor supply with respect to the real wage. Equation (1c) is written on the assumption that the current supply disturbance is not observed instantaneously. In the event that v_t is observed, $E_t(v_t) = v_t$ and (1c) becomes

$$Y_t = \left(\frac{1-\theta}{\theta}\right)(1-\tau)(P_t - P^*_{t,t-1}) + \frac{1}{\theta}\left[v_t - \frac{1-\theta}{1+n\theta}v^*_{t,t-1}\right] \tag{1c'}$$

Finally, expectations are rational so that

$$P^*_{t+s,t} = E_t(P_{t+s}) \quad \text{for all } s$$

Monetary policy is assumed to be specified by a rule of the form

$$M_t = \mu_0 E_t(v_t) + \mu_1 v^*_{t+1,t} + \mu_2 v^*_{t,t-1} + \lambda_1 E_t(u_t) + \lambda_2 E_t(w_t) \tag{1d}$$

That is, on the one hand, the money stock is adjusted to perceptions of the current stochastic disturbances, $E_t(v_t)$, $E_t(u_t)$, $E_t(w_t)$. At the same time, it is adjusted in anticipation of the next period's supply shock, as well as in response to the anticipated supply disturbance for the present period. It can be shown that for the objective function to be introduced below, this rule suffices to achieve minimum welfare costs. If, for example, the rule was augmented to allow the money stock to respond to $v^*_{t+j,t}$, the anticipated supply shock for time $t+j$, it can be shown that the corresponding coefficient μ_j say, in the optimal rule, would be zero; see, e.g., footnote 5 below. As already noted, our main concern is with the coefficients μ_0, μ_1, μ_2, which pertain to supply disturbances.[4] Further, in the case where the stochastic disturbances are observed instantaneously, the rule (1d) is modified to

$$M_t = \mu_0 v_t + \mu_1 v^*_{t+1,t} + \mu_2 v^*_{t,t-1} + \lambda_1 u_t + \lambda_2 w_t \tag{1d'}$$

To conclude the model requires the specification of a stabilization objective. As a benchmark, we consider a frictionless economy in which wages and prices are perfectly flexible so that labor markets clear. It is well known that the supply of output in such an economy is given by

$$Y_t^f = \frac{n(1-\theta)}{1+n\theta}E_t(v_t) + v_t \tag{1e}$$

In the case that firms observe v_t instantaneously, (1e) reduces to

$$Y_t^f = \left(\frac{1+n}{1+n\theta}\right)v_t \tag{1e'}$$

The stabilization objective is then taken to be to minimize the variance of output Y_t about the frictionless level Y_t^f. This criterion can be shown to be equivalent to minimizing the welfare losses arising from labor market distortions due to the existence of wage contracts and the rigidities they impose; see Aizenman and Frenkel (1985).

3. THE SOLUTION

The system outlined above is a standard rational expectations macro model. The solution procedures are familiar, enabling our description to be brief.

For notational convenience let

$$Z_t \equiv \left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d} + \alpha_1\right)v_t + w_t - \frac{\alpha_2}{d}u_t \tag{2}$$

so that

$$Z_{t+j,t}^* = \left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d} + \alpha_1\right)v_{t+j,t}^* + w_{t+j,t}^* - \frac{\alpha_2}{d}u_{t+j,t}^* \tag{2'}$$

and

$$E_t(Z_t) \equiv Z_{t,t}^* = \left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d} + \alpha_1\right)E_t(v_t) + E_t(w_t) - \frac{\alpha_2}{d}E_t(u_t) \tag{2''}$$

Taking conditional expectations of equations (1a) - (1c) at time t, for time $t+j$, and eliminating the conditional expectations variables $Y_{t+j,t}^*$, $r_{t+j,t}^*$ leads to the following difference equation in price expectations

$$\alpha_2 P^*_{t+j+1,t} - (1+\alpha_2)P^*_{t+j,t} = Z^*_{t+j,t} - M^*_{t+j,t} \quad j=1,2,\ldots \tag{3}$$

where

$$M^*_{t+j,t} = (\mu_0+\mu_2)v^*_{t+j,t} + \mu_1 v^*_{t+j+1,t} + \lambda_1 u^*_{t+j,t} + \lambda_2 w^*_{t+j,t} \tag{4}$$

The solution to (3) is

$$P^*_{t+j,t} = \frac{1}{1+\alpha_2}\sum_{k=0}^{\infty}\left[M^*_{t+j+k,t} - Z^*_{t+j+k,t}\right]\left(\frac{\alpha_2}{1+\alpha_2}\right)^k \tag{5}$$

and setting $j = 1$,

$$P^*_{t+1,t} = \frac{1}{1+\alpha_2}\sum_{k=0}^{\infty}\left[M^*_{t+1+k,t} - Z^*_{t+1+k,t}\right]\left(\frac{\alpha_2}{1+\alpha_2}\right)^k \tag{5'}$$

Price expectations therefore reflect the net discounted effects of the expected future money stocks and the various stochastic disturbances impinging on the economy.

Setting $j = 1$ and $t = t-1$ in (3), equations (1a)-(1c), (1e) can be solved for the deviation in output from its frictionless level, $Y_t - Y_t^f$ in the following form

$$\begin{aligned} Y_t - Y_t^f = \frac{d}{D}\left[\frac{1-\theta}{\theta}\right]\Bigg\{&(1-\tau)\left[(M_t - M^*_{t,t-1}) - (E_t(Z_t) - Z^*_{t,t-1})\right] \\ &+ \alpha_2(1-\tau)[P^*_{t+1,t} - P^*_{t+1,t-1}] + \frac{1+\alpha_2}{1+n\theta}[E_t(v_t) - v^*_{t,t-1}] \\ &+(1-\tau)\left[\frac{\alpha_2}{d}[u_t - E_t(u_t)] - (\frac{\alpha_2}{d}+\alpha_1)[v_t - E_t(v_t)] - [w_t - E_t(w_t)]\right]\Bigg\} \end{aligned} \tag{6}$$

where $D \equiv (1-\tau)\left[\frac{1-\theta}{\theta}\right](\alpha_2 + \alpha_1 d) + d(1+\alpha_2) > 0$ and price expectations are given by (5) and (5'). Written in this way, we see that the deviation in output from its frictionless level depends most critically upon revisions to information between time $t-1$ and time t. Most importantly, it depends upon updates to the forecast of the price level for time $t+1$, made between time $t-1$ and time t. It is through these revisions that expected future supply shocks, and the expected future monetary response, impact on the current behavior of the economy. But $(Y_t - Y_t^f)$ also depends upon the differences between the actual and perceived disturbances at time t.

Substituting for $M^*_{t+k+1,t}$, $Z^*_{t+k+1,t}$ into $P^*_{t+1,t}$, $P^*_{t+1,t-1}$, and thence into (6), the solution can be expressed explicitly in terms of the policy parameters and current and expected future shocks as follows where

$$
\begin{aligned}
Y_t - Y_t^f = \frac{d}{D}\left(\frac{1-\theta}{\theta}\right)\Bigg\{ & (1-\tau)(\mu_0 - \phi)[E_t(v_t) - v^*_{t,t-1}] + (1-\tau)\mu_1(v^*_{t+1,t} - v^*_{t+1,t-1}) \\
& + (1-\tau)(\lambda_1 + \frac{\alpha_2}{d})[E_t(u_t) - u^*_{t,t-1}] \\
& + (1-\tau)(\lambda_2 - 1)[E_t(w_t) - w^*_{t,t-1}] + \left(\frac{1+\alpha_2}{1+n\theta}\right)[E_t(v_t) - v^*_{t,t-1}] \\
& + (1-\tau)\Bigg[\sum_{j=1}^{\infty}\Big[(\mu_0 + \mu_2 - \phi)(v^*_{t+j,t} - v^*_{t+j,t-1}) + \mu_1(v^*_{t+j+1,t} - v^*_{t+j+1,t-1}) \\
& + (\lambda_1 + \frac{\alpha_2}{d})(u^*_{t+j,t} - u^*_{t+j,t-1}) + (\lambda_2 - 1)(w^*_{t+j,t} - w^*_{t+j,t-1})\Big]\left(\frac{\alpha_2}{1+\alpha_2}\right)^j\Bigg] \\
& + (1-\tau)\left[\frac{\alpha_2}{d}[u_t - E_t(u_t)] - (\frac{\alpha_2}{d} + \alpha_1)[v_t - E_t(v_t)] - [w_t - E_t(w_t)]\right]\Bigg\}
\end{aligned}
\tag{7}
$$

where

$$
\phi \equiv \left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d} + \alpha_1\right)
$$

Before determining the optimal monetary policy rules, we briefly consider the case of full wage indexation, $\tau = 1$, when (7) reduces to

$$
Y_t - Y_t^f = \frac{d}{D}\left(\frac{1-\theta}{\theta}\right)\left(\frac{1+\alpha_2}{1+n\theta}\right)(E_t(v_t) - v^*_{t,t-1})
$$

The deviation in output about its frictionless level is independent of all monetary policy parameters, so that monetary policy becomes totally ineffective. Or, expressed differently, monetary policy can be effective only if wage indexation is partial, which is the reason for imposing the constraint on τ in (1c). As is well known, with full indexation, demand and monetary shocks have no effect on the output of the economy. More interestingly, the effect on output due to a supply shock depends solely on the revision of the estimate of the shock between $t-1$ and t. Perfectly anticipated supply shocks, therefore, also have no effect on output. Further analysis of the case of full indexation would require investigation of the effects of shocks on the demand for, and supply of, labor. With failure to replicate the frictionless level of output, and therefore with disequilibrium in the labor market, supply of labor constraints may become binding.

4. FULL INFORMATION

We begin with the case where agents have perfect information on current disturbances, so that

$$E_t(v_t) = v_t; \quad E_t(u_t) = u_t; \quad E_t(w_t) = w_t$$

In this case, (7) simplifies to

$$\begin{aligned} Y_t - Y_t^f = \frac{d}{D}\left[\frac{1-\theta}{\theta}\right]\Bigg\{&(1-\tau)(\mu_0-\phi)(v_t - v^*_{t,t-1}) + (1-\tau)\mu_1(v^*_{t+1,t} - v^*_{t+1,t-1}) \\ &+ (1-\tau)(\lambda_1 + \frac{\alpha_2}{d})(u_t - u^*_{t,t-1}) \\ &+ (1-\tau)(\lambda_2 - 1)(w_t - w^*_{t,t-1}) + \left[\frac{1+\alpha_2}{1+n\theta}\right](v_t - v^*_{t,t-1}) \qquad (7') \\ &+ (1-\tau)\Bigg\{\sum_{j=1}^{\infty}\Big[(\mu_0+\mu_2-\phi)(v^*_{t+j,t} - v^*_{t+j,t-1}) + \mu_1(v^*_{t+j+1,t} - v^*_{t+j+1,t-1}) \\ &+ (\lambda_1 + \frac{\alpha_2}{d})(u^*_{t+j,t} - u^*_{t+j,t-1}) + (\lambda_2 - 1)(w^*_{t+j,t} - w^*_{t+j,t-1})\Big]\left[\frac{\alpha_2}{1+\alpha_2}\right]^j\Bigg\}\Bigg\} \end{aligned}$$

The stabilization problem is to choose the policy parameters μ_0, μ_1, μ_2, λ_1, λ_2, to minimize Var $(Y_t - Y_t^f)$. In fact, with full information, Y_t can be stabilized exactly at Y_t^f, thereby replicating the output of the frictionless economy and eliminating the welfare losses due to unemployment. This optimum is achieved by setting[5]

$$\lambda_1 = -\frac{\alpha_2}{d} \tag{8a}$$

$$\lambda_2 = 1 \tag{8b}$$

$$(1 - \tau)(\mu_0 - \phi) + \left[\frac{1 + \alpha_2}{1 + n\theta}\right] = 0 \tag{8c}$$

$$\mu_1 + (\mu_0 + \mu_2 - \phi)\frac{\alpha_2}{1 + \alpha_2} = 0 \tag{8d}$$

First, setting λ_1, λ_2, as in (8a), (8b) ensures that all current and expected future demand disturbances are eliminated entirely. Since these are not of direct concern, we shall not comment on them further. Substituting for μ_0, μ_1, μ_2, we see that the nominal money stock should be adjusted to supply disturbances in accordance with the rule

$$\begin{aligned} M_t = & \left[\left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d} + \alpha_1\right) - \frac{1+\alpha_2}{(1+n\theta)(1-\tau)}\right] v_t \\ & + \left[\frac{\alpha_2}{(1+n\theta)(1-\tau)} - \frac{\alpha_2\mu_2}{1+\alpha_2}\right] v^*_{t+1,t} + \mu_2 v^*_{t,t-1} \end{aligned} \tag{9}$$

where μ_2 is arbitrary. The rule specified in (9) describes the general form of accommodation and a number of cases require discussion.

A. White Noise Disturbances

In the case of white noise disturbances, $v^*_{t+1,t} = v^*_{t,t-1} = 0$ and the optimal rule reduces to

$$M_t = \left[\left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d}+\alpha_1\right) - \frac{1+\alpha_2}{(1+n\theta)(1-\tau)}\right]v_t \tag{10}$$

This calls for monetary contraction or expansion in response to a positive supply (quantity) shock according to whether[6]

$$(1+n)\left(\frac{\alpha_2}{d}+\alpha_1\right) \lessgtr \left(\frac{1+\alpha_2}{1-\tau}\right) \tag{11}$$

On the one hand, the direct effect of a positive supply shock is to raise output in an economy with wages fixed by contracts above that in a frictionless economy, where the rise in real wages resulting from the shock inhibit the rise in output. On the other hand, the positive supply shock tends to lower the price level and this tends to reduce Y_t below Y_t^f. If the former effect dominates, monetary contraction is required to reduce Y_t back to Y_t^f; if the latter effect dominates, monetary expansion is required.

The optimal rule incorporates the tradeoff between monetary policy and wage indexation emphasized by Aizenman and Frenkel (1985) and Turnovsky (1983). For low degrees of indexation ($\tau \cong 0$), either the positive direct effect or the negative price effect of the supply shock may dominate and the optimal policy may call for either monetary contraction or expansion, depending upon which is larger. However, for a sufficiently high degree of indexation, the positive direct effect dominates, causing Y_t to increase above Y_t^f, and requiring a monetary contraction to generate a fall in price necessary to reduce Y_t back to the frictionless level.

Fischer's (1985) analysis, calling for a passive monetary policy, was based on a classical money demand function ($\alpha_1 = 1, \alpha_2 = 0$), with no wage indexation ($\tau = 0$) and with a fixed supply of labor ($n = 0$). For these parameter values, (10) implies the optimality of the passive policy $M = 0$ as well. With a classical money demand function, but with a positively elastic supply of labor, $n > 0$, a passive policy will be optimal if and only if money wages are partially indexed to unexpected price movements to the extent

$$\tau = \frac{n}{1 + n} \tag{12}$$

The reason for this is that with $n > 0$, the direct effect of a positive supply shock is to raise Y_t above Y_t^f, as already noted. The amount of indexation specified in (12) will induce a sufficient rise in the real wage to cut back the rise in output to exactly that in the frictionless economy.

B. General Disturbances

Returning to the optimal rule (9), it is seen that the optimal adjustment of the money stock to supply disturbances can be expressed in an infinite number of ways, depending upon the arbitrary choice of μ_2.

Substituting for the optimal policy parameters into (4), the expected money supply for time $t+j$ is given by

$$M^*_{t+j,t} = Z^*_{t+j,t} + \left[\mu_2 - \frac{1 + \alpha_2}{(1 + n\theta)(1 - \tau)}\right]\left[v^*_{t+j,t} - \left(\frac{\alpha_2}{1 + \alpha_2}\right)v^*_{t+j+1,t}\right] \tag{13}$$

so that (5), (5′) imply

$$\begin{aligned} P^*_{t+1,t} &= \frac{1}{1 + \alpha_2}\left[\mu_2 - \frac{1 + \alpha_2}{(1 + n\theta)(1 - \tau)}\right]v^*_{t+1,t}; \\ P^*_{t+1,t-1} &= \frac{1}{1 + \alpha_2}\left[\mu_2 - \frac{1 + \alpha_2}{(1 + n\theta)(1 - \tau)}\right]v^*_{t+1,t-1} \end{aligned} \tag{14}$$

The expected price for time $t+1$ depends only upon the expected supply shock for that period. The optimal monetary rule neutralizes the effects of anticipated supply shocks for all subsequent periods. However, the response of the expected price level does depend upon the chosen value of μ_2 and two values are natural to consider.

(i) $\mu_2 = 0$: In this case the optimal monetary response to supply disturbances is given by

$$M_t = \left[\left(\frac{1 + n}{1 + n\theta} \right) \left(\frac{\alpha_2}{d} + \alpha_1 \right) - \frac{1 + \alpha_2}{(1 + n\theta)(1 - \tau)} \right] v_t + \frac{\alpha_2}{(1 + n\theta)(1 - \tau)} v^*_{t+1,t} \qquad (15)$$

The optimal response to the current disturbance is the same as for white noise, discussed previously. But, in addition, the rule requires accommodation for the expected shock for next period, $v^*_{t+1,t}$. Moreover, this accommodation should be the same, whether the future shock is expected to last just one period, or indefinitely. The reason is simply that expectations of future supply shocks beyond one period are fully compensated for by the expected money supply and leave price expectations $P^*_{t+1,t}$ or $P^*_{t+1,t-1}$ unaffected.

While the adjustment to the current disturbance can be either expansionary or contractionary, as we have seen, the expected positive future shock calls for monetary expansion. The reason is that an expected positive future supply shock causes $P^*_{t+1,t}$ to fall. This in turn means that the real interest rate will rise and that current output will decline. In order to restore output to the level of the frictionless economy, an expansion in the money supply is required in order to offset this contractionary effect.

The optimal rule (15) implies further that a positive *current* supply disturbance which is expected to last for at least one period into the future (i.e., $v^*_{t+1,t} = v_t$) can be stabilized perfectly by setting

$$M_t = \left[\left(\frac{1 + n}{1 + n\theta} \right) \left(\frac{\alpha_2}{d} + \alpha_1 \right) - \frac{1}{(1 + n\theta)(1 - \tau)} \right] v_t \qquad (16)$$

Denoting the coefficient of v_t in (10) and (16) by μ_0, μ_0^* respectively, we see that $\mu_0^* > \mu_0$; i.e., the monetary policy should be more accommodating or less contractionary to such a disturbance than to a white noise shock.[7] The reason again is the negative price effect which needs to be offset in order to avoid the contraction in output which would otherwise occur.[8]

(ii) $\mu_2 = (1 + \alpha_2)/(1 + n\theta)(1 - \tau)$: For this choice of μ_2, the expected future supply disturbance drops out of the optimal rule, which now may be written as

$$M_t = \left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d}+\alpha_1\right) v^*_{t,t-1} + \left[\left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d}+\alpha_1\right) - \frac{1+\alpha_2}{(1+n\theta)(1-\tau)}\right](v_t - v^*_{t,t-1}) \tag{17}$$

expressing the response in terms of the anticipated current shock, $v^*_{t,t-1}$, and its unanticipated component $(v_t - v^*_{t,t-1})$. The response to the latter is the same as if it were white noise and can be either expansionary or contractionary. By contrast, a positive anticipated current supply shock requires monetary expansion. This is because an expected positive supply shock leads to a higher contract wage. This tends to reduce the demand for labor and output, unless offset by a monetary expansion which raises the price level and stimulates output.

It is interesting to observe that when μ_2 is chosen in this way, the monetary authorities need not forecast the future at all. They can simply base their policies on the anticipated and unanticipated components of the *current* supply disturbance. The reason is that when $\mu_2 = (1+\alpha_2)/(1+n\theta)(1-\tau)$, $P^*_{t+1,t} = P^*_{t+1,t-1} = 0$. That is, the expected future price level is fixed and is independent of future supply disturbances.

Our analysis treats the degree of wage indexation as a given parameter. It is interesting to note that when τ is considered as a policy instrument, further degrees of freedom with respect to the determination of optimal policy arise. For example, setting

$$1-\tau = \frac{1+\alpha_2}{(1+n)(\frac{\alpha_2}{d}+\alpha_1)} \tag{18a}$$

$$\mu_2 = \left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d}+\alpha_1\right) \tag{18b}$$

the coefficients of both v_t and $v^*_{t+1,t}$ in the optimal money supply rule (9) are zero. Optimal policy will consist of *partial* wage indexation, together with a monetary expansion based solely on the forecast of the supply shock at time t, formed at time $t-1$, namely

$$M_t = \left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d} + \alpha_1\right) v^*_{t,t-1} \tag{19}$$

In effect, the indexation eliminates the need to adjust the money to the unanticipated component of the supply shock in (17). A rule based entirely on past forecasts is obviously very convenient in an economy where there are lags in information.

C. *Effects on Other Variables*

So far, we have focused on the monetary rules which will ensure $Y_t = Y_t^f$, so that the contract economy replicates exactly the output of the frictionless economy. Combining (1c′), (1d′) with (5′), it is seen that the adoption of the optimal monetary rule causes the current price level to respond in accordance with

$$P_t = P^*_{t,t-1} - \frac{(v_t - v^*_{t,t-1})}{(1+n\theta)(1-\tau)} = \frac{\mu_2}{1-\alpha_2} v^*_{t,t-1} - \frac{1}{(1+n\theta)(1-\tau)} v_t \tag{20}$$

A current positive supply shock causes the current price level to fall, while to the extent that the monetary authorities accommodate to an anticipated positive current supply shock, the current price level will rise.

The demand for labor generated by the supply shock and resulting policy responses increases by an amount

$$N_t^d = \frac{Y_t - v_t}{1-\theta} = \frac{n}{1+n\theta} v_t > 0$$

while the supply of labor

$$N^s = n(W - P) = n(\tau - 1)(P_t - P^*_{t,t-1}) + \frac{n v^*_{t,t-1}}{1+n\theta} = \frac{n}{1+n\theta} v_t > 0$$

rises by the same amount. The optimal monetary policy therefore ensures that the supply shock has no effect on unemployment. Upon reflection, this is hardly surprising, since the optimal rule ensures that the economy replicates the frictionless economy, in which the labor market always clears and the unemployment rate is therefore zero.

D. A Monetary Rule Based on only Current Supply Shocks

The striking feature of the optimal monetary rules (15) and (17) is their simplicity. Completely *general* supply shocks can be stabilized perfectly by using remarkably simple rules based on very limited information about the transitory or permanent nature of the shocks. The monetary authorities need consider only the current period and just one period ahead; they need *not* be concerned with what might occur in any subsequent periods beyond.

This form of rule is now compared to the usual kind of policy rule where the monetary intervention is in response to only current disturbances in supply. Analytically, this involves setting $\mu_1 = \mu_2 = 0$ in (1d′). Eliminating the demand disturbances by setting $\lambda_1 = -\alpha_2/d$, $\lambda_2 = 1$ in (7′), the deviation in output about its frictionless level, $Y_t - Y_t^f$, is given by

$$Y_t - Y_t^f = \frac{d}{D}\left(\frac{1-\theta}{\theta}\right)\left\{\left[(1-\tau)(\mu_0 - \phi) + \frac{1+\alpha_2}{1+n\theta}\right](v_t - v^*_{t,t-1}) + (1-\tau)(\mu_0 - \phi)\left[\sum_{j=1}^{\infty}(v^*_{t+j,t} - v^*_{t+j,t-1})\left(\frac{\alpha_2}{1+\alpha_2}\right)^j\right]\right\} \tag{7"}$$

The optimal rule for stabilizing white noise disturbances is obviously still given by (10), as before. But for any other forms of disturbances, to determine the optimal monetary response involves forming forecasts of the supply shocks, $v^*_{t+j,t}$, for *all* future periods $t+j$. The informational requirements are clearly severe.

In fact, perfect stabilization for Y_t about Y_t^f is possible for any arbitrary autoregressive moving average (ARMA) process generating supply disturbances v_t. Suppose, for example, v_t is generated by

$$v_t = \rho v_{t-1} + \epsilon_t + \lambda \epsilon_{t-1} \tag{21}$$

Then,

$$v_t - v^*_{t,t-1} = \epsilon_t$$

$$v^*_{t+j,t} - v^*_{t+j,t-1} = \rho^{j-1}(\rho + \lambda)\epsilon_t \quad j = 1, 2, \ldots$$

and substituting into (7″), yields

$$Y_t - Y_t^f = \frac{d}{D}\left(\frac{1-\theta}{\theta}\right)\left[\frac{(1-\tau)(\mu_0 - \phi)(1 + \alpha_2 + \lambda\alpha_2)}{1 + \alpha_2 - \rho\alpha_2} + \frac{1 + \alpha_2}{1 + n\theta}\right] \tag{22}$$

We see from (22) that perfect stability of output Y_t about the frictionless level Y_t^f is attained by choosing the parameter μ_0 in accordance with

$$\mu_0 = \left(\frac{1+n}{1+n\theta}\right)\left(\frac{\alpha_2}{d} + \alpha_1\right) - \left(\frac{1+\alpha_2}{1+n\theta}\right)\left(\frac{1 + \alpha_2 - \rho\alpha_2}{(1 + \alpha_2 + \lambda\alpha_2)(1-\tau)}\right) \tag{23}$$

This rule depends upon ρ, λ, the two parameters characterizing the stochastic process generating v_t. It reduces to (10) when $\rho = \lambda = 0$ and v_t is a white noise process; it reduces to (16) when $\rho = 1$, $\lambda = 0$, and v_t follows a random walk with current shifts expected to be permanent.

In general, all parameters characterizing an ARMA process will appear in the optimal policy rule, and perfect stabilization is possible as long as information on all relevant parameters is correct. If, on the other hand, information is incorrect, perfect stabilization will not be achieved and indeed if the information is sufficiently inaccurate, intervention may serve only to destabilize the economy!

5. IMPERFECT INFORMATION

We now determine the optimal degree of monetary response in the situation where information on the current disturbances is unavailable, so that only $E_t(v_t)$, $E_t(u_t)$ and $E_t(w_t)$ are known to all agents (both private and public). In this case, returning to the fundamental expression (7), we can easily show that Var $(Y_t - Y_t^f)$ is minimized by choosing μ_0, μ_1, μ_2, λ_1, λ_2, precisely as before, in accordance with (8). Thus the response to the supply disturbance is now given by

$$M_t = \left[\left(\frac{1 + n}{1 + n\theta} \right) \left(\frac{\alpha_2}{d} + \alpha_1 \right) - \frac{1 + \alpha_2}{(1 + n\theta)(1 - \tau)} \right] E_t(v_t)$$
$$+ \left[\frac{\alpha_2}{(1 + n\theta)(1 - \tau)} - \frac{\alpha_2 \mu_2}{1 + \alpha_2} \right] v^*_{t+1,t} + \mu_2 v^*_{t,t-1} \tag{24}$$

This is of the same form as (9), the only difference being that the current perception of the supply disturbance, $E_t(v_t)$, replaces the actual shock. Thus the comments made previously with respect to the optimal policy rules in response to the various forms of supply disturbances applies to (24) as well.

There are, however, two differences which need to be considered. First, the perceived supply disturbance depends upon the information set available to agents. Secondly, the optimal rule may, or may not, yield perfect stabilization about the frictionless level of output.[9] That too, depends upon the information set. In general, we find that the minimized value of Var $(Y_t - Y_t^f)$ is

$$(1 - \tau)^2 \text{ Var } \left\{ \frac{\alpha_2}{d}(u_t - E_t(u_t)) - (\frac{\alpha_2}{d} + \alpha_1)(v_t - E_t(v_t)) - (w_t - E_t(w_t)) \right\}$$

We shall consider two examples.

First, suppose that agents observe both the price level P_t and the interest rate r_t. Substituting (1a) into (1b) yields the relationship

$$M_t - P_t = -\alpha_1 d[r_t - (P^*_{t+1,t} - P_t)] - \alpha_2 r_t + \alpha_1 u_t + w_t \tag{25}$$

The observability of M_t, $P^*_{t+1,t}$, along with r_t and P_t implies the observability of the composite disturbance $(\alpha_1 u_t + w_t)$. Similarly, substituting the supply function (1c) into (1b), the observability of M_t, $P^*_{t,t-1}$, $v^*_{t,t-1}$, $E_t(v_t)$, along with r_t and P_t implies the observability of $(\alpha_1 v_t + w_t)$. Optimal predictions of u_t, v_t, and w_t can be obtained by regressing these variables on the two observed composite disturbances. Assuming the underlying stochastic shocks are uncorrelated, the resulting expressions are given by[10]

$$E_t(v_t) = \frac{\sigma_v^2[\sigma_w^2 + \alpha_1^2\sigma_u^2](w_t + \alpha_1 v_t) - \sigma_v^2\sigma_w^2(w_t + \alpha_1 u_t)}{\alpha_1(\sigma_u^2 + \sigma_v^2)\sigma_w^2 + \alpha_1^3\sigma_u^2\sigma_v^2} \tag{26a}$$

$$E_t(u_t) = \frac{-\sigma_u^2\sigma_w^2(w_t + \alpha_1 v_t) + \sigma_u^2[\sigma_w^2 + \alpha_1^2\sigma_v^2](w_t + \alpha_1 u_t)}{\alpha_1(\sigma_u^2 + \sigma_v^2)\sigma_w^2 + \alpha_1^3\sigma_u^2\sigma_v^2} \tag{26b}$$

$$E_t(w_t) = \frac{\sigma_u^2\sigma_w^2(w_t + \alpha_1 v_t) + \sigma_v^2\sigma_w^2(w_t + \alpha_1 u_t)}{(\sigma_u^2 + \sigma_v^2)\sigma_w^2 + \alpha_1^2\sigma_u^2\sigma_v^2} \tag{26c}$$

where σ_u^2, σ_v^2, σ_w^2, are the variances of u_t, v_t, and w_t, respectively. Notice that the absence of any one of u_t, v_t, w_t implies the observability of the remaining two.[11] This is because the observations contain two independent pieces of information, enabling the remaining two random variables to be inferred. Further, equations (26a)-(26c) imply

$$\alpha_1 E_t(u_t) + E_t(w_t) = \alpha_1 u_t + w_t \tag{27a}$$

$$\alpha_1 E_t(v_t) + E_t(w_t) = \alpha_1 v_t + w_t \tag{27b}$$

which together yield

$$\frac{\alpha_2}{d}[u_t - E_t(u_t)] - (\frac{\alpha_2}{d} + \alpha_1)[v_t - E_t(v_t)] - [w_t - E_t(w_t)] = 0 \tag{28}$$

so that minimized Var $(Y_t - Y_t^f) = 0$; i.e., output is stabilized perfectly about its frictionless level.[12]

Thus, if the monetary authorities observe P_t, r_t, the appropriate prediction of the contemporaneous supply disturbance is given by (26a). It is clear that because of the signal extraction problem

$$\frac{\partial E_t(v_t)}{\partial v_t} = \frac{\sigma_v^2[\sigma_w^2 + \alpha_1^2\sigma_u^2]}{(\sigma_u^2 + \sigma_v^2)\sigma_w^2 + \alpha_1^2\sigma_u^2\sigma_v^2} < 1$$

As a consequence of the inability of the monetary authorities to identify unambiguously movements in the observed variables $(E_t(v_t))$ with actual supply disturbances, such disturbances are discounted somewhat, leading to less response in the money supply than if they were observed exactly. It is also possible for movements in the supply to be accompanied by concurrent movements in demand, so that while $v_t > 0$, the perceived supply disturbance, as determined by (26a), is negative. In this case, the direction of the monetary response will be reversed.

As a second example, suppose that the monetary authorities observe only the nominal interest rate r_t. In this case eliminating Y_t, P_t from (1a) - (1c), we find that the observability of r_t, along with the expectations and other predetermined variables, is equivalent to the observability of the composite term

$$\left[1 + \alpha_1(\frac{1-\theta}{\theta})(1-\tau)\right]u_t + (\alpha_1 d - 1)v_t + \left[d + (\frac{1-\theta}{\theta})(1-\tau)\right]w_t$$

The optimal prediction of the current supply disturbance is now

$$E_t(v_t) \equiv \frac{\Psi_2\sigma_v^2}{\Psi_1^2\sigma_u^2 + \Psi_2^2\sigma_v^2 + \Psi_3^2\sigma_w^2}[\Psi_1 u_t + \Psi_2 v_t + \Psi_3 w_t]$$

where

$$\Psi_1 \equiv 1 + \alpha_1(\frac{1-\theta}{\theta})(1-\tau); \quad \Psi_2 \equiv \alpha_1 d - 1; \quad \Psi_3 \equiv d + (\frac{1-\theta}{\theta})(1-\tau)$$

In this case we can now show that

$$\frac{\alpha_2}{d}[u_t - E_t(u_t)] - (\frac{\alpha_2}{d} + \alpha_1)[v_t - E_t(v_t)] - [w_t - E_t(w_t)] \neq 0$$

so that perfect stabilization of Y_t about Y_t^f is *not* achieved. We can also show that because of the deterioration in information from the first example, the response of $E_t(v_t)$ to v_t is damped even further.

6. CONCLUSIONS

Supply shocks continue to impinge on Western economies. This paper has analyzed the optimal monetary responses to such disturbances, emphasizing the distinction between disturbances that are transitory or permanent, on the one hand, and anticipated or unanticipated, on the other. Two main conclusions can be drawn from the analysis, although these are obviously subject to the specific assumptions of the model.

First, we have shown that if current shocks are observed instantaneously, output can be stabilized perfectly for completely general supply disturbances, by using remarkably simple monetary rules, requiring relatively little information about the nature of the disturbances. Specifically, the monetary authorities need consider only: (i) the current shock, (ii) the forecast of the current shock formed in the previous period, (iii) the forecast for just one period ahead. They need not be concerned with what might occur in subsequent periods beyond, and therefore do not need to determine whether an anticipated shock for the next period is temporary or permanent. The optimal rule will completely eliminate these subsequent effects from the current expected inflation rate, thereby neutralizing their effects on current output. In fact, the optimal rule can be expressed in an infinite number of different ways and only (ii) *or* (iii) need be considered, in conjunction with the current shock itself.

Perhaps the most convenient form specifies the monetary adjustment in terms of an expansion in response to the anticipated component of a (positive) current supply shock, together with an adjustment to the unanticipated component, which may be either expansionary or contractionary, depending upon the parameters. Expressed in this way, perfect output stabilization can be achieved for any form of supply disturbance without the need to forecast the future at all. If the degree of wage indexation is chosen optimally, the optimal monetary rule can be simplified further by eliminating the unanticipated component of the current supply shock from the optimal monetary rule. By contrast, monetary rules based on responses to current disturbances alone require substantially more information for optimal stabilization. Forecasts of supply shocks for all future periods are necessary.

Secondly, we have shown that if current shocks are not observed instantaneously, but are inferred from other signals such as the interest rate and price level, the optimal rules are of the same form, with the current perceived disturbance replacing the actual. The current perception of the shock depends upon the information set and perfect stabilization of output may, or may not, be possible, again depending upon the information available.

APPENDIX

Derivation of Supply Function

The supply function is based on the one-period wage contract model. We assume that the contract wage for time t is determined at time t-1 such that, given expectations of firms and workers, the labor market is expected to clear. The expected supply of labor at the contract wage is

$$N^{s}_{t,t-1} = n(W^{c}_{t,t-1} - P^{*}_{t,t-1}) \qquad n > 0 \tag{A.1}$$

where $N^{s}_{t,t-1}$ = expected supply of labor formed at time t-1, for time t, expressed in logarithms,

$W^{c}_{t,t-1}$ = contract wage, determined at time t-1 for time t, expressed in logarithms,

$P^{*}_{t,t-1}$ = forecast of P_t formed at time t-1.

Output is produced by means of a Cobb-Douglas production function

$$Y_t = (1-\theta)N_t + v_t \qquad 0 < \theta < 1 \tag{A.2}$$

where N_t = employment of labor, expressed in logarithms,

v_t = stochastic disturbance in productivity.

The expected demand for labor, $N^{d}_{t,t-1}$, (based on expected profit maximation), is determined by the marginal productivity condition

$$\ln(1-\theta) - \theta N^{d}_{t,t-1} + v^{*}_{t,t-1} = W^{c}_{t,t-1} - P^{*}_{t,t-1} \tag{A.3}$$

The contract wage is determined by equating the expected demand and supply of labor in (A.1) and (A.3), yielding

$$W^{c}_{t,t-1} = P^{*}_{t,t-1} + \frac{\ln(1-\theta)}{1+n\theta} + \frac{v^{*}_{t,t-1}}{1+n\theta} \tag{A.4}$$

The contract wage therefore depends upon the expected productivity disturbance as well as the expected price level.

Actual employment is assumed to be determined by the short-run marginal productivity condition, after the actual wage and price are known. This is expressed by

$$\ln(1-\theta) - \theta N_t + E_t(v_t) = W_t - P_t \tag{A.5}$$

Introducing the current perceived productivity disturbance, $E_t(v_t)$, into the optimality condition (A.5), allows for the possibility that firms do not observe this disturbance instantaneously. If it is observed, then $E_t(v_t) = v_t$; otherwise they must infer it from available information on current observable variables, using the forecasting technique discussed in the text. Combining (A.2) and (A.5), current output is given by,

$$Y_t = \left(\frac{1-\theta}{\theta}\right)\ln(1-\theta) + \left(\frac{1-\theta}{\theta}\right)(P_t - W_t) + \left(\frac{1-\theta}{\theta}\right)E_t(v_t) + v_t \tag{A.6}$$

which depends upon both the firm's estimate of v_t and v_t itself. In the event that v_t is observed, (A.6) simplifies to

$$Y_t = \left(\frac{1-\theta}{\theta}\right)\ln(1-\theta) + \left(\frac{1-\theta}{\theta}\right)(P_t - W_t) + \frac{v_t}{\theta} \tag{A.6'}$$

Finally, current wages are assumed to be determined in accordance with the indexation scheme

$$W_t = W^c_{t,t-1} + \tau(P_t - P^*_{t,t-1}) \qquad 0 < \tau < 1 \tag{A.7}$$

Combining (A.7) and (A.4) with (A.6) or (A.6'), yields the following alternative forms of supply functions, which correspond to the observability or otherwise of the productivity disturbance,

$$Y_t = \frac{(1-\theta)\,n\ln(1-\theta)}{1+n\theta} + (1-\tau)\left(\frac{1-\theta}{\theta}\right)(P_t - P^*_{t,t-1}) + \left(\frac{1-\theta}{\theta}\right)\left[E_t(v_t) - \frac{v^*_{t,t-1}}{1+n\theta}\right] + v_t \tag{A.8}$$

$$Y_t = \frac{(1-\theta)\,n\ln(1-\theta)}{1+n\theta} + (1-\tau)\left(\frac{1-\theta}{\theta}\right)(P_t - P^*_{t,t-1}) + \frac{v_t}{\theta} - \left(\frac{1-\theta}{\theta}\right)\frac{v^*_{t,t-1}}{1+n\theta} \tag{A.8'}$$

Suppressing the constant and measuring everything in deviation form, (A.8), (A.8′) are equivalent to (1c), (1c′) of the text.

FOOTNOTES

* The comments of an anonymous referee are gratefully acknowledged.

1. An exception is Blinder (1981) who considers a rule in which the money stock is adjusted in response to anticipated and unanticipated supply shocks.

2. Aizenman and Frenkel (1985) allow for supply shocks which are not observed instantaneously. But the focus of their analysis is quite different, being on the tradeoff between wage indexation and monetary policy, rather than on stabilizing for supply shocks themselves. Marston and Turnovsky (1985b) allow for firm-specific productivity disturbances which may, or may not, be observed generally. Their analysis too is directed at different issues from those being pursued here.

3. See Fischer (1977), Gray (1976).

4. It is also possible to augment the rule to respond to anticipated demand shocks, analogous to those for supply. Including $\nu_1 u^*_{t+1,t} + \nu_2 u^*_{t-1,t}$, for example, it can be shown that ν_1, ν_2, satisfy

$$\nu_1 + \nu_2\left(\frac{\alpha_2}{1 + \alpha_2}\right) = 0$$

and since our interest does not lie in demand shocks, we have chosen the simplest solution $\nu_1 = \nu_2 = 0$.

5. If the money supply here were augmented to include in addition a response to the expected supply shock two periods hence, $\mu_3 v^*_{t+2,t}$ say, we can show that in addition to (8a) - (8d), the optimality conditions will include

$$\mu_3 + \mu_1\left(\frac{\alpha_2}{1 + \alpha_2}\right) + (\mu_0 + \mu_2 - \phi)\left(\frac{\alpha_2}{1 + \alpha_2}\right)^2 = 0$$

This together with (8d) implies $\mu_3 = 0$. The same is true for all expectations beyond two periods ahead.

6. Note that whereas some authors refer to a positive supply shock in terms of an increase in input price, we are focusing on positive quantity shocks.

7. It is also possible for monetary policy to be contractionary in response to a white noise disturbance, but expansionary to a permanent shift. This occurs if

$$(1 + \alpha_2) > (1 + n)(1 - \tau)(\frac{\alpha_2}{d} + \alpha_1) > 1$$

8. With a classical supply function, $\alpha_2 = 0$ and price expectations disappear from the solution (6) for output deviations. In this case (10) and (16) are identical, so that both temporary and permanent supply shocks call for the same monetary response.

9. In the case where perfect stabilization is not achieved, so that disequilibrium in the labor market exists, labor supply constraints might be binding and need to be considered.

10. It is also possible to form predictions $E_t(v_t)$ from observations on $(\alpha_1 v_t + w_t)$ alone. However, by ignoring information, this yields a less efficient estimate than than given in (23a).

11. These relationships also imply the observability of $(u_t - v_t)$.

12. Much of the monetary policy literature specifies monetary rules in terms of responses to the directly observed variables, which in this case are P and r. Given that our forecasts of current shocks are just linear combinations of these variables, our formulation is clearly identical in terms of its stabilization performance. However, since the focus of our analysis is on responding to supply disturbances, we find our specification is more appropriate for our purposes.

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