Optimal Monetary Policy and the Sacrifice Ratio

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The annual average rate of inflation in the GDP deflator for 1980 was 10.1 percent. By 1984, the same measure had dropped to 4.4 percent, and from 1990 through the end of 1993, the rate of inflation has averaged 3.2 percent, deviating only moderately from that average over the period. From 1981 to 1984, the civilian unemployment rate averaged 8.6 percent, peaking at 10.7 percent in the fourth quarter of 1982. A common interpretation of this episode is that intentionally contractionary monetary policy caused the rise in unemployment, and the fall in inflation was a consequence of the high unemployment rate. Under this interpretation, the period from 1982 to the present was a successful disinflation engineered by the Federal Reserve.

The disinflation was evidently successful insofar as it lowered the inflation rate. But was it in any sense an *optimal* disinflation? Was the *path* that the real economy took during the course of disinflation satisfactory? Did the Federal Reserve move its instrument so as to obtain the desired rate of inflation while minimizing the disruption to the real economy? If not, what course would have been better?

Fuhrer (1994) considers one way of assessing the performance of monetary policy. The measure is a steady-state, rather than a path-specific, notion of optimality. A policy is considered optimal if, given relative preferences (distastes may be a better word) over deviations of policy goals from their targets, the policy minimizes the weighted

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average of the unconditional variances implied by the policy for policy goals. Thus, an optimal monetary policy according to this metric will systematically set the policy instrument in response to deviations of policy goals—usually inflation and real output—from their targets so as to minimize this weighted average. The weights on inflation and real output reflect the monetary authority's relative distaste for inflation and real output deviations. An *optimal policy frontier* depicts the minimum attainable combination of variances for all possible preferences (weights on inflation and output variance), given the structure of the economy.

This paper explores the relationship between the optimal policy frontier and another, more commonly used measure of monetary policy performance, the *sacrifice ratio* entailed in altering the inflation rate. The sacrifice ratio is defined as the discounted percentage point shortfall of output below its potential, per point of inflation reduction. In many macroeconometric models, the size of the sacrifice ratio does not depend on the path that the economy follows during a disinflation; it is a fixed constant that translates points of inflation decrease into points of lost output and employment. In the contracting model considered here, the sacrifice ratio is *not* a constant; it depends on the rate at which the monetary authority disinflates. Because multi-period nominal contracts are outstanding at any particular time, a faster disinflation will cause greater output disruption (other things being equal), while a slower disinflation will yield less output disruption.

While the link from slower disinflation to less real disruption seems plausible, others have argued the reverse (see, for example, Ball 1994). If more rapid disinflations are also more credible disinflations, and if enhanced credibility decreases the stickiness of prices and inflation, then a more vigorous disinflation could lower the sacrifice ratio. However, the importance of credibility in the conduct of monetary policy must be viewed as marginal at best. It is hard to argue that the high cost of the disinflation in the 1980s arose because monetary policy did not act credibly. The Fed visibly and aggressively raised short-term rates in the early 1980s, pushing the short real rate over 10 percent in early 1981, with annual average real rates of 5 to 8 percent from 1981 to 1984. Still, because the link between monetary policy and the sacrifice ratio in this paper arises through the overlapping contract structure in the model, the conclusions reached here must be viewed as model-dependent.

Throughout the paper, monetary policy is characterized as a linear reaction function in which the short-term nominal interest rate is moved in response to deviations of policy goals from their desired values. The range of policies considered is thus limited to those that differ in the policy goals pursued and in the coefficients that determine the vigor with which the instrument responds to deviations of goals from targets. The reaction function approach appears to be a good approximation to the actual conduct of monetary policy. Empirically, the reaction function captures most of the systematic variation of the short nominal rate.[1]

The next section briefly describes the data and the model used here to assess the performance of monetary policy. Next, the sacrifice ratios implied by the model are computed for a wide variety of policy responses, and the impact of backward- versus forward-looking policy responses on the sacrifice ratio is estimated. The optimal policy frontier for this model is then displayed, as derived in Fuhrer (1994). The sacrifice ratios along the optimal policy frontier are computed, and interactions between the two measures of monetary policy performance are considered.

The Data

A minimal characterization of monetary policy requires a description of the instrument of policy, here taken to be a short-term interest rate, as well as its targets, which include the rate of inflation, the growth rate of real output, and/or the real output gap. The transmission channel from policy instrument to ultimate goals also involves these variables. Thus, the data on which this study focuses are described in Table 1.

Table 1
Description of the Data
1966:I to 1993:I

Mnemonic	Definition
p_t	log of the implicit GDP deflator
π_t	inflation rate, $4\,\Delta p_t$
f_t	quarterly federal funds rate
y_t	log of per capita GDP ($1987)
$\tilde{y}_t$	deviation of y_t from trend, 1965:I to 1993:I
$m2_t$	log of $M2$

Table 2 presents the results of univariate augmented Dickey-Fuller tests for the data series of interest. The log of per capita output appears trend stationary. The inflation rate and the federal funds rate appear to be at best borderline stationary. Because monetary policy may have shifted the mean of the inflation process (and possibly its order of integration) over time, these longer sample tests for mean reversion may not be terribly informative. However, tests based on the last 12 years, reported in the last two rows of the table, include very few observations

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[1] Fuhrer and Moore (1993b) and Fuhrer (1994) provide evidence of the reaction function's goodness-of-fit.

Table 2
Augmented Dickey-Fuller Test Results

Test regression: $\Delta x_t = \beta_0 x_{t-1} + \sum_{i=1}^{n} \beta_i \Delta x_{t-i} + \mu + \gamma t + \varepsilon_t$

Series	n	$Q(12)$	β_0	τ_μ	τ_τ
1966:I to 1993:I					
π_t	2	13.8	−.14	−2.03	
f_t	3	13.4	−.09	−2.34	
y_t	2	17.5	−.12		−3.23
$\tilde{y}_t$	2	15.1	−.08	−3.10	
1982:IV to 1993:I					
π_t	1	14.1	−.42	−2.70	
f_t	1	11.2	−.15	−2.86	

and thus are also suspect. In general, the magnitude of the coefficient β_0 for the subsample test regressions is larger, although the value of the ADF test statistic is not uniformly larger. For more discussion on the time-varying mean of inflation and the issue of the stationarity of the nominal variables in the model, see Fuhrer (1994). It is assumed for this paper, as in previous work, that inflation and interest rates are stationary and that real output is stationary about a deterministic trend.

The Model

This section will briefly describe the model. The price specification of the model has been shown to be stable across monetary policy regimes since 1966 (Fuhrer 1994); the aggregate demand specification shows some evidence of instability, so some of its parameters are estimated separately for the pre-1980 and the post-1979 periods; the reaction function is estimated only on the post-nonborrowed reserves operating procedure period, 1982:IV to the present. For more detail, see Fuhrer and Moore (1993b) and Fuhrer (1994).

The I–S Curve

The real economy is represented with a simple I–S curve that relates the output gap, y_t, to its own lagged values and one lag of the long-term real interest rate, ρ_{t-1}.

$$\tilde{y}_t = a_0 + a_1\tilde{y}_{t-1} + a_2\tilde{y}_{t-2} + a_\rho \rho_{t-1} + \varepsilon_{y,t}. \qquad (1)$$

Monetary policy cannot affect potential output or the output gap in the long run; the output gap is 0 in equilibrium for all feasible monetary policies.[2] The long-term real rate is the yield to maturity on a hypothetical long-term real bond. The realization of ρ_t is set equal to the weighted average of expected real returns on federal funds forecast by the restricted structural model.

The intertemporal arbitrage condition that equalizes the expected holding-period yields on federal funds and real long-term bonds is

$$\rho_t - D[E_t(\rho_{t+1}) - \rho_t] = f_t - E_t(\pi_{t+1}), \tag{2}$$

where D is a constant approximation to Macaulay's duration. Solving equation (2) for ρ_t in terms of ρ_{t+1} and $f_t - E_t(\pi_{t+1})$, then recursively substituting the result into itself, the long-term real rate is an exponentially weighted moving average of the forecast path of the real rate of return on federal funds.

$$\rho_t = \frac{1}{1+D} \sum_{i=0}^{\infty} \left(\frac{D}{1+D}\right)^i E_t(f_{t+i} - \pi_{t+i+1}). \tag{3}$$

The Reaction Function

The systematic behavior of monetary policy is summarized with a reaction function in which the monetary authority moves the federal funds rate in response to deviations of target variables from target. Limited information estimates of the reaction functions find no evidence of a response to M2 growth during the post-nonborrowed reserves operating procedure period. Thus the form of the reaction function is

$$f_t = \alpha_0 + \alpha_f f_{t-1} + \sum_{j=0}^{n} \alpha_{\pi,j} \pi_{t-j} + \sum_{k=0}^{p} \alpha_{y,k} \tilde{y}_{t-k} + \sum_{l=0}^{q} \alpha_{dy,l} \Delta y_{t-l} + \varepsilon_{f,t}. \tag{4}$$

The monetary policy reaction function relates the quarterly average of the federal funds rate to lags of the funds rate, contemporaneous and lagged levels of the inflation rate, contemporaneous and lagged levels of the output gap, and contemporaneous and lagged real output growth. In long-run equilibrium, the funds rate equals the equilibrium real rate of interest (determined by the I–S curve) plus the target rate of inflation (implicit in α_0).

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[2] See McCallum (1994) and the writer's comments in the same volume for further discussion of this point.

The Contracting Specification

The contracting specification is identical to that used in Fuhrer and Moore (1993a), and the reader is referred to that paper for greater detail. Agents negotiate nominal contracts that remain in effect for four quarters. The aggregate log price index in quarter t, p_t, is a weighted average of the log contract prices, x_{t-i}, that were negotiated in the current and the previous three quarters and are still in effect. The weights, ω_i, are the proportions of the outstanding contracts that were negotiated in quarters $t - i$,

$$p_t = \sum_{i=0}^{3} \omega_i x_{t-i} \tag{5}$$

where $\omega_i \geq 0$ and $\Sigma\omega_i = 1$. A downward-sloping linear function of contract length is used,

$$\omega_i = .25 + (1.5 - i)s, \quad 0 < s \leq 1/6, \quad i = 0, \ldots, 3. \tag{6}$$

Let v_t be the index of real contract prices that were negotiated on the contracts currently in effect,

$$v_t = \sum_{i=0}^{3} \omega_i (x_{t-i} - p_{t-i}). \tag{7}$$

Now suppose that agents set nominal contract prices so that the current real contract price equals the average real contract price index expected to prevail over the life of the contract, adjusted for excess demand conditions:

$$x_t - p_t = \sum_{i=0}^{3} \omega_i E_t(v_{t+i} + \gamma \tilde{y}_{t+i}) + \varepsilon_{p,t}. \tag{8}$$

Substituting equation (7) into equation (8) yields the real version of Taylor's (1980) contracting equation,

$$x_t - p_t = \sum_{i=1}^{3} \beta_i (x_{t-i} - p_{t-i}) + \sum_{i=1}^{3} \beta_i E_t(x_{t+i} - p_{t+i}) + \gamma^* \sum_{i=0}^{3} \omega_i E_t(\tilde{y}_{t+i}) + \varepsilon_t \tag{9}$$

where $\beta_i = \Sigma_j \omega_j \, \omega_{i+j}/(1 - \Sigma_j \omega_j^2)$, and $\gamma^* = \gamma/(1 - \Sigma_j \, \omega_j^2)$.

In their contract price decisions, agents compare the current real contract price with an average of the real contract prices negotiated in the recent past and those expected to be negotiated in the near future; the weights in the average measure the extent to which the past and future contracts overlap the current one. When output is expected to be high, the current real contract price is high relative to the real contract prices on overlapping contracts.

Upon announcement of a disinflation, the rate of inflation begins to respond to lower current and expected excess demand conditions. Two aspects of the model moderate inflation's decline. First, nominal contracts negotiated prior to the disinflation and still in effect cannot (by assumption) adjust to the news. Thus, the rate of increase in these nominal contracts continues to feed into the rate of increase in the price level, albeit with diminishing weight as the disinflation proceeds (equation (5) implies that today's inflation rate is a weighted average of the rates of inflation in the current and last three quarters' nominal contract wages). Second, equation (9) implies that the current rate of change of contract wages depends on lagged and expected rates of change of inflation. In this way, the persistence in the inflation rate is extended through overlapping beyond the length of the longest contract.[3] A disinflationary policy that shrinks aggregate demand cannot alter this overhanging dependence on lagged inflation. Hence, a more rapid disinflation will cause greater output disruption than a gradual disinflation.

Parameter Estimates

Fuhrer (1994) provides details of subsample stability of the contracting and I–S parameters, including particulars of the method of estimation. The estimates presented here are taken from that paper. The final estimates for the reaction function estimated over the post-nonborrowed reserves operating procedure period (1982:IV to 1993:I) are summarized in Table 3. Interestingly, the parameters for the contracting specification appear stable across monetary policy regimes since 1966; the elasticity of the output gap with respect to the ex ante real rate is also stable across regimes, while the lags in the I–S curve show some sign of instability. Thus, the final specification uses contracting parameters and a real rate elasticity estimated since the mid-1960s, and I–S curve lagged output parameters that split at 1982:IV.

As shown in the table, the parameters of the I–S curve, the reaction function, and the contracting specification are of the expected sign and

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[3] The Taylor specification exhibits the first, but not the second, kind of persistence. The equation in the Taylor specification that is analogous to equation (9) is $x_t = f(L^{-1})p_t + \gamma y_t$ (where $f(L^{-1})$ is a lead polynomial), so that the change in the contract wage depends on current and expected inflation, but not on lagged inflation.

Table 3
FIML Parameter Estimates: Final Specification

Equation	Parameter	Estimate	Standard Error	t-statistic
I-S Curve				
Full Sample	a_0	.012	.004	2.8
	a_p	−.350	.094	−3.7
1979:IV to 1993:I	a_1	1.527	.115	13.3
	a_2	−.551	.115	−4.8
Reaction Function				
1982:IV to 1993:I	α_0	−.003	.004	−.8
	α_{f1}	.838	.048	17.4
	$\alpha_{\pi 0}$	.271	.091	3.0
	$\alpha_{\pi 1}$	.142	.097	1.5
	α_y	.113	.035	3.3
	$\alpha_{\Delta y}$	.424	.117	3.6
Contracting Specification				
Full sample	s	.112	.010	11.1
	γ	.002	.001	1.6

Sample: 1982:IV to 1993:I
Ljung-Box Q(12) Statistics:

I-S curve	18.2
Reaction function:	4.5
Contracting equation:	21.8

Dominant Roots Decay Rate (complex): 6.6% per quarter

are estimated precisely. The slope of the contract distribution is a bit higher than that estimated in Fuhrer and Moore (1993a,b); the excess demand parameter is a bit smaller. The reaction function estimates indicate a significant response to inflation and to real output growth, as well as a strong tendency to smooth movements in the instrument ($\alpha_{f1} \simeq 0.8$).[4] The response of aggregate demand to the ex ante real interest rate is sizable and precisely estimated.[5] Aside from the reaction function parameters, which will be varied in the policy exercises that follow, the key parameters in the model are a_p, the real rate parameter in the I–S curve; s, the slope of the contract distribution; and γ, the

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[4] Note that the reaction function indicates a response to contemporaneous output and inflation. Of course, policymakers have only partial information about the current quarter by the end of the quarter, so they cannot literally respond to current quarter variables. Thus, this estimate gives policymakers some information that they could not have had historically.

[5] See Fuhrer and Moore (1993b) for a discussion of the magnitude of the estimated real rate parameter in the I–S curve.

sensitivity of contract prices to excess demand. The sensitivity of the results to uncertainty surrounding these parameter estimates will be checked below.

Forward-Looking Monetary Policy

Previous work, and the estimated model presented above, have considered reaction functions that respond only to observable current and lagged information. This characterization appears to fit the data quite well. However, in the context of characterizing *optimal* monetary policy, the possibility that monetary policy is forward-looking must be considered, as in Hall and Mankiw (1993). Accordingly, all the parameters in the model are reestimated, allowing as many leads of policy targets to enter as there are lags in the estimated reaction function, restricting the coefficients on the lead variables to be proportional to the coefficients on the lagged variables. The estimated weight on lagged data is 0.97 with a standard error of 0.53, indicating little support in the data for a forward-looking reaction function.

A less restricted version of the forward-looking reaction function allows the funds rate to react to the four-quarter moving averages of the expected inflation rate, the expected growth rate of real output, and the expected output gap. The full information estimates of all of these effects are jointly and individually insignificantly different from zero.

How do we interpret the absence of forward-looking behavior in the estimated reaction function? After all, Federal Reserve System staff devote much of their time to preparing forecasts of policy goals. However, at least two explanations can be offered for the disparity between this observation and the empirical findings of this study. First, the forecasts in this specification are model-consistent expectations of future output and inflation; they may not closely resemble forecasts assembled by Fed staff. Staff forecasts may resemble fairly unrestricted projections of actuals on lagged values; the estimated reaction function already captures this. Second, voting members of the Federal Open Market Committee are not *required* to base their decisions on the staff forecasts. Thus, while the staff may have provided considerable forward-looking information, it may not have been reflected in movements of the policy instrument. For example, one would not necessarily characterize the disinflation of the early 1980s as the result of a forward-looking monetary policy. During this episode, the inflation rate rose above 10 percent while the unemployment rate stood below 6 percent; only a year later did short-term real rates rise above 1 percent.

Note that in addition to finding no support for forward-looking policy in the data, this study also finds that the optimal policy frontier displayed below is approximately invariant to the inclusion of forward-looking monetary policy.[6]

The Effect of the Monetary Policy Rule on the Sacrifice Ratio

The contracting specification employed here implies different sacrifice ratios for different monetary policy responses. The more vigorous the policy response, the more outstanding contracts are caught unexpired during a disinflation, and thus the larger are the output costs. The converse is also true. To illustrate the magnitude of this effect, the sacrifice ratio implied by the model is computed for a grid of policy parameters that surround the estimated parameters from the last subsample and extend an order of magnitude in either direction.

To accomplish this, the simplified reaction function

$$f_t - f_{t-1} = \alpha_{\pi}(\pi_t - \pi^*) + \alpha_y \tilde{y}_t + .42\Delta y_t \tag{10}$$

is used, where a constant is suppressed, the estimated coefficient on the lagged funds rate of 0.8 is set to 1, and the baseline values for α_π and α_y are [0.5, 0.1], approximately equal to those estimated for the last subsample and displayed in Table 3. The coefficient on output growth is held fixed at its estimated value.[7] Because these parameters will be varied by an order of magnitude in either direction, exactly where the baseline is set is not crucial. The output sacrifice ratio is defined as the cumulative annual deviation of output from trend over the disinflation, discounted at 3 percent per year, for each percentage point reduction in inflation.[8]

Figure 1 displays the sacrifice ratio as a function of the policy parameters, varied over a logarithmic grid spanning two orders of magnitude around the baseline values. Table 4 displays the sacrifice ratios at selected policy parameter settings. The sacrifice ratio implied by the estimated reaction function is 4.0, almost exactly as estimated in Gordon (1985). Using the baseline parameters in the simplified reaction function (an approximation to the estimated reaction function) yields a sacrifice ratio of 3.7. The overall range of sacrifice ratios is impressive, from a low of 0.56 to a high of about 6.0. One striking feature of Figure

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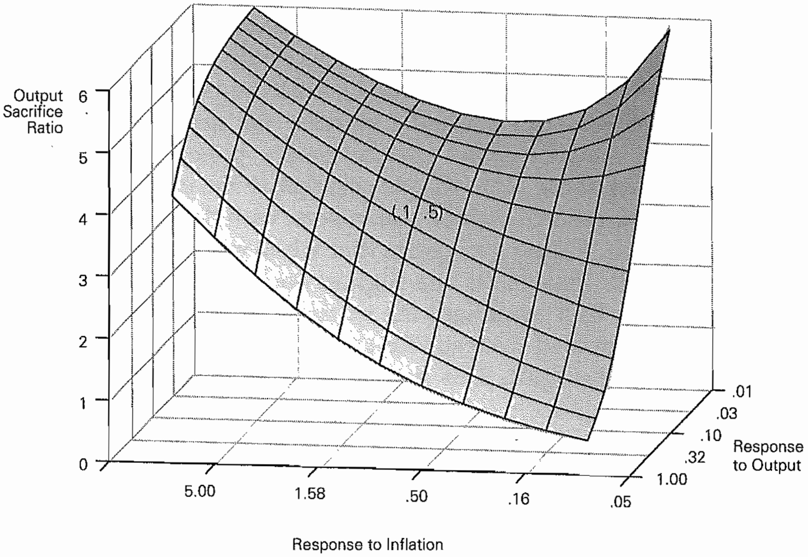
[6] Fuhrer (1994) provides evidence of this point.

[7] Changes in the response to real output growth produce relatively small changes in the grid of sacrifice ratios. For example, decreasing the response to real growth from 0.42 to 0 increases the sacrifice ratios by 0.05 to 0.4.

[8] The sacrifice ratio is computed analytically, rather than by simulation. See the Appendix for details of computation.

Figure 1

Sacrifice Ratio as a Function of Policy Parameters



1 is that the baseline policy's sacrifice ratio sits atop a large region of considerably lower sacrifice ratios.

For relatively balanced policies (α_π approximately equal to α_y), it is not possible to reduce the sacrifice ratio below 2.0. The sacrifice ratio is

Table 4
Sacrifice Ratios at Various Policy Settings

	Output Gap Response (α_y)						
Inflation Response (α_π)	.01	.03	.06	**.10**	.25	.63	1.00
.05	5.80	4.74	3.31	2.60	1.47	.78	.56
.32	4.24	4.06	3.68	3.38	2.59	1.73	1.36
.50	4.34	4.21	3.92	**3.68**	2.98	2.10	1.69
1.26	4.81	4.73	4.55	4.40	3.87	3.03	2.55
1.99	5.14	5.08	4.94	4.81	4.36	3.57	3.08
3.15	5.53	5.48	5.37	5.27	4.89	4.16	3.67
5.00	5.96	5.93	5.84	5.75	5.44	4.80	4.32

strictly decreasing in α_y and almost strictly increasing in α_π.[9] Significantly lower sacrifice ratios can be obtained for markedly unbalanced policies that respond strongly to output gap deviations and more weakly to inflation deviations. For inflation responses as low as 0.05, however, credibility becomes an issue. While the model contains no measure of credibility, it is likely that a 5-basis-point increase in the funds rate for every 1 percentage point that inflation exceeds its target (the top row of Table 4) would hardly be noticed by the markets and would not be viewed as a credible disinflationary policy. Policies that attack inflation even more vigorously than the estimates from the 1980s—increases in α_π holding α_y constant—can markedly increase the sacrifice ratio.

Thus, this model implies that monetary policy can significantly affect the sacrifice ratio. Note that in contrast to the evidence presented in Ball (1994), the costs of disinflation *increase* with the vigor and rapidity of the disinflation. Figure 1 suggests that while monetary policy has not pursued a course that yields the highest sacrifice ratio, neither has it pursued a course that minimizes the sacrifice ratio. It may be that doing so would have entailed undesirable trade-offs, perhaps in the variance of inflation or real output. This possibility is pursued below.

The Timing of Policy Responses and the Sacrifice Ratio

The simplified reaction function employed in the previous section assumed contemporaneous response of the funds rate to inflation and real output. The estimated model, however, shows a significant response to lagged inflation, as well as a tendency to keep the funds rate close to its most recent setting. The latter tendency will be denoted "interest rate smoothing." How do interest rate smoothing and lagged responses to policy outcomes affect the sacrifice ratio in this model?[10]

Table 5 displays the decrease (increase) in the sacrifice ratio relative to the baseline in Table 4, for various alterations in the timing of the funds rate response to policy targets. As shown in the first panel of the table, responding to lagged policy targets instead of the current period's expectation of the targets,

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[9] The sacrifice ratio *increases* as α_π and α_y both approach zero. With extremely low emphasis on both inflation and output, the model is stable, but behaves qualitatively differently. Under vigorous policy responses, policy moves nominal rates aggressively and controls short real rates (and thus long real rates). Under weak policy responses, inflation exhibits wide oscillations that dominate the movements in short real rates. Large real rate fluctuations cause large output fluctuations, and thus this policy implies a high sacrifice ratio. Ultimately, such policies are stable, but the dynamics of the economy are quite different from those under more standard policies.

[10] Roberts (1993) looks at the effects of information and response lags in a simplified annual version of Taylor's (1980) contracting specification.

Table 5
Change in Sacrifice Ratio Due to Change in Policy Response

	Output Gap Response (α_y)						
Inflation Response (α_π)	.01	.03	.06	**.10**	.25	.63	1.00
Lagged Response to π and y							
.05	.31	.25	.16	.12	.06	.02	.01
.32	.40	.38	.33	.30	.20	.11	.07
.50	.46	.44	.40	**.36**	.26	.15	.11
1.26	.61	.59	.56	.54	.44	.30	.23
1.99	.71	.70	.68	.65	.56	.42	.33
3.15	.84	.83	.81	.79	.71	.55	.45
5.00	1.00	.99	.97	.95	.88	.73	.62
Response to lagged 4-quarter moving averages of π and y							
.05	.72	.51	.29	.19	.08	.03	.02
.32	1.01	.91	.73	.60	.34	.15	.10
.50	1.15	1.06	.89	**.77**	.48	.23	.15
1.26	1.56	1.49	1.35	1.23	.89	.50	.35
1.99	1.84	1.78	1.65	1.54	1.18	.73	.52
3.15	2.19	2.14	2.01	1.91	1.55	1.03	.76
5.00	2.61	2.57	2.45	2.35	1.99	1.42	1.09
Response to 1-quarter leads of π and y							
.05	−.27	−.22	−.14	−.11	−.05	−.02	−.01
.32	−.34	−.32	−.28	−.25	−.17	−.10	−.07
.50	−.37	−.36	−.33	**−.30**	−.23	−.14	−.10
1.26	−.48	−.47	−.45	−.43	−.36	−.26	−.20
1.99	−.55	−.54	−.53	−.51	−.45	−.34	−.27
3.15	−.64	−.63	−.62	−.60	−.55	−.44	−.37
5.00	−.74	−.73	−.72	−.71	−.66	−.56	−.48
Response to 4-quarter average leads of π and y							
.05	−.56	−.45	−.30	−.23	−.11	−.05	−.03
.32	−.73	−.69	−.61	−.54	−.37	−.20	−.14
.50	−.80	−.77	−.70	**−.64**	−.48	−.28	−.20
1.26	−1.01	−.99	−.94	−.90	−.75	−.53	−.40
1.99	−1.15	−1.13	−1.09	−1.06	−.92	−.69	−.55
3.15	−1.31	−1.29	−1.25	−1.23	−1.11	−.89	−.73
5.00	−1.50	−1.49	−1.46	−1.43	−1.33	−1.11	−.96

$$f_t - f_{t-1} = \alpha_\pi \pi_{t-1} + \alpha_y \tilde{y}_{t-1},$$

increases the sacrifice ratio by 1 to 100 basis points. For parameter values approximately like those in the estimated reaction function ($\alpha_\pi = .5$, $\alpha_y = .1$), the deterioration is relatively small, perhaps 40 basis points.

The next panel shows how much damage can be done by responding to smoothed averages of lagged quarterly data. In this panel, policy responds to lagged four-quarter moving averages of inflation and the output gap:

$$f_t - f_{t-1} = \alpha_\pi .25 \sum_{i=1}^{4} \pi_{t-i} + \alpha_y .25 \sum_{j=1}^{4} \tilde{y}_{t-j}.$$

In this case, the sacrifice ratio deteriorates by as much as 2.6; at the estimated parameter values, the deterioration is a bit less than 1.0.

The bottom two panels display the advantages of responding to the expected levels of the target variables. In the third panel, policy responds to the one-quarter lead of both inflation and real output,

$$f_t - f_{t-1} = \alpha_\pi E_t \pi_{t+1} + \alpha_y E_t \tilde{y}_{t+1},$$

while in the bottom panel, the funds rate responds to the average expected level of inflation and output over the next four quarters,

$$f_t - f_{t-1} = \alpha_\pi .25 E_t \sum_{i=1}^{4} \pi_{t+i} + \alpha_y .25 E_t \sum_{j=1}^{4} \tilde{y}_{t+j}.$$

Improvements in the sacrifice ratio of 1.0 to 1.5 are possible, relative to the baseline of response to (expected) current targets. Overall, comparing a policy that responds to lagged, smoothed information to one that responds to expected four-quarter-ahead information, the sacrifice ratio can be improved by as much as 4.0; for parameters like those in the estimated reaction function, the improvement is about 1.5. Thus, the model implies that a more forward-looking monetary policy could lower the sacrifice ratio from a bit above 4.0 to a bit below 3.0.

Figure 2 displays the sacrifice ratio as a function of the lagged interest rate parameter in the reaction function, α_f, for fixed values of α_π and α_y.[11] The figure plots the relationship for three pairs of policy parameters: the baseline setting ($\alpha_\pi = .5$, $\alpha_y = .1$); a "low output emphasis" setting ($\alpha_\pi = .5$, $\alpha_y = .01$); and a "high output emphasis" setting ($\alpha_\pi = .5$, $\alpha_y = 1$). In each case, for a given emphasis on inflation and real output, a higher α_f almost always implies a lower sacrifice ratio. For the baseline and the "low output emphasis" cases, the function turns up slightly at $\alpha_f = .94$ and .93, respectively. The function declines monotonically for the "high output emphasis" case. As expected, the

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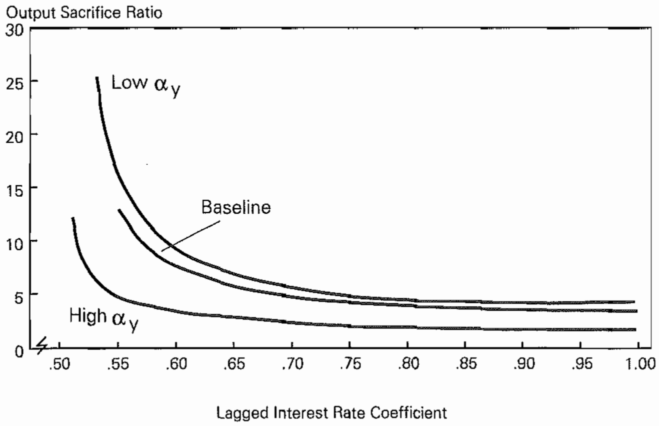
[11] The model does not have a unique, stable solution for all values of α_f, α_π, and α_y. As α_f falls below about 0.5, the model requires much larger responses to inflation and output to remain stable.

Figure 2

Sacrifice Ratio as a Function of Interest Rate Smoothing Parameter



contour of sacrifice ratios for policies with high emphasis on output deviations lies strictly below the contour for the baseline and lower output emphasis policies.

These results suggest the following: (1) To the extent that monetary policy has responded to lagged and time-averaged observations on policy goals, it could improve the sacrifice ratio by responding more to expectations of its goals. (2) Making somewhat gradual changes in the operating instrument may be justified in that, given preferences over policy goals, increased interest rate smoothing generally lowers the sacrifice ratio.

Uncertainty in Estimates of the Sacrifice Ratio

This section will attempt to quantify the robustness of the model's sacrifice ratio estimates with respect to parameter uncertainty. Two related measures will be used. The first estimates the partial derivative of the sacrifice ratio with respect to the key structural parameters in the model, assessing the impact on the sacrifice ratio of a two-standard-error deviation of the parameter from its estimated value. The second measure computes approximate confidence intervals for the sacrifice ratio, given the estimated covariance matrix of the estimated (non-policy) parameters in the model.

Partial Derivatives

An increase in the slope, s, of the contract distribution is expected to decrease the sacrifice ratio. An increase in the magnitude of the slope corresponds to a shortening of the average length of outstanding contracts. More rapidly expiring contracts make the real disruption of a contractionary demand policy smaller, so the sacrifice ratio should fall. Numerical derivatives of the sacrifice ratio with respect to s confirm this intuition: If the slope increased by two standard errors (0.02), the sacrifice ratio would decrease by 0.6.[9] Given the precision of the slope estimate and the influence of the slope on the implied sacrifice ratio, the slope is not an important source of uncertainty in the estimates of the sacrifice ratio.

An increase in the interest sensitivity of the I–S curve, a_ρ, is expected to increase the sacrifice ratio. For a given response of the short rate to policy targets during a disinflation, a higher interest rate elasticity translates into larger output disruption. The numerical estimate of the partial derivative suggests that a two-standard-error increase in a_ρ (about 0.19) will yield a 0.3 increase in the sacrifice ratio. Once again, this parameter appears not to be an important source of uncertainty in computing the sacrifice ratio.

Finally, an increase in the response of the real contract price to the output gap, γ, should lower the sacrifice ratio. If less downward demand pressure is required to lower inflation, then the output cost of a disinflation should diminish. The numerical estimate of the impact of γ on the sacrifice ratio implies that a two-standard-error increase in γ would yield a decrease of 3.0 in the sacrifice ratio. Thus, γ is the parameter that most contributes to uncertainty about the sacrifice ratio, given its estimation error and its effect on the sacrifice ratio.

Confidence Intervals

Uncertainty in the estimated sacrifice ratios at various policy parameter settings arises from the joint sampling error in the estimated non-policy parameters in the model, as well as from uncertainty about the form of the specification. The latter has been set aside as well beyond the scope of this paper; this section will concentrate on the former.

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[9] This estimate is based on two-sided numerical derivatives about the estimated parameters using a differencing interval of 1×10^{-4}. The estimate is insensitive to the particular differencing interval chosen.

Table 6
Confidence Intervals for Sacrifice Ratios

Policy Parameters		Percentile						
α_π	α_y	5	10	20	Median	80	90	95
.50	.10	2.16	2.42	2.78	3.73	5.54	7.31	9.62
.05	1.00	.47	.49	.52	.59	.75	1.16	1.42
5.00	.01	3.16	3.65	4.30	6.06	10.10	14.60	20.00

Assuming asymptotic normality, the distribution of the estimated parameters is

$$\beta \sim N[\hat{\beta}, \Omega]$$

where $\hat{\beta}$ is the vector of estimated parameter values and Ω is the estimated covariance matrix of the parameter estimates that underlies the standard errors presented in Table 3. The *k* percent confidence intervals for the sacrifice ratios can be estimated by repeatedly drawing the parameter vector from this distribution and computing the implied sacrifice ratio. In principle, the confidence intervals so obtained will depend on the setting of the policy parameters. The sensitivity of the confidence intervals will be tested by computing them at three different policy parameter settings.[10]

The percentile boundaries for the sacrifice ratio for three policy settings are displayed in Table 6. As expected, because the sacrifice ratio has a minimum of 0, the distribution of sacrifice ratios is skewed to the right. For the baseline case (approximately the estimated policy parameters), the median sacrifice ratio is 3.7, and the 60 percent confidence interval (20th percentile to 80th percentile) is [2.8, 5.5]. The 90 percent confidence interval (5th to 95th percentile) is [2.2, 9.6], suggesting considerable upside risk in the estimate of the sacrifice ratio. For the aggressive output response, the median sacrifice ratio is 0.59, with a 60 percent confidence interval of [0.52, 0.75]. The aggressive output response mutes the effect of parameter uncertainty on the implied sacrifice ratio, markedly compressing the confidence intervals. The lower end of

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[10] The exercise uses 10,000 draws at each policy parameter setting to estimate the frequency distributions. Note that the model has no unique, stable solution for values of a_p or γ below zero; similarly, the admissible range for s is the interval [0, 1/6]. In the simulations, these parameters are forced to remain within the admissible range. The standard errors for a_p and s are small enough that the number of bound violations is quite small, about 1 percent for a_p and none for s. For γ, however, approximately 9 percent of the draws fall below the zero bound.

the 90 percent confidence interval differs only by 1 from the upper bound for this setting, compared with a range of about 7 for the baseline case. For the weak output response, the 60 percent confidence interval is [4.3, 10.1], centered about a median of 6.1.

Overall, these confidence intervals suggest that parameter uncertainty, largely attributable to uncertainty about γ, implies considerable uncertainty about the estimated sacrifice ratios. The effect of parameter uncertainty on sacrifice ratio uncertainty is amplified as the emphasis on output in the reaction function decreases—the 80 percent and 90 percent confidence ranges increase in absolute terms as α_y decreases. However, at the baseline policy parameter setting, even the 90 percent confidence interval includes sacrifice ratios only as low as 2.2; recall that these correspond to *high* draws for γ; the truncation of γ at zero truncates the mass in the high end of the sacrifice ratio distribution, not the low end.

The Optimal Policy Frontier

A second measure of optimality for monetary policy suggests that policy attempts to minimize the weighted average of the unconditional variances of inflation and output (or unemployment) around target values.[11] For many reasonable characterizations of the economy, an "optimal policy frontier" will exist that depicts the combinations of inflation variance and output variance attainable by policymakers. The policy frontier is generally expected to be convex to the origin; that is, one must trade higher inflation variance for lower output variance, and vice versa. The frontier describes the variance combinations that are possible; it says nothing about which combinations are desirable. However, any reasonable set of preferences over inflation and output variance will lead to an interior solution in which the policymakers accept some of both inflation and output variance.

Fuhrer (1994) addresses the characteristics required of a model to produce a plausible estimate of the optimal frontier and argues that the final specification detailed in Table 3 meets these criteria. In essence, the model fits the data quite well, accurately replicating the dynamic interactions that are found in the data. Thus, the model should yield a plausible estimate of the optimal policy frontier.

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[11] It may be that the monetary authority cares about the unconditional variance of its instrument as well. This concern does not enter the implicit objective function in this paper, in part because it is not clear why, given policies that yield stable economies, the variance of the instrument matters once the variances of the ultimate targets are minimized.

The Definition of the Optimal Policy Frontier

The optimal policy frontier is computed by tracing out the minimum weighted unconditional variances at different slopes along the frontier (implicitly, at different relative preferences for inflation versus output gap variance). Denote the relative weight attached to inflation variance as μ. Given the model specification described above, Fuhrer (1994) performs the following optimization

$$\min_{\theta} \left[\mu V(\pi - \pi^*, \theta) + (1 - \mu)V(\tilde{y}, \theta)\right] \tag{11}$$

over a grid for μ from 0.05 to 0.95 in increments of 0.05. θ includes all the parameters in the monetary policy reaction function (except the constant, which cannot affect the unconditional variances). While the estimated reaction function for the 1980s and 1990s indicates a funds rate response to the *growth rate* of output, a response to the output gap as well is allowed for in the optimal policy exercise. Note that because optimal combinations of inflation and output variances are attained by optimally choosing the reaction function parameters, the points on the frontier imply different values for the sacrifice ratio as well. The discussion will return to this connection below.

Results

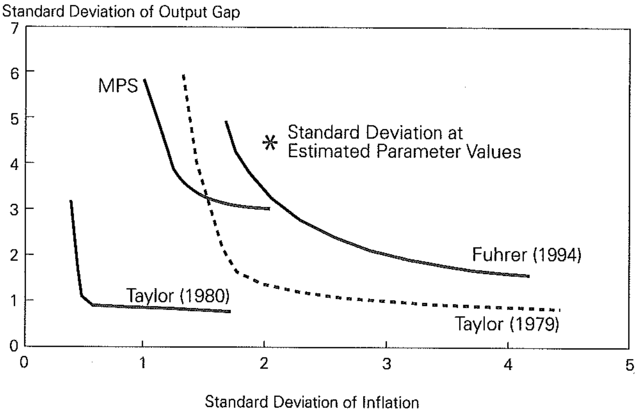
The line labeled "Fuhrer 1994" in Figure 3 displays the optimal policy frontier presented in Fuhrer (1994), computed from the estimated reaction function in Table 3, the full sample contracting specification, and the partially constrained I–S curve. The asterisk indicates the combinations of unconditional variances that arise for this model at the estimated parameter values. The estimated frontier has several interesting implications:

- The actual policy outcome, summarized by the combination of unconditional variances at the estimated parameter values, lies just outside the optimal frontier. Policy in the 1980s has not been far from optimal according to this metric.
- The actual policy outcome lies near the frontier at a point where the relative emphasis on inflation, μ, is about 0.8, thus implying a 4 to 1 distaste for inflation variability relative to output variability.
- Decreasing inflation variance (a move to the left and upward along the frontier) entails a substantial increase in the variance of the output gap.

As a check on this estimate of the locus and slope of the optimal policy frontier, the optimal policy frontiers computed in Fuhrer (1994)

Figure 3

Optimal Policy Frontiers



for structural models with different price specifications are reported. The first model uses the simple Phillips curve

$$\pi_t = \sum_{i=1}^{3} \delta_i \pi_{t-i} + \Gamma \tilde{y}_t + \varepsilon_\pi \tag{12}$$

where $\Sigma\delta_i = 1$ is imposed. This is a simplified version of the type of expectations-augmented Phillips curve that appears in the MPS quarterly model (see Brayton and Mauskopf 1985). As shown in the line labeled "MPS" in Figure 3, the optimal frontier for this MPS-style model lies in about the same position as the frontier for the baseline model. The contours of the MPS frontier are a bit different from the real contracting model; the frontier flattens out at a higher output gap standard deviation, suggesting a less severe penalty in output variation for a decrease in inflation variation at that point. However, the output penalty for decreasing the standard deviation of inflation below 1.5 percent is severe, as it is for the relative contracting model.

The second model is the overlapping nominal contracts model of Taylor (1980). The policy reaction function and the I–S curve are held at their estimates from Table 3. As shown in the line labeled "Taylor

(1980)" in Figure 3, the policy frontier for the nominal contracting model lies well inside the frontiers for the Phillips curve and the real contracting models. The general contours are similar to the other models' frontiers.[15]

Finally, the line labeled "Taylor (1979)" in Figure 3 displays the policy frontier from a model developed in Taylor (1979). That frontier lies much closer to the MPS and real contracting frontiers. With the exception of the Taylor (1980) nominal contracting model, the other models imply similar estimates of the optimal policy frontier, suggesting that the estimate implied by the Fuhrer-Moore model is in the right ballpark.

What about the '90s?

At considerable econometric hazard, the reaction function for the period 1988 to the present can be estimated and the sacrifice ratio and unconditional variances implied by that policy response computed. The funds rate reaction function for this sample is well represented by (standard errors in [ ]):

$$f_t = 1.24[.120] * (1/4) \sum_{i=1}^{4} \pi_{t-i} + .52[.028]\tilde{y}_{t-1} + .028[.005].$$

Note that no evidence of interest rate smoothing is present (the lagged funds rate did not enter significantly in preliminary estimates of the equation), and the emphasis on inflation has more than doubled over the estimate for the period 1982–93. The funds rate appears to respond to a smoothed average of past inflation. The response to real GDP *growth* is not significantly different from zero, while the response to the output gap is higher than during the entire post-1982 period. The actual and fitted values for this equation appear in the top panel of Figure 4.

Given the estimates of the effects of higher relative emphasis on inflation, response to smoothed averages, and lack of interest rate smoothing, the sacrifice ratio implied by this more recent reaction function can be expected to be high. In fact, the sacrifice ratio implied by this policy is 7.2, nearly double the sacrifice ratio implied by the estimates for the entire post-1982 period. The bottom panel of Figure 4 shows the baseline optimal policy frontier from Figure 3, along with the estimate of the unconditional variance implied by the reaction function for the period 1988–93. The unconditional variance outcome implied by the model with the late '80s and early '90s reaction function lies yet a bit

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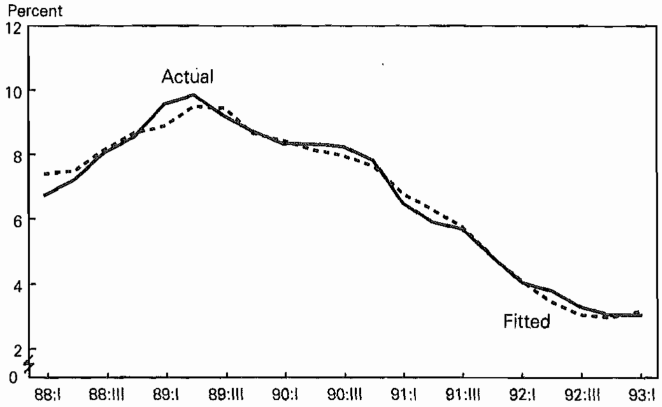
[15] Taylor (1992) presents a similar juxtaposition of policy frontiers.

Figure 4

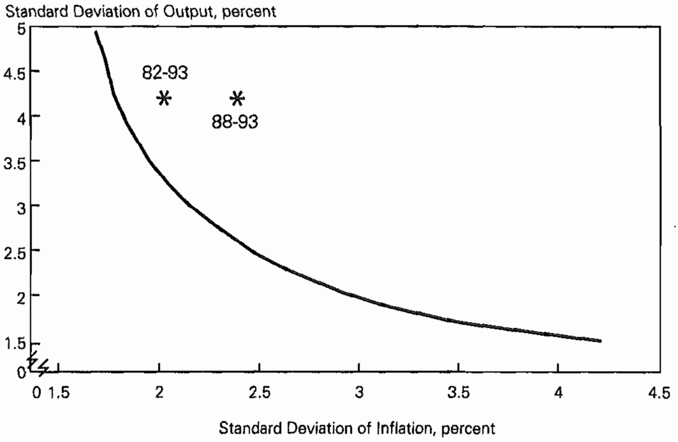
Federal Funds Rate

Actual versus Fitted, 1988:I to 1993:I



Policy Frontier, 1982 to 1993

with Unconditional Variances from Two Reaction Functions



further from the frontier than the outcome implied by the model for a fixed reaction function for the post-1982 period. Given the degrees of freedom available to estimate the three parameters of the reaction function, these results should be taken with a grain of salt. Still, they suggest that recently the Fed has chosen a policy that has led to a modest deterioration in the *variance* measure of optimality and has markedly increased the sacrifice ratio.

Interaction of the Two Measures of Policy Performance

Table 7 presents the policy parameters that are required to attain the optimal policy responses for various preferences (various points along the frontier). The final row displays the sacrifice ratio implied by the model at those parameter settings. The results show the following:

(1) The policy responses required to attain the frontier are more vigorous than the estimated historical responses. The historical responses to inflation and output are smaller than *all* of the optimal frontier responses, regardless of the relative emphasis placed on inflation versus output variance.

(2) The sacrifice ratios entailed in moving to the frontier are *lower* regardless of preferences than the sacrifice ratio implied by the model at the historical estimates.

These results suggest that, while monetary policy behavior over the past 12 years has been reasonably "close to the frontier" when measured in (variance of inflation, variance of output) space, it may have been somewhat further from optimal in terms of the sacrifice ratio. The distance from the frontier and the level of the sacrifice ratio have been increased in the last six years. More vigorous responses to both inflation and real output would improve policy, whether measured by the weighted average of inflation and output variance (in which case the gain is relatively small) or by the sacrifice ratio (in which case the gain could be substantial).

Table 7
Sacrifice Ratios along the Optimal Policy Frontier, 1982 to 1993

	Reaction Function Parameters							
		Optimal parameter value for μ =						
Mnemonic	Estimated Value	.06	.22	.42	.54	.70	.82	.98
$\alpha_{\pi 0}$	.27	.40	.40	.41	.41	.40	.41	.48
$\alpha_{\pi 1}$	.14	.18	.24	.26	.27	.28	.29	.37
α_y	.11	2.91	1.56	.91	.67	.42	.28	.19
$\alpha_{\Delta y}$	.42	.57	.54	.52	.51	.50	.50	.48
α_τ	.84	.76	.81	.83	.84	.85	.87	1.00
Sacrifice Ratio	**4.01**	1.26	1.70	2.18	2.46	2.89	3.23	3.86
1988 to Present	**7.20**							

A Three-Way Optimal Policy Frontier?

The foregoing results show that one can improve both the sacrifice ratio and the unconditional variances by moving onto the two-dimensional optimal policy frontier. Because *all* of the sacrifice ratios on the frontier displayed in Table 7 are *below* 4, all of the points on the frontier of Figure 3 are improvements relative to the asterisk, in all three dimensions. Thus, regardless of preferences over the objectives discussed here, actual policy performance cannot be on the surface of the three-dimensional frontier.

From the optimal three-dimensional frontier the maximum efficient sacrifice ratio can be determined for *any* preferences over the three objectives. Here, the three-dimensional frontier is computed for a variety of preferences (weights) over the two variances and the sacrifice ratio. Formally, the augmented optimization problem is

$$\min_{\theta} \left[\mu_1 V(\pi - \pi^*, \theta) + \mu_2 V(\tilde{y}, \theta) + (1 - \mu_1 - \mu_2)\Lambda(\theta)\right], \qquad (13)$$

where $\Lambda(\theta)$ summarizes the dependence of the sacrifice ratio, Λ, on the parameter settings in the model. The weights $(\mu_1, \mu_2, 1 - \mu_1 - \mu_2)$ take values on the unit simplex.

Interestingly, only for extremely imbalanced preferences does the sacrifice ratio exceed 4. A policy with 80 percent weight on inflation deviations, and a total of 20 percent weight on output deviations and the sacrifice ratio, yields a sacrifice ratio of 3.6. Even a policy that places 98 percent weight on inflation, and 1 percent each on output and the sacrifice ratio, implies an efficient sacrifice ratio of 4.6. Thus, only for policies that are extremely imbalanced in their concern for inflation would the efficient sacrifice ratio rise as high as 4; sacrifice ratios of 7 are almost certainly inefficient.[16]

Other Measures of Optimality

This paper ignores at least one other potential measure of optimality: the steady-state cost of nonzero rates of inflation. While this cost could be an important counterbalance to other costs discussed above, it has been omitted for two reasons. First, the evidence on the quantitative significance of such costs for low levels of inflation is mixed at best.[17]

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[16] Note that this minimization problem was not nearly as robust numerically as the two-dimensional optimal frontier problem described in Fuhrer (1994). The reason may be that, at least for this model and data set, concern for output variance is not sufficiently independent of concern for the sacrifice ratio. These two objectives are sufficiently correlated that it may not always be possible to precisely identify a well-defined minimum of the function.

[17] Motley (1994) and Lucas (1994) are typical of two different approaches to estimating the cost of positive inflation rates.

Second, the model used here has no explicit welfare function and, further, implies no effect of the level of inflation on real output in the long run.

Conclusions

The optimal policy frontier implied by the Fuhrer-Moore model indicates that the actual performance of the economy lies quite close to the frontier. In addition, the shape of the frontier implies that a reduction in the standard deviation of inflation below 2 percent entails an enormous increase in output variability. Similarly, reducing the standard deviation of output below 2 percent entails a large increase in inflation variability. Policy frontiers for alternative specifications—an MPS Phillips curve and a Taylor nominal contracting model—show that the qualitative feature of sharp trade-offs below a threshold for either inflation or output variability is preserved across models. This consistency was noted in Taylor (1992).

While recent monetary policy may have resulted in performance that is not too far from the two-dimensional variance policy frontier, policy may have been considerably less efficient with respect to the output sacrifice ratio. Estimates of the sacrifice ratio implied by the model using reaction functions estimated over the last 12 years run from moderate (about 4) to high (above 7).

Regardless of underlying policy preferences, monetary policy could have achieved a lower sacrifice ratio by responding more to *expectations* of policy targets, rather than to lagged and current observations on targets. The improvement in the sacrifice ratio ranges from about 1 to 4, relative to a lagged response reaction function.

Improvements in the sacrifice ratio and in the variability of inflation and output can be attained by moving closer to the optimal policy frontier. If the estimate of the most recent reaction function is taken literally, moving to the frontier would halve the sacrifice ratio and modestly decrease inflation and output variances. Regardless of preferences over inflation and output variability, improvements in either measure of optimality are obtained by more vigorous response to both inflation and real output.

The link between monetary policy and the sacrifice ratio in this paper arises through the overlapping contract structure in the model. Models in which credibility plays a central role may reach different conclusions. Models that employ a traditional Phillips curve will imply that monetary policy cannot affect the sacrifice ratio. Thus, all the conclusions reached here must be viewed as model-dependent.

Appendix

Computing the Sacrifice Ratio

All of the linear rational expectations models in this paper may be expressed as

$$\sum_{i=-\tau}^{0} H_i x_{t+i} + \sum_{i=1}^{\theta} H_i E_t(x_{t+i}) = \varepsilon_t \tag{A1}$$

where τ and θ are positive integers, x_t is a vector of variables, and the H_i are conformable square coefficient matrices.

The generalized saddlepath procedure of Anderson and Moore (1985) is used to solve equation (A1) for expectations of the future in terms of expectations of the present and the past. For a given set of initial conditions, $E_t(x_{t+k+i})$; $k > 0$, $i = -\tau, \ldots, -1$, if equation (A1) has a unique solution that grows no faster than a given upper bound, that procedure computes the vector autoregressive representation of the solution path,

$$E_t(x_{t+k}) = \sum_{i=-\tau}^{-1} B_i E_t(x_{t+k+i}),\ k > 0. \tag{A2}$$

In the models considered here, the roots of equation (A2) lie on or inside the unit circle.

Using the fact that $E_t(x_{t-k}) = x_{t-k}$ for $k \geq 0$, equation (A2) is used to derive expectations of the future in terms of the realization of the present and the past. These expectations are then substituted into equation (A1) to derive a representation of the model that is denoted the *observable structure*,

$$\sum_{i=-\tau}^{0} S_i x_{t+i} = \varepsilon_t. \tag{A3}$$

The model includes two auxiliary equations for computing the sacrifice ratio. The first simply allows for a shock, ψ_t, that causes a permanent shift in the steady-state value of the inflation rate, $\bar{\pi}$:

$$\bar{\pi}_t = \bar{\pi}_{t-1} + \psi_t.$$

In the reaction function, the funds rate responds to deviations of inflation from $\bar{\pi}$. The second equation implicitly defines Y_t as the expected discounted sum of the output gaps from the present to the infinite future:[18]

$$Y_t - 0.9924 * E_t Y_{t+1} = \tilde{y}_t.$$

The sacrifice ratio is then obtained by solving equations (A3) for the contemporaneous impact of a unit decrease in the steady-state inflation rate (a unit pulse in ψ_t) on the discounted sum of output gaps, Y_t. Thus, the sacrifice ratio, Λ, is the (i,j)th entry of S_0^{-1}, where S_0 is the contemporaneous coefficient matrix in equation (A3), i denotes the row of S_0 defining the sacrifice ratio, and j denotes the column corresponding to the shock ψ_t. The entry is divided by 4 to convert it to the appropriate units.

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[18] Solving this difference equation forward yields $Y_t = \Sigma_{i=0}^{\infty} \delta^i \tilde{y}_{t+i}$.

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Discussion

N. Gregory Mankiw*

It is a rare pleasure to read a paper about the sacrifice ratio written by someone under the age of 50. The sacrifice ratio is one of those subjects in macroeconomics that is at the heart of many practical policy discussions but, at the same time, rarely finds its way into serious academic publications. It is good to see someone trying to be both practical and serious at the same time.

My comments on Jeffrey Fuhrer's paper are divided into three areas: motivation, methodology, and results. In each area, I have some disagreements with the author.

Before I launch into these disagreements, however, let me emphasize one point of agreement: This type of exercise is exactly what is needed if research is to help improve the conduct of monetary policy. In practice, the Fed follows a seat-of-the-pants approach to making policy. The Fed does not bind itself to any explicit monetary rule, and it probably will continue to exercise such discretion for the foreseeable future. But this kind of research on monetary rules is nonetheless useful. Even if a monetary rule is never adopted, research on alternative rules can potentially show the ways in which policy has overreacted or underreacted to economic conditions. In essence, this kind of research can improve seat-of-the-pants policymaking by raising the sensitivity of Alan Greenspan's posterior.

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Motivation

Why do we care about the sacrifice ratio? The sacrifice ratio was a key issue in the late 1970s when prices were rising about 10 percent per year. Everyone wanted to reduce inflation, but people disagreed about how the large the costs would be in terms of lost output. Economists proposed various ways to reduce the cost of disinflation: gradualism, cold-turkey, wage-price controls, credibility, tax-based incomes policy, profit-sharing, and on and on. Yet everyone seemed to agree that a smaller sacrifice ratio was better than a bigger one. If we are going to reduce inflation from 10 to 3 percent, as we in fact did, it is better to lose less output than more in the process.

The question that this paper addresses, however, is different in a subtle but important way. Rather than discussing the one-time cost of a transition from a high-inflation policy to a low-inflation policy, this paper considers how the ongoing policy rule affects the sacrifice ratio. This rule has the Fed trying to achieve a target level of inflation, but sometimes the Fed changes the target for no good reason. The sacrifice ratio measures the cost in output when the Fed gets a negative 1-percentage-point shock to its target inflation rate.

It is not at all clear why we should care about the sacrifice ratio in this way. It is true that a larger sacrifice ratio means a larger output loss when the Fed's inflation target happens to fall, but it also means a larger output gain when the target happens to rise. As long as the natural rate of output is below the social optimum, as it probably is for various reasons, a larger sacrifice ratio is desirable during periods of rising inflation. We might suspect that a larger sacrifice ratio means more volatile output. But if this is the source of concern about the sacrifice ratio, then it is better to look at volatility directly, as in fact the paper does. At one point in this paper, the sacrifice ratio enters as an argument in the Fed's objective function, but its inclusion is not well-motivated. Holding the mean and variance of output and inflation constant, why should policymakers care what their policy rule implies for the sacrifice ratio? My guess is that they should not.

Methodology

The approach that the paper takes is to estimate a simple macroeconomic model of the economy—an I-S equation, an aggregate-supply equation, and the Fed's interest-rate reaction function—and then to simulate the model for alternative policy parameters. In this way, we can compute the policy frontier in terms of inflation and output volatility. We can then see the trade-off between volatility in output and volatility in inflation and how far actual policy has been from the efficient frontier.

The utility of this exercise, of course, depends on the credibility of the model and the estimation procedure. Both are open to dispute. Ever since Robert Lucas (1976) called attention to the neglected role of expectations, economists have been skeptical about macroeconometric models. The particular model in this paper does take a step in the direction of incorporating forward-looking expectations. But, nonetheless, the degree of forward-looking behavior is quite limited. Expectations enter the I-S equation, for example, only through long-term interest rates. Forward-looking consumers are completely absent. Those who found the Lucas critique compelling two decades ago will not find much solace in this paper.

In my view, Christopher Sims (1980) provided an even more important critique of macroeconometric models. Sims argued that these models were estimated with "incredible" identifying assumptions. This paper, for example, contains almost no discussion of the identification problem. A good rule of thumb is that when an author fails to mention his identifying assumptions, the reader should presume they are not appealing. In this particular paper, it is hard to find any variable in the estimated model that is exogenous. If this model is identified at all, identification must come from the tight structure that the model imposes on the data.

This brings me to my last concern about methodology—the particular theoretical structure. In some ways, I am quite sympathetic with the theory used here. It is a variant of a sticky-price model, in which long-term, staggered contracts cause the overall level of wages and prices to adjust only gradually to changes in aggregate demand.

Yet we must admit that we do not know very much about the details of aggregate supply. The theoretical literature on sticky prices does not point in a single direction about how to specify a price-adjustment equation. In some sticky-price models, firms adjust prices at periodic intervals; in others, firms adjust prices at any time by paying a fixed menu cost. In some models, firms set prices at fixed levels between adjustments; in others, firms specify a predetermined path of prices. In some models, firms face only aggregate shocks; in others, firms face idiosyncratic shocks as well. These details might seem quite secondary, but in fact they turn out to have important ramifications for the dynamics of the economy.

A paper by Andrew Caplin and Daniel Spulber (1987) shows how important subtle modeling issues can be. Caplin and Spulber examine a model in which firms adjust prices infrequently because they face menu costs. Nonetheless, in their model, the overall price level moves one-for-one with changes in the money supply, leading to monetary neutrality. Intuitively, the reason is that the few firms that do adjust prices change them by large amounts; moreover, the larger the change in the money supply, the greater the number of firms that choose to pay the cost of adjustment. In this model, even though prices are sticky at the firm level, the overall price level appears quite flexible.

I bring up this theoretical result not because it has great practical relevance but because it sounds a warning for those who think we understand the right way to model the dynamics of the price level. Seemingly innocuous assumptions about the microeconomic price-adjustment process can lead to profound and surprising conclusions about macroeconomic dynamics in general and monetary policy in particular. Thus, any conclusions reached in this paper rest heavily on the Fuhrer-Moore model of price adjustment. Unless we are committed to that particular model, we should treat any policy conclusions with more than the usual dose of skepticism.

Where, then, does this ambiguity about modeling price adjustment leave those of us interested in serious, practical research on monetary policy? It leaves us in a position where we must admit the limits of our knowledge. In particular, three modest conclusions are warranted. First, we should acknowledge that many of the various models of monetary non-neutrality in the literature have some appeal. We have no reason to commit ourselves to any one of them. Second, we should avoid asking our models to answer very subtle questions, as this paper often does. The more subtle the question, the more likely the answer is to be model-dependent, and the more skeptical we have a right to be. Third, when evaluating rules for monetary policy, we need to admit our ignorance and try to find rules that are robust. That is, rather than trying to find the rule that is optimal in any single model, we should be looking for rules that are reasonably good across a wide variety of competing models.

Results

Having questioned this paper's motivation and methodology, let me now turn to my last topic—the results. One of the conclusions of this paper is that a slower disinflation is less costly than a rapid disinflation. In other words, as judged by the sacrifice ratio, gradualism is better than cold-turkey. This is, of course, one of the classic issues regarding disinflation. And I am deeply skeptical of Fuhrer's resolution of it.

In a recent paper, Laurence Ball (1994) addresses this question using an approach that imposes less theoretical structure. Ball identifies 28 episodes in OECD countries in which an economy experienced a large, sustained reduction in inflation. He then computes the sacrifice ratio for each episode. He shows that the more rapid the disinflation, the smaller the sacrifice ratio. This is just the opposite of what Fuhrer concludes. In my view, Ball's empirical regularity is more compelling than Fuhrer's model simulations. At the very least, to convince me that he is right, Fuhrer needs to explain how his model's simulations can be made consistent with Ball's finding.

Table 1
Expected and Actual Inflation: The Volcker Episode
Percent

Year	CEA Forecast January 1981	Actual
1980		12.5
1981	12.6	8.9
1982	9.6	3.8
1983	8.2	3.8
1984	7.5	3.9
1985	6.7	3.8

Note: CEA Forecast is from the *1981 Economic Report of the President*, p. 178.

A case in point is the Volcker episode. The early 1980s saw the most rapid disinflation in recent U.S. history. When I do a back-of-the-envelope calculation of the sacrifice ratio for this episode, I find that it was much smaller than most economists had predicted in advance (Mankiw 1994, p. 312). Certainly, the cost of this rapid disinflation was not much larger than had been predicted. Thus, this episode seems inconsistent with a key conclusion of this paper.

Finally, let me say something about credibility. In many models of aggregate supply, such as Stanley Fischer's (1977) model of nominal-wage contracts, policy has real effects by causing the price level to deviate from the price level that people expected at some point in the past. In this class of models, credibility is crucial for determining the sacrifice ratio in any particular episode of disinflation. Yet, in the introduction of this paper, Fuhrer dismisses credibility with the statement, "However, the importance of credibility in the conduct of monetary policy must be viewed as marginal at best. It is hard to argue that the high cost of the disinflation in the 1980s arose because monetary policy did not act credibly."

I do not think it is hard to argue that at all. Table 1 shows the inflation rates predicted at the beginning of 1981 by the Council of Economic Advisers. The table shows that the Volcker policy was not credible even to the Administration that had appointed Volcker. The Council forecast only a gradual reduction in inflation, whereas in fact Volcker oversaw a rapid reduction. If we add the first two forecasting errors, we find that the price level at the end of 1982 was 9 percentage points below the price level forecast at the beginning of 1981. These data are completely consistent with the view that monetary policy affects real output by causing the price level to deviate from the expected price level. In the end, it is hard to draw strong conclusions from the Volcker episode about the effects of credibility. The only sure lesson from this episode is that credibility is hard to establish.

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Summary Discussion

*Martin S. Eichenbaum**

The purpose of this session is to consider the question "How Efficient Has Monetary Policy Been?" Jeffrey Fuhrer and John Taylor attack this question within the confines of simple but explicit dynamic models that stress the importance of nominal rigidities in goods and labor markets. Indeed, the two papers share virtually identical views about the nature of the monetary transmission mechanism and similar predictions about the effects of changes in monetary policy. Roughly speaking, the Fuhrer paper can be thought of as a state-of-the-art econometric attempt to implement the qualitative vision embodied in the Taylor paper.

The Framework

The vision itself is elegant in its simplicity. To a first approximation, it can be summarized as follows.

1. Monetary policy actions induce changes in short-term nominal interest rates.
2. For various reasons, the inflation rate is "sticky" and does not respond immediately either to developments on the real side of the economy or to Federal Reserve actions.
3. Given an expectations model of the term structure and interest rate smoothing by the Federal Reserve, a policy-induced rise in

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the short-term nominal interest rate induces a rise in the long-term real interest rate.

4. The rise in the long-term real interest rate generates a fall in aggregate demand, which causes actual output to fall. By how much depends crucially on the extent to which the Federal Reserve can lower the long-term real interest rate and on the sensitivity of aggregate demand to changes in the long-term real interest rate.
5. With a lag, monetary policy affects inflation through its effect on deviations of actual from potential output.

Strikingly, this vision abstracts entirely from all other rigidities, such as the financial market imperfections that have been the focus of so much debate in the academic literature and—I might add—Chairman Greenspan's recent testimony to the House Banking Committee. Credit crunches, liquidity constraints, the deficit, and the collapse of traditional money demand, loan demand, and velocity relationships—all are simply absent from the framework. So the key questions are: Have the authors made the "right" decisions in modeling the monetary transmission mechanism, and how can we tell? That the answers matter for assessing the efficiency of monetary policy is obvious. Frankly, Chairman Greenspan's defense of recent monetary policy is simply incoherent from the perspective of the vision embodied in the Fuhrer and Taylor papers.

How convincing is the evidence presented by Fuhrer and Taylor for their vision? Not very. To begin with, neither paper offers any evidence whatsoever regarding the central implication of the model: the existence of a significant trade-off between the volatility of inflation and output. This is because no such evidence exists. Perhaps Fuhrer and Taylor could rationalize the absence of such a relationship as reflecting suboptimal behavior on the part of policymakers. But absent a convincing rationalization, the apparent lack of a trade-off must be viewed as a grave embarrassment for the model.

Next, neither paper offers any direct evidence on the plausibility of their view of the monetary transmission mechanism. Consider, for example, the key assumption that aggregate demand depends sensitively on long-term interest rates. Which rate? And where is the evidence that aggregate demand actually does depend on it? More fundamentally, what evidence do we have that the Federal Reserve can significantly lower the unnamed long-term real interest rate by lowering the current nominal federal funds rate? In fact, it is exactly the absence of such evidence that has led various researchers to look at alternative, perhaps complementary models of the monetary transmission mechanism that stress frictions in financial markets.[1] Perhaps these types of

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[1] See, for example, Christiano and Eichenbaum (1992).

frictions could be incorporated into Fuhrer's and Taylor's models. But (almost) surely their quantitative characterization of efficient monetary policy would then change.

To be fair, Fuhrer has estimated his models in other papers, and the "fit"—for the limited number of variables that he looks at—is reasonably good. But given the level at which the model is formulated, it would be shocking if it was not. After all, if you start off by assuming that output is an unconstrained AR(2) about a deterministic trend (with a correction for a long-term real interest rate), how wrong can you go? Similarly, if you start off by assuming that the short-term interest rate is an unconstrained distributed lag of itself and current and lagged values of output and inflation, how wrong can you go?

If the issue is finding a way to statistically reject the model, that is easy. Just take a stand on what the mysterious long-term interest rate is and test the term structure theory embedded in the model. For any long-term interest rate I can think of, that theory is soundly rejected. In fact I would conjecture that if anyone ever constructs a "top 10" list of economic hypotheses that have been tested and rejected, the risk-neutral, expectations model of the term structure will surely be included. So overall tests of the model are not the issue. Relative to a small, selective number of variables, the fit is fine. But once we include other key variables whose behavior is central to the monetary transmission mechanism being considered, then the model is easy to reject.

A more interesting question is whether the evidence that is presented provides support for the Fuhrer/Taylor vision of how monetary policy works. The answer is no. McCallum (1994) shows this in a particularly dramatic way. One of the key parameters in Fuhrer's model is γ, which governs the sensitivity of contract prices to excess demand conditions (see equation 8). Fuhrer estimates γ to be small and statistically insignificantly different from zero. But if this parameter is equal to zero, then the model dichotomizes, prices are exogenous, and the nominal contracting features are simply irrelevant to the real side of the economy. So interpreted, Fuhrer's empirical work is stunningly supportive of a real business cycle view of the world. The claim that his model fits well is equivalent to the claim that a real business cycle model fits well. In this sense, Fuhrer's answer to the question "Has monetary policy been efficient?" is: "Who cares?"

A VAR Approach

I am not convinced by Fuhrer's evidence that we live in a real business cycle world. To ensure that readers of his paper do not develop an intense yearning for lakeside property, I will develop the connection between the Fuhrer and Taylor papers and the recent vector autoregression (VAR)-based literature that tries to document what the effects of exogenous shocks to monetary policy are. This link will be used to do two things. First, I show that the current formulation of the Fuhrer/Taylor model—certainly as it pertains to the behavior of the Federal Reserve—is implausible, although fixable. Second, this link makes it possible to point to a literature that, in contrast to the Fuhrer and Taylor papers, provides strong evidence of monetary non-neutralities. While this literature has not yet resolved the nature of the monetary transmission mechanism, it is assembling a set of "facts" that any plausible business cycle theory ought to be consistent with.

Fuhrer's model and his identifying assumptions about the nature of shocks to monetary policy map perfectly into the VAR literature that focuses on the following simple question: How do monetary policy actions affect the economy? The central problem in answering this question is that monetary policy actions often reflect policymakers' responses to non-monetary developments. For the sake of precision, I will refer to the rule that relates policymakers' actions to the state of the economy as the feedback rule. To the extent that a policy action is an outcome of the feedback rule, the response of economic variables reflects the combined effects of the action itself and of the variables that policy reacts to. To isolate the effects of Federal Reserve policy actions per se, we need to identify the component of those actions that is not reactive to other variables. I refer to this component as the exogenous component of a monetary policy action. I call the realizations of this component exogenous monetary policy shocks. With this definition, monetary policy actions are the sum of two components: the feedback rule and the exogenous shock. The VAR literature focuses on the question: "How does the economy respond to an exogenous monetary policy shock?"

A harder and more interesting question is "What is the impact on the economy of a change in the monetary authority's feedback rule?" It is exactly this type of question that underlies Fuhrer and Taylor's characterizations of the optimal frontier between volatility in inflation and in output. But before we trust the models' answers to this type of difficult question, we should insist that those models give us the right answer to the simple question that is the focus of the VAR literature. Granted, giving the right answer to the simple question is not a sufficient condition for acting on the implications of a particular model. But this test does help narrow the field of choice and give guidance to the development of future theory.

To see the connection between the Fuhrer paper and the VAR literature, recall that Fuhrer characterizes monetary policy via a time invariant linear policy rule of the form:

$$f_t = \sum_{j=1}^{n} \beta_{f,j} f_{t-j} + \sum_{j=0}^{n} f_{\pi,j} + \sum_{j=0}^{n} \beta_{t,j} y_{t-j} + \varepsilon_{ft} . \tag{1}$$

Here f_t denotes the time t federal funds rate, π_t is the time t inflation rate, y_t is the time t deviation of the log of output from a deterministic trend, and n is a positive integer. The term ε_{ft} is the time t exogenous shock to policy. It is assumed to be orthogonal to the other variables on the right-hand side of equation (1). Broadly speaking, ε_{ft} can be interpreted as reflecting the fact that actual policy decisions are the outcome of the ongoing interaction of policymakers with different preferences and constituencies that have different political strengths at different times. In his Appendix, Fuhrer interprets ε_{ft} as reflecting exogenous shocks to policymakers' target rates of inflation. Similar interpretations can be derived from Taylor's model.

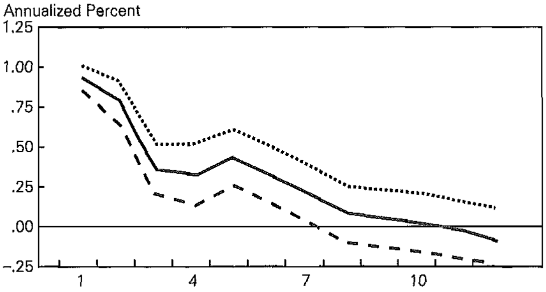
Under Fuhrer's assumptions, exogenous shocks to policy are easy to measure: They are just the residuals from equation (1). So the dynamic response of the economy to a policy action corresponds to the impulse response function from an exactly identified VAR in which we impose a particular Wold ordering on f_t, π_t, and y_t. The only aspect of the ordering that is relevant (for our purposes) is that f_t appears behind y_t and π_t. In simple English, this corresponds to two key assumptions: (i) policymakers set f_t on the basis of current and lagged values of output and inflation, as well as lagged values of f_t, and (ii) contemporaneous movements in f_t do not affect current output or the current inflation rate. Policy shocks affect these variables with at least a one-quarter lag.

Figure 1 displays the dynamic response functions of f_t, y_t, and π_t to a one-standard-deviation shock to ε_{ft}. This shock will be referred to as an FF policy shock. Solid lines correspond to point estimates, while the dotted lines denote a two-standard-deviation band about the point estimates. These were estimated from a trivariate VAR that included four lags of f_t, y_t, and π_t. The sample period was 1966:I to 1992:III. A number of interesting points emerge from Figure 1.

1. Consistent with the notion that the Federal Reserve smooths interest rates, positive FF policy shocks generate persistent but transitory movements in the federal funds rate (top panel).
2. Positive FF policy shocks are associated with persistent declines in aggregate output (middle panel), with the peak effect occurring roughly after one and one-half years. Assuming a discount rate of 3 percent per year, the discounted percentage-point loss in real GNP induced by a 100-basis-point shock to the federal funds rate is roughly 2.75. While the experiment underlying this statistic does not correspond to the one underlying standard

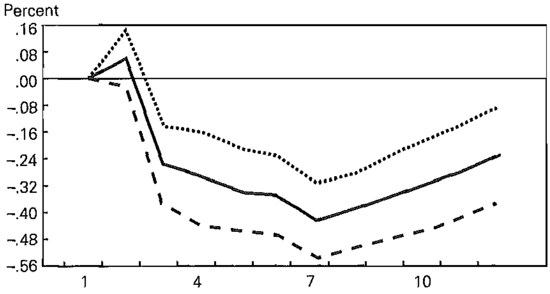
Figure 1

Effect of FF Policy Shock on Fed Funds Rate

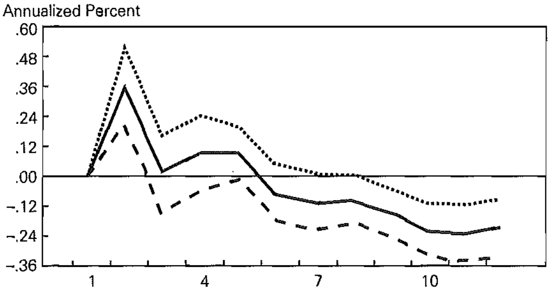


Effect of FF Policy Shock on Output

(Deviation from Trend)



Effect of FF Policy Shock on Inflation Rate



Note: Estimated over sample period 1966:I to 1992:III.

estimates of the sacrifice ratio, it is interesting that the number is in the ballpark of the sacrifice ratio reported by Fuhrer.

3. Finally, notice that the specification has very strange implications for the relationship between monetary policy shocks and movements in inflation (bottom panel). In fact, the infamous *price puzzle* emerges with a vengeance. This is the result that a positive shock to the federal funds rate is associated with a prolonged *rise* in the inflation rate.[2]

The problem is that the Federal Reserve reaction function used by Fuhrer (and Taylor) is overly parsimonious. Christiano, Eichenbaum, and Evans (1994) argue that the key variable that has been omitted from the reaction function is some measure of commodity prices, which acts as an indicator of future inflation. On several occasions in the postwar era, a rise in the inflation rate was preceded by a rise in the federal funds rate and in commodity prices. An example is the oil shock in 1974. Identification schemes that treat the federal funds rate as the Federal Reserve's policy instrument but that do not include commodity prices in the Fed's feedback rule have the perverse implication that contractionary policy shocks lead to a sustained rise in both the price level and the rate of inflation. Christiano, Eichenbaum, and Evans (1994) and Sims and Zho (1994) show that allowing for a measure of commodity prices in the feedback rule resolves the price puzzle. It is hard to say what the impact of this modification would be in Fuhrer's model. Still, it is clear that the current specification is troublesome, to say the least. Even researchers who have stressed the ability of monetary policy to shift the aggregate supply curve of output by affecting the price and quantity of working capital do not believe that contractionary policy actions are followed by prolonged rises in the inflation rate. On this basis, I conclude that while the reaction function used by Fuhrer and Taylor is useful for pedagogical purposes, it is misspecified for the purposes of empirical work.

An obvious question is whether the evidence for non-neutralities survives including commodity prices in the Federal Reserve's reaction function. The answer is yes. In contrast to Fuhrer's paper, the (recent) VAR literature provides strong, credible evidence that shocks to monetary policy have important effects on aggregate economic activity. In particular, according to this literature, contractionary policy shocks have the following properties: (i) they are associated with a rise in the federal funds rate and a fall in monetary aggregates like nonborrowed reserves, total reserves, and M1; (ii) they lead to persistent declines in real GDP, employment, retail sales, and nonfinancial corporate profits as well as

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[2] See Christiano, Eichenbaum, and Evans (1994) and Sims and Zho (1994).

increases in unemployment and manufacturing inventories; (iii) they generate sharp, persistent declines in commodity prices; and (iv) the aggregate price level does not respond to them for roughly a year. After that, the price level declines. Given my space constraints, I refer the reader to Christiano, Eichenbaum, and Evans (1994) or Cochrane (1994) for discussions of these results. Ongoing work is aimed at using VAR methods in conjunction with sectoral and micro data to provide a more detailed view of the monetary transmission mechanism.[3] It is far from clear just what picture will emerge when all is said and done. It is clear that pure real business cycle theories cannot reproduce the patterns that have already been documented. Whether Fuhrer's model can do so is an open question. We won't know until the model is enriched to have a more realistic specification of the Fed's reaction function and we see the constrained impulse response functions.

If Fuhrer's model passes the impulse response function "test" and direct evidence is presented on the plausibility of the Fuhrer/Taylor view of the monetary transmission mechanism, then the answers these papers give us to the hard questions that ultimately interest us merit very serious consideration. But until then, their answers must be taken with a very large grain of salt.

Conclusion

Let me conclude by emphasizing that while I have criticized various aspects of the Fuhrer and Taylor papers, there is much to admire in them. Fuhrer in particular takes an explicit stand on the monetary transmission mechanism and ruthlessly pursues the logic of his model to tell us—bottom line—what he thinks the sacrifice ratio is and what different policy rules would imply for the operating characteristics of the economy. There just is not enough of this kind of work being done. To be useful in the policy process, researchers need to help policymakers understand the quantitative implications of their actions as well as the quantitative trade-offs involved in adopting different policy regimes. Granted, the costs of proceeding this way are high. But what is the alternative? The social marginal product of a researcher announcing that the Federal Reserve should push the LM curve to the right is about as high as that of praying for a positive technology shock. While I have reservations about the Fuhrer and Taylor papers, they're not just praying for good shocks.

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[3] See, for example, Gertler and Gilchrist (1991) on the role of financial market frictions and the impact of monetary policy shocks on large and small firms.

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