PETER CLARK
DOUGLAS LAXTON
DAVID ROSE

An Evaluation of Alternative Monetary Policy Rules in a Model with Capacity Constraints

A small model of the U.S. output-inflation nexus is used to examine the implications of two policy rules, one where the interest rate responds to contemporaneous inflation and one where the response is a forecast of future inflation. The model is asymmetric in that positive deviations of aggregate demand from potential are more inflationary than negative deviations are disinflationary. With asymmetry, following a myopic rule and allowing the economy to overheat requires deep or protracted recessions to control inflation, whereas following a forward-looking rule not only reduces volatility but also raises the equilibrium level of output.

> Shifts in the stance of monetary policy influence the economy and financial markets with a considerable lag, as long as a year or more. The challenge of monetary policy is to interpret current data on the economy and financial markets with an eye to anticipating future inflationary forces and to countering them by taking action in advance.
>
> Alan Greenspan (1994, p. 609)

THE MONETARY POLICYMAKER can be likened to an admiral piloting an aircraft carrier through a narrow passage in turbulent conditions. Given the long lags between changes in course and their effects on the future path of the carrier, it is important for the admiral to know as precisely as possible the effects of his actions on the current and future path of the aircraft carrier. As future sea and wind conditions, which affect this path, cannot be known with certainty, it is necessary to monitor them constantly and make appropriate adjustments in course. Keep-

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PETER CLARK (pclark1@imf.org) *is Assistant Director and* DOUGLAS LAXTON (dlaxton@imf.org) *is Senior Economist in the Research Department of the International Monetary Fund.* DAVID ROSE (drose@cyberus.ca) *is with QED SOLUTIONS, Ottawa, Canada.*

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ing track of these changing conditions is obviously facilitated by relying on sophisticated radar technology and other monitoring devices.

A similar control problem exists for the monetary policymaker, but two factors make the task of steering the economy considerably more daunting. Firstly, the policymaker has a much less precise radar system, and consequently lacks some of the admiral's foreknowledge of where the "ship" is heading and of what shocks will disturb it in the near future. Secondly, the policymaker typically faces criticism, especially for policy actions that involve increases in interest rates in situations where there is no obvious evidence that inflation has risen or is about to rise.[1] The admiral faces no such problem. Although a sailor swabbing the decks may wonder why the carrier is suddenly turning, he does not question such actions and likely has come to trust the Admiral's guidance system and judgment.

It is widely accepted that there are significant lags in the monetary transmission mechanism. All recent models that purport to reflect reality contain important lags between monetary action and the subsequent effects on the economy and inflation. Monetary policymakers also widely accept the implication that their actions must be based on a forward-looking evaluation of the likely course of the economy and inflation.[2] Many central banks devote considerable resources to modeling and forecasting, and their public discussion of policy issues is increasingly cast in a forward-looking mode.[3] It also appears accepted, at least in principle, that a myopic strategy of responding only when inflation has palpably changed will delay necessary stabilization action and engender or exacerbate boom-and-bust cycles.[4] Nevertheless, the task of justifying a policy action on a forward-looking basis is difficult, as it can be done only through abstract reasoning from models and current economic indicators. Consequently, the monetary policymaker may feel constrained to wait until the evidence is difficult to dispute.[5]

One characteristic of business cycles in industrial countries in the postwar period has been that periods of deep or protracted recession have been required to reverse inflationary forces generated during periods of economic boom. Some recent empirical evidence, which is reviewed in the next section, suggests that the inflation process may be asymmetric, in that excess demand has a larger effect on inflation than an equivalent degree of excess supply. One implication of such an asymmetry is precisely that removing entrenched inflation will be relatively costly, and that early

1. Indeed, the monetary policymaker can face the frustrating situation where critics point to the absence of an outburst of inflation as evidence that the action previously taken to ensure that result was unnecessary.

2. See, for example, the comments by Mervyn King in the foreword to Bank of England (1995).

3. Several central banks issue regular forward-looking reviews, including the Reserve Bank of New Zealand, the Bank of Canada, and the Bank of England. The Reserve Bank of New Zealand and the Bank of England both include numerical forecasts in these documents.

4. Recognition of this point has no doubt been a major consideration leading a number of countries to adopt explicit targets to keep inflation low and confined to particular bands as the primary goal of monetary policy. This helps focus discussion on forward-looking issues.

5. The quality of the information, and the monitoring and forecasting tools also enter into the decision, of course.. We do not deal with this aspect of uncertainty in this paper, which is dealt with by Bean (1996) and Wieland (1998).

action to counteract emerging inflation pressures can reduce the need to take stronger action later. Moreover, as shown in Laxton, Meredith, and Rose (1995), for example, a prompt monetary policy response can raise the trend level of output as well as reduce the variance of output around that trend.[6]

It would not be very interesting to evaluate an overtly myopic rule where only contemporaneous inflation was considered relevant. Serious candidates for reaction functions without an explicit forward-looking structure, such as the Taylor (1993) rule, also contain additional variables, such as the contemporaneous output gap, which can act as a leading indicator for inflation. Thus, a Taylor rule is not obviously myopic. Moreover, in linear models one can, in principle, choose the coefficients of a Taylor rule to achieve certain "optimal" properties—for example, see Svensson (1998). Indeed, Levin, Wieland, and Williams (1999) have found that a generalized Taylor rule that allows for interest rate smoothing can deliver good macroeconomic performance in a class of linear rational expectations models. A Taylor rule may indeed be myopic, however, in a model with lags in the control process and asymmetry in the inflation-output nexus. We show this by contrasting the results from an explicitly forward-looking rule proposed by Clarida, Gali, and Gertler (1998) with those of an optimally calibrated backward-looking Taylor rule that allows for interest rate smoothing.

Taylor (1999) and others have argued that policy reaction functions like the simple Taylor rule provide a reasonable description of how U.S. monetary policy has been conducted over the past few decades. Moreover, the analysis in Mussa (1994) suggests that U.S. monetary policy response has been more retrospective than prospective. However, some recent empirical evidence by Clarida, Gali, and Gertler (1998) shows that the monetary authorities in the United States, as well as Germany and Japan, were forward looking in the period since 1979, in that they responded to anticipated inflation as opposed to lagged inflation. Moreover, central banks that have adopted an explicit inflation-targeting regime typically adjust interest rates in response to prospective, not contemporaneous inflation. Our purpose here is to ask, in the context of stochastic simulations of a model with asymmetry, what the costs of responding to contemporaneous inflation might be relative to explicitly forward-looking decision rules.

The paper is organized as follows. In section 1, we review the recent evidence that suggests that there may be significant asymmetries in the Phillips curves of modern industrial economies. We then describe, in section 2, a simple empirical model of the output-inflation nexus for the United States that features asymmetry in the Phillips curve and significant lags in the monetary transmission mechanism. Section 3 contains the results of stochastic simulations showing the implications of alternative monetary policy reaction functions both for the variance and for the average level of output. In section 4 we illustrate some key policy implications of short-run capacity constraints using simple deterministic simulation experiments. Section 5 provides a summary of our main conclusions.

6. This point was anticipated by Evans (1986).

1. RECENT EVIDENCE ON ASYMMETRY IN THE INFLATION PROCESS

The idea that there is asymmetry in the inflation process, whereby excess demand has a greater effect on inflation than a similar degree of excess supply, is not new. The original Phillips curve featured such an asymmetry. Nevertheless, through the years linear specifications came to be considered standard in econometric work.[7] The view that asymmetry in the inflation-output relationship arises, at least in part, from capacity constraints, would appear to underlie the Congressional testimony of Chairman Greenspan referred to above, as suggested by the following quotation (Greenspan 1994, p. 343):

> Knowing in advance our true growth potential obviously would be useful in setting policy because history tells us that economies that strain labor force and capital stock limits tend to engender inflationary instabilities that undermine growth. Moreover, in such an environment asset prices can begin to rise unsustainably, contributing to an unstable financial and economic environment . . . the appropriate analogy is a flexible ceiling that can be stretched when pressed; but as the degree of pressure increases, the extent of flexibility diminishes.

Recently, empirical evidence has begun to emerge to support this view. Laxton, Meredith, and Rose (1995), henceforth LMR, using pooled data for the group of seven major industrial economies, find statistically significant and large asymmetry in the aggregate "price" Phillips curve. LMR also show that tests for asymmetry are likely to be biased toward rejection if care is not taken in the specification of the effective output gap for the estimation and testing. The essential point is that the "gap" measure that is used in estimating an asymmetric Phillips curve cannot be the mean-zero measure that is generated by standard detrending techniques. As this point is of considerable importance for the policy issues pursued in the paper, we discuss it in more detail below.

Turner (1995) considers the G-7 countries individually and finds evidence of statistically significant asymmetry in three cases—Canada, Japan, and the United States—with some compelling, albeit not statistically significant, evidence for asymmetry for Germany and France. In the Canadian case, evidence of asymmetry is also provided in Laxton, Rose, and Tetlow (1993). Evidence of asymmetries for both Canada and the United States is provided by Dupasquier and Ricketts (1998). Bean (1996) finds mild evidence of asymmetry for a panel of OECD economies.[8] For the United Kingdom, Dicks (1996) finds no evidence for asymmetry, but his work appears to be subject to the LMR criticism regarding the bias in tests that use a mean-zero gap measure. Fisher, Mahadeva, and Whitley (1996), who take this point into account in their estimation, do find evidence of asymmetry in the U.K. data, albeit with a lower degree of convexity than found in the LMR pooled estimate. For the United States, Clark, Laxton, and Rose (1995, 1996) report statistically significant asymmetry in the price Phillips curve, as well as further evidence documenting the

7. See Clark and Laxton (1997) for elaboration and a recent review of the literature.

8. There is a related empirical literature starting with Cover (1992) that suggests that there may be an asymmetric response of real activity to positive and negative monetary policy shocks.

importance of the LMR point regarding the nature of the estimation and testing methodology. These authors argue that other results for the U.S. case, where asymmetry has been rejected (for example, Gordon 1997), can be reconciled as arising from a biased testing procedure.[9]

Some researchers have posed the asymmetry question using labor market measures of excess demand. Debelle and Laxton (1997) provide evidence of significant asymmetry in this relationship for Canada, the United States, and the United Kingdom. Clark and Laxton (1997) provide additional evidence for the United States and Faruqee, Rose, and Laxton (1997) find further evidence for the G-7 countries and Spain.

The importance of a convex nonlinear relationship between activity and inflation has been noted by Evans (1986), DeLong and Summers (1988), Laxton, Meredith, and Rose (1995) and Laxton, Rose, and Tambakis (1999). The alternative assumption of a linear relationship implies that there is no upper bound to the short-run impact on output of expansionary policies, whereas experience with inflation suggests that prices start to accelerate rapidly as aggregate demand rises and presses against capacity constraints. Moreover, in the convex case, as excess demand raises inflation by more than excess supply of the same magnitude lowers it, a sharper and/or more extended period of contraction will be required to offset the inflationary consequences of periods of overheating.

A key implication of such asymmetry is that the greater the degree of convexity and the greater the variance of output about its trend, the lower will be the level of trend output. This point follows directly from an application of Jensen's inequality. A formal general proof is provided in Appendix 1 of Laxton, Meredith, and Rose (1994). Here, we consider the simple special case of a quadratic function:[10]

$$\pi = \pi^e + \beta\, gap^* + \lambda\, (gap^*)^2, \text{ with } \beta, \lambda > 0\,, \tag{1}$$

where π is the rate of inflation, $gap^* = y - y^*$, and y^* is the (log) level of output at which there is no tendency for inflation to either rise or fall in the absence of shocks to the economy.

Taking unconditional expectations in equation (1) gives

$$E[\pi] = E[\pi^e] + \beta\, E[gap^*] + \lambda\, E[(gap^*)^2]\,. \tag{2}$$

In a sustainable equilibrium with a constant rate of inflation and no systematic error in inflation expectations, $E[\pi] = E[\pi^e]$. It follows that

$$\beta\, E[gap^*] + \lambda\, E[(gap^*)^2] = 0, \text{ or} \tag{3}$$

9. This point is also relevant in considering why Evans (1986) was unable to find statistical support for asymmetry in the U.S. case.

10. The quadratic functional form is chosen only for analytical convenience here; it does not give rise to a sensible general Phillips curve because after some point increasingly negative gaps will be associated with higher inflationary pressures.

$$E[gap^*] = \frac{-\lambda}{\beta}\left[\text{Var}(gap^*) + (E[gap^*])^2\right] < 0\,, \tag{4}$$

where Var indicates a variance. As long as there is some convexity in the Phillips curve, that is, $\lambda > 0$, and there is some variance in output, then the expected value of gap^* will be negative. Recalling that $gap^* = y - y^*$, and representing the right-hand side of (4) by α, we have

$$E[gap^*] = E[y] - E[y^*] = \alpha\,, \tag{5}$$

that is, $\bar{y} = y^* + \alpha$, where $\alpha < 0$.[11] Thus, an important implication of a convex Phillips curve is that the average level of realized output will lie below the level that would be observed in the absence of shocks.

The economic intuition underlying this result is that if output were maintained, on average, equal to y^*, then the asymmetry in the response of prices to aggregate demand shocks would make it impossible to maintain a constant inflation rate. Because deviations of demand above y^* have a larger positive effect on inflation than deviations of the same magnitude below y^* have in reducing inflation, an attempt to keep $y = y^*$ would lead to an acceleration in inflation without bound. Thus, the equilibrium level of output lies below y^*. It is important to note that it is the equilibrium level that will be observed in the data because what is measured with filters or other techniques applied to the data will be $\bar{y}$.[12] The point is that this lies below the level of y^*, which we must use in estimating the Phillips curve.

Equation (4) also shows that the degree of the shift is directly related to the variance of the effective output gap and the degree of convexity (here, λ/β provides a measure). Of great importance is the implication that a policy rule that works to stabilize output (reduce its variance) will also raise the mean value; the level of trend output will be permanently higher.[13]

2. A MODEL OF THE U.S. OUTPUT-INFLATION NEXUS WITH ASYMMETRY

In this section, we present a simple model of the U.S. inflation nexus that captures certain key features of the interactions linking excess demand, inflation, and mone-

11. We abstract from growth here to simplify the exposition. In a growing economy, the levels and their expectations are time dependent. The arguments are not affected substantively by this simplification, which allows us to drop cumbersome time subscripts. Where we refer to the level of output, the reader should think of it as the base for the whole steady-state growth path.

12. Some readers have asked how this interpretation of potential can be reconciled with a traditional production-function view, where technology and the supplies of factors determine potential output. The answer lies in the interpretation of productivity. In an economy with the type of asymmetry we are considering, the effective technology is not independent of factors that influence the variability of outcomes. What will be observed as the trend level of productivity will depend on, among other things, the success of stabilization policy in reducing output variability.

13. This implication of convexity for economic stabilization policies was pointed out by Evans (1986) and Mankiw (1988, p. 483) in his comments on DeLong and Summers (1988).

tary policy. The model consists of two estimated behavioral equations, one describing a Phillips curve and the other the dynamics of aggregate demand, which is specified in terms of the output gap. To close the model, a monetary policy reaction function is specified in which the monetary authorities are assumed to vary the short-term interest rate to achieve their output and inflation objectives.

This stylized model characterizes the dynamics of the inflation process as primarily dependent on excess demand, that is, the output gap, and on inflation expectations. The fundamental role of the monetary authority is to act to ensure that the economy has a nominal anchor, which we specify in the form of an inflation target. The instrument for monetary control is the short-term interest rate (the Federal funds rate), which has an effect on inflation through aggregate demand.[14] The monetary control mechanism is not perfect, however, since the economy is subject to shocks that cannot be foreseen and the influence of monetary policy on aggregate demand through interest rates operates with a lag.

The Phillips Curve

The particular equation used here is described by Clark, Laxton, and Rose (1996), henceforth CLR. CLR report extensive sensitivity analysis that shows that the estimation and test results are relatively robust to a number of alternative measurement and specification options. We refer the reader to that discussion for details on the estimation and test results. Here, we focus on describing the nature of the equations used in our simulation model.

Although the existence of short-run capacity constraints suggests that there may be asymmetry in the Phillips curve, economic theory does not provide much guidance in terms of a functional form. Furthermore, even if the "true" functional form were known, there would still be substantial difficulty in identifying its parameters in small samples. Indeed, one reason econometricians tend to opt for linear models is that parameter estimates are less sensitive to outliers than is the case with nonlinear models. LMR attempt to overcome this problem by pooling data from the G-7 economies. Here, by contrast, the focus is on one country—the United States—and the number of observations of cyclical periods of excess demand and supply is therefore quite restricted. Our strategy is therefore to estimate a piecewise linear approximation of a general convex function that involves adding a separate term for the *gap** variable when it is positive:

$$\pi_t = \delta\, \bar{\pi}^e_{t+4} + (1 - \delta)\, \pi_{t-1} + \beta\, gap^*_t + \gamma\, gappos^*_t + \varepsilon^\pi_t \tag{6}$$

where:

$$\bar{\pi}^e_{t+4} \quad = 0.2\, ({}_t\pi^e_{t+4} + {}_{t-1}\pi^e_{t+3} + {}_{t-2}\pi^e_{t+2} + {}_{t-3}\pi^e_{t+1} + {}_{t-4}\pi^e_t)\ ;$$

14. The U.S. economy is really the only one for which this is a minimally adequate macro model. For most economies, the external linkages and, in particular, the role of the exchange rate in the inflation process is extremely important.

$$gap^* = y - y^*;$$

$$y^* = \bar{y} - \alpha;$$

$$\bar{y} = \text{average value of } y;$$

$$gappos^* = \text{positive values of } gap^*.$$

We treat α as a parameter to be estimated simultaneously with β and γ.[15] We require $\alpha < 0$ for consistency with a convex form. A major advantage of this approach is that it is easy to test the restriction to linearity. However, this "kinked" function may not be the best choice for a policy simulation model, since it may overstate the degree of asymmetry in the neighborhood of the kink.[16]

Traditional backward-looking Phillips curves rely on past inflation to reflect inertia in the wage- and price-contracting process as well as to proxy expectations of future inflation. In contrast, models of overlapping contracts with forward-looking agents represent inflation as a function of its expected future realization based on all available information about the state of the economy. Our use of a weighted average of past and expected future inflation reflects elements of both approaches, with the importance of each determined empirically.

For estimation, expected future inflation, ${}_t\pi^e_{t+4}$, is represented by the Michigan Survey one-year-ahead measure of inflation expectations. The use of a moving average of these expectations in the Phillips curve is intended to capture a periodic decision-making framework, as in contracting models.[17] The estimated weights on past $(1-\delta)$ and expected future inflation (δ) determine the relative importance of the forward- and backward-looking components of the inflation process. Imposing the constraint that these weights sum to unity ensures that no long-run trade-off exists between the level of inflation and excess demand pressures; it is in this sense that the long-run, natural-rate hypothesis holds in our model. CLR report estimates of equation (6) using various approaches to measuring the trend level of output; the estimates used here are based on a two-sided, 25-quarter, moving average of the logarithm of actual GDP.

Table 1 reports two sets of estimates based on an update of the estimated equation reported in CLR. The first set, which includes an estimate for α, is used in our model. All the coefficients have the expected signs and are statistically significant.[18]

15. Laxton, Rose, and Tambakis (1999) show that previous tests for asymmetry were biased against finding asymmetry in the data because researchers in many cases detrended the data and then imposed α to be zero.

16. Several studies have extended the model presented here for other countries and have used other functional forms and arrived at similar conclusions—see Isard, Laxton, and Eliasson (1998, 1999) and Isard and Laxton(1998a).

17. See Fuhrer and Moore (1995a and 1995b) for an example of a model with a similar structure.

18. We find that our proxy for expected future inflation—the Michigan survey of one-year-ahead inflation expectations—has a significant weight in explaining current inflation. This contrasts with the recent study by Fuhrer (1997) which finds little role for expected future inflation.

TABLE 1

ESTIMATES OF THE PHILLIPS CURVE (t-statistics in parentheses)

Estimated equation: $\pi_t = \delta\,\bar{\pi}^e_{t+4} + (1-\delta)\,\pi_{t-1} + \beta\, gap^*_t + \gamma\, gappos^*_t + \varepsilon^\pi_t$

where:

$gap^* \quad = y - y^* = y - \bar{y} + \alpha$,

$gappos^* \quad$ = positive values of gap^*

$\bar{\pi}^e_{t+4} \quad = .2\,({}_t\pi^e_{t+4} + {}_{t-1}\pi^e_{t+3} + {}_{t-2}\pi^e_{t+2} + {}_{t-3}\pi^e_{t+1} + {}_{t-4}\pi^e_t)$

$\pi \quad \equiv$ percent change in the CPI at annual rates

$\pi^e_{t+4} \quad \equiv$ one-year-ahead inflation expectations from the Michigan Survey data

$$\bar{y} \equiv \frac{1}{2K+1}\left[y_t + \sum_{i=1}^{k}(y_{t+i} + y_{t-i})\right]$$

DATA: U.S. Quarterly Data, 1964:Q1–1995:Q3.

α	γ	β	δ	R^2	σ	Wald Test SL($\alpha,\gamma=0$)
−1.428 (−4.08)	0.944 (2.50)	0.235 (3.53)	0.641 (8.22)	0.8000	1.5066	0.001
0.00	0.044 (0.30)	0.373 (3.57)	0.591 (7.45)	0.7831	1.5628	

In particular, the estimated value of γ implies a significant degree of asymmetry.[19] In addition, the statistically significant estimate of α indicates an economically important difference of 1.43 percent between the y^* and y, that is, the trend level of output lies 1.43 percent below the notional level of output that would be achievable in the absence of shocks. The final column shows the significance level for a Wald test of the joint restriction of and to zero, which is the linear model. The restriction to linearity is strongly rejected.[20]

We have argued that the ability to obtain a reasonable estimate of γ depends crucially on specifying the effective output gap appropriately to include the shift. The second set of estimates reported in Table 1 imposes $\alpha = 0$. The estimated coefficient of the positive value of the gap, γ, is now only 0.04 and is not significantly different from zero. Ignoring the α shift in a test for convexity is tantamount to ignoring a key implication of the hypothesis being tested. Our results confirm the LMR argument that this has important implications for the power of econometric identification of the parameters and the test for convexity itself.

19. Note that when gap^* is positive, the effective coefficient is $\beta+\gamma$, whereas when gap^* is negative, the effective coefficient is simply β.

20. There is some evidence that the Federal Reserve's reaction function has shifted over the sample period considered here. See Brunner (1994), Clarida, Gali, and Gertler (1998) and Fuhrer and Moore (1995a) for some recent discussion of this issue. Our estimate of may therefore be some average value reflecting the effects of different monetary policy response functions.

The Dynamics of Excess Demand

The next stage in constructing the model involves estimating the link between the instrument controlled by the monetary authorities—the Federal funds rate—and aggregate demand. We estimate an equation for the output gap as a function of lagged values of the gap and the real short-term interest rate. We do not attempt to identify any nonlinearity here; we assume that the aggregate demand curve is linear (in logs) and the gap is the conventional measure of $y - \bar{y}$, where $\bar{y}$ is the same 25-quarter, centered moving average used in estimating the Phillips curve.

Our specification reflects two stylized facts that are critical for the ability of policymakers to control the economy. Firstly, there are lags between changes in interest rates and their effects on aggregate demand. Secondly, there is persistence in movements in the output gap, implying that shocks to aggregate demand propagate into future periods.

In estimating the response of aggregate demand to interest rates, a choice must be made as to which rate(s) to use. A longer maturity would likely be most relevant for such components of demand as residential investment and business-fixed investment. A medium-term maturity, for example, three to five years, might be appropriate for consumer durables, especially automobiles. However, we have chosen to use the nominal interest rate controlled directly by the Federal Reserve, namely, the Federal funds rate. This simplifies the model by avoiding the need to specify a term-structure equation. This nominal rate is converted to a real interest rate by subtracting the one-year-ahead inflation expectations as measured by the Michigan Survey.

The estimation results are reported in Table 2 for a simple parsimonious specification of an output gap equation that includes two lags on the gap and a two-quarter lag on the short-term real interest rate term. This dynamic specification was arrived at by estimating an initial model that included eight lags on both variables and then estimating all possible combinations of lag structures that were shorter than eight quar-

TABLE 2

ESTIMATION RESULTS FOR U.S. OUTPUT GAP EQUATION (T-STATISTICS IN PARENTHESES)

$$gap_t = \underset{(1.68)}{0.157} + \underset{(12.85)}{1.116}\, gap_{t-1} - \underset{(3.10)}{0.268}\, gap_{t-2} - \underset{(2.50)}{0.077}\, rr_{t-2} + \varepsilon_t^{gap}$$

Sample 1964Q1–1995Q3 $R^2 = 0.820$ Standard Error = 0.821

where	gap	$= 100^*(y - \bar{y})$
	y	= log of real GDP
	$\bar{y}$	= 25-quarter centered moving average estimate of trend GDP
	rr_t	= real interest rate $(rs_t - \pi^e_{t+4})$
	rs_t	= federal funds rate
	π^e_{t+4}	= one-year-ahead inflation expectations from the Michigan Survey data
	ε_t	= disturbance term

ters. The final dynamic specification reported in Table 2 was then chosen by selecting the regression on the basis of the Akaike Information Criterion.[21]

The complete model is listed in Table 3. Note that we measure interest rates net of an equilibrium real level. This has no effect on the results, since we are not concerned here with the issues surrounding interest rate floors.

3. STOCHASTIC SIMULATIONS WITH ALTERNATIVE POLICY RULES

In this section we consider two types of monetary policy reaction functions to illustrate the welfare implications associated with adhering to a backward-looking and myopic policy rule when there are asymmetries in the output-inflation process. The specific backward-looking policy rule we consider is a generalization of a rule advanced by John Taylor (1993, 1998, 1999). We therefore refer to this rule as a "generalized Taylor rule" (GTR rule). To illustrate the macroeconomic implications of

TABLE 3

A Small Simulation Model of the U.S. Output-Inflation Nexus

Phillips curve:
$\pi_t = .641\bar{\pi}^e_{t+4} + (1 - .641)\pi_{t-1} + .235\, gap^*_t + .944\, gappos^*_t + \varepsilon^{\pi}_t$

Average inflation expectations:
$\bar{\pi}^e_{t+4} = .2\,({}_t\pi^e_{t+4} + {}_{t-1}\pi^e_{t+3} + {}_{t-2}\pi^e_{t+2} + {}_{t-3}\pi^e_{t+1} + {}_{t-4}\pi^e_t)$

Inflation and inflation expectations:
$\pi_t = [(P_t/P_{t-1})^4 - 1]^* \, 100,\ \pi^e_{t+4} = (P_{t+4}/P_t - 1)^* \, 100$

Aggregate demand equation:
$gap_t = 1.116\, gap_{t-1} - .268 gap_{t-2} - .077 rr_{t-2} + \varepsilon^{gap}_t$

Myopic backward-looking linear policy reaction function:
$rs_t = \rho rs_{t-1} + (1 - \rho)[\omega_\pi \pi 4_t + \omega_{gap}\, gap_t]$

Forward-looking linear policy reaction function:
$rs_t = \rho rs_{t-1} + (1 - \rho)[\omega_\pi \pi 4_{t+4} + \omega_{gap}\, gap_t]$

Asymmetric backward-looking policy reaction function:
$rs_t = \rho rs_{t-1} + (1 - \rho)[\omega_\pi \pi 4_t + \omega_{gap}\, gap_t + \omega_{gappos}\, gappos_t]$

Definitions:

π	≡ CPI inflation at annual rates	gap	≡ Output gap ($y - \bar{y}$)
$\pi 4$	≡ Year-on-year CPI inflation	gap^*	≡ $y - y^* = y - \bar{y} + \alpha$
rr_t	≡ $rs_t - \pi^e_{t+4}$	rs	≡ Federal funds rate
π^e_{t+4}	≡ Inflation expectations	P_t	≡ Price level

21. We obtained the same lag structure when we used the Schwarz criterion instead of the Akaike criterion. We have compared our results with those obtained from models, including the MPS, used at the Federal Reserve Board. Our equation produces estimates of the magnitude and time profile of the sensitivity of U.S. aggregate demand to monetary policy that are not unlike those from various Federal Reserve models. For a description of the MPS model and simulation results, see Mauskopf (1990).

following such a policy rule, we consider an alternative that embodies more information about the asymmetric structure of the economy, as well as the lags in the monetary policy transmission mechanism. Since this rule involves an explicit forecast of inflation, we refer to it as an "inflation-forecast-based rule" (IFB rule). Both rules have been optimally calibrated so that the results are not subject to the criticism that bad performance reflects inappropriate weights on inflation and the output gap.

Generalized Taylor Rule (GTR Rule)

The GTR rule that we consider was proposed by Levin, Wieland, and Williams (1999), henceforth LWW, and is written as

$$rs_t = \rho rs_{t-1} + (1 - \rho)[\omega_\pi \pi 4_t + \omega_{gap}\, gap_t]\,, \tag{7}$$

where rs is the Federal funds rate, $\pi 4$ is year-on-year inflation rate, gap is the output gap, ρ is a parameter that indicates the degree of interest rate smoothing, ω_π is the weight on inflation and ω_{gap} is the weight on the output gap.[22] Equation (7) is a generalization of the rule suggested by Taylor because it includes a lagged interest rate term and therefore allows for interest rate smoothing. It can be characterized as a backward-looking and myopic rule because the short-term interest rate is adjusted gradually in response to movements in past inflation and to a measure of the contemporaneous output gap.

LWW have found that optimizing the parameters of this rule will result in good macroeconomic performance (in terms of unconditional variances of inflation and the output gap) in four linear rational expectations models of the U.S. economy. Within this particular class of models, LWW have found that optimizing the parameters of the rule in one of the models also results in good macroeconomic performance when these (suboptimal) parameters are imposed on the other models. For this reason LWW claim that this form of policy rule is robust to model uncertainty. They also find that rules that incorporate forecasts of the output gap and the inflation rate generally do not outperform optimal rules based on current and lagged values of these variables. The nonlinear model estimated in this paper provides a rather different perspective on the robustness issue and suggests that the LWW rules would result in poor macroeconomic performance.[23]

Inflation-Forecast-Based Rule (IFB Rule)

The second rule that we consider is an inflation-forecast-based (IFB) rule where the short-term interest rate is adjusted in response to a model-consistent forecast of

22. This equation does not have a constant term because we have assumed that both the equilibrium real interest rate and the inflation target are zero.

23. In fact, the "optimal" rules proposed by LWW perform so poorly in nonlinear models with capacity constraints that they do not in general satisfy the stability conditions that are necessary to provide an anchor for inflation expectations. Christiano and Gust (1998) and Isard and Laxton (1998a,b) argue that following such rules would risk a repeat of the excessive monetary accommodation and overheating that occurred in the 1970s that was caused by monetary policy falling systematically behind shifts in the Phillips curve. See also Black, Macklem, and Rose (1998).

future inflation. The approach has been analyzed by Black, Macklem, and Rose (1998) and Batini and Haldane (1999) provide extensive discussion of the benefits of IFB rules in terms of reducing the variability of inflation, interest rates, and output. As the latter point out, in those countries that have adopted inflation targeting (Australia, Canada, Finland, New Zealand, Spain, Sweden, and the United Kingdom), inflation forecasts are a fundamental part of the monetary policy process, and in three (Canada, New Zealand, and the United Kingdom) monetary policy is based on explicit—and in some cases published—inflation forecasts. Thus it seems reasonable to specify the interest rate controlled by the monetary authority as responding to expected future inflation. As this rule incorporates information about the asymmetric response of future inflation to output gaps, it is effectively nonlinear even though the reaction function is a linear function of the output gap and the inflation forecast. The formulation of this rule is the same as the GTR rule, except that that the interest rate is adjusted in response to projected inflation:

$$rs = \rho rs_{t-1} + (1 - \rho)[\omega_{\pi}\pi 4_{t+4} + \omega_{gap}\, gap_t] , \tag{8}$$

where $\pi 4_{t+4}$ represents the model-consistent forecast of inflation four quarters ahead. This rule has been estimated for the United States by Clarida, Gali, and Gertler (1998), henceforth CGG. As shown below, this forward-looking monetary policy reaction function results in considerably better macroeconomic performance than the GTR rule.

Stochastic Simulations and the Optimal Calibration of the Two Rules

The parameters, or weights, for the two reaction functions have been optimized for a quadratic loss function suggested by Rudebusch and Svensson (1999) that imposes equal weights on squared output and inflation deviations and a smaller weight on interest rate volatility. The specific form of the loss function in period t is given by

$$L_t = (\pi_t - \pi^{TAR})^2 + gap_t^2 + .5(rs_t - rs_{t-1})^2 , \tag{9}$$

where π^{TAR} represents the long-run desired rate of inflation, which has been set equal to zero for purely illustrative purposes. The value of the parameters [ρ, ω_{π}, ω_{gap}] in equations (7) and (8) have been optimized by performing stochastic simulations on the model to minimize the loss function given by equation (9) over all periods. This is accomplished by doing a grid search over [ρ, ω_{π}, ω_{gap}] and finding the values that minimize the loss function.

In the simulations, the model is subjected to shocks to the disturbance terms of both the Phillips curve and aggregate demand function. These shocks are drawn quasi randomly from normal distributions with standard deviations of 1.51 and 0.82, respectively. These values are the estimated residual standard errors for the two equations. In the first quarter the model is solved with shocks drawn from these two distributions. As the model is forward looking, we must solve for a sufficiently long future path to assure that the first-period solution has converged. In the second quarter the economy is again subjected to two new shocks drawn from the same distributions and the model is again solved taking into account the solution values of the variables from the first quarter. This process continues for a period of forty quarters, that is, ten years. This procedure is then repeated sixty-four times (2,560 draws in total). Each sequence provides distributions for the output gap, inflation, and other variables. The average value of the estimates from the sixty-four replications provides our final estimate of α.

A Comparison of GTR and IBF Rules

The results of these stochastic simulations are reported in Table 4. The optimal calibration of the IFB rule places a zero weight on the output gap, a weight of 5.8 on the year-on-year inflation rate four quarters ahead, and a weight of 0.6 on the lagged Federal funds rate. By contrast, the optimal calibration of the GTR rule implies fairly high weights of 2.4 on the inflation rate and 2.8 on the output gap, but involves a weight of zero on the lagged interest rate. Thus, the optimally calibrated GTR rule for this model boils down to a Taylor rule with roughly comparable weights on both inflation and output. While both rules have been optimally derived, it is noteworthy that they result in vastly different values for the loss function; the IFB rule is associated with a value of 13.48, less than a fourth of the 55.29 generated by the GTR rule. On this basis, the monetary policy reaction function that adjusts the short-term rate

TABLE 4
IFB RULE VERSUS A GTR RULE

	Policy Rule Assumption:		
	IFB Rule (1)	GTR Rule(2)	(2) − (1)
Value of loss function	13.48	55.29	41.81
Mean level of the output gap: $\bar{y} - y^* = \alpha$	−0.52	−0.92	−0.40
Mean level of inflation (pdot)	0.64	3.55	2.91
Standard deviations:			
σ_y	1.52	2.34	0.82
σ_π	2.43	3.94	1.51
σ_{PS}	4.91	10.67	5.76
σ_{MRS}	2.80	6.00	3.20

Optimized policy rules:

Forward-looking IFB reaction function: $rs_t = .6rs_{t-1} + (1 - .6)[5.8\pi4_{t+4} + 0\ gap_t]$

GTR reaction function: $rs_t = 0rs_{t-1} + (1 - 0)[2.4\pi4_t + 2.8\ gap_t]$

Definitions:

rs: Federal funds rate
$\pi4_{t+4}$ model-consistent forecast of year-on-year inflation four quarters ahead
gap: output gap.

in response to expected future inflation is clearly superior. This is reflected in the fact that the standard deviations for inflation, interest rates, and the output gap are all considerably larger when the interest rate adjusts to the current inflation rate. The key finding of the stochastic simulations is that as a result of the greater volatility in output with the GTR policy rule, there is a larger shift (−0.92 percent versus −0.52 percent of output) and substantial average inflation bias (3.55 percentage points under the GTR rule and 0.64 percentage points with the IFB rule). The conclusion of this analysis is that, in a world with asymmetry in the inflation-output nexus, a forward-looking approach in which the current stance of policy takes explicit account of expected future inflation can achieve significant benefits in terms of a higher realized average level of output as well as a reduction in its volatility.

The analysis in section 1 shows that the degree of asymmetry in the Phillips curve will affect the size of α. In discussing our "kinked" approximation to a general convex function, we noted that this functional form is likely to overstate the effective degree of asymmetry. The reason is that while it captures the global convexity conveniently for estimation, it is likely to overstate the degree of asymmetry in the region close to the kink point. This is important in the stochastic analysis because there will be a concentration of outcomes close to this point.

Table 5 provides some indication of the sensitivity of the results to the degree of asymmetry. The stochastic simulations were repeated under the assumption that the

TABLE 5

IFB Rule versus a GTR Rule with Less Asymmetry (Gamma = 1/2 the Estimated Gamma)

	Policy Rule Assumption:		
	Rule (1)	GTR Rule(2)	(2) − (1)
Value of loss function	10.18	18.83	8.65
Mean level of the output gap: $\bar{y} - y^* = \alpha$	−0.34	−0.31	0.03
Mean level of inflation	0.38	1.84	1.46
Standard deviations:			
σ_y	1.50	1.65	0.15
σ_π	2.13	2.53	0.40
σ_{RS}	4.22	6.00	1.78
$\sigma_{\Delta RS}$	2.28	3.43	1.15

Optimized policy rules:

Forward-looking IFB reaction function: $rs_t = .6rs_{t-1} + (1 - .6)[5.7\pi4_{t+4} + 0\ gap_t]$

GTR reaction function: $rs_t = 0rs_{t-1} + (1 - 0)[1.8\pi4_t + 2.5\ gap_t]$

Definitions:

rs: Federal funds rate
$\pi4_{t+4}$ model-consistent forecast of year-on-year inflation four quarters ahead
gap: output gap.

estimated value of γ—the coefficient on *gappos**—is half the estimated value, that is, the value of γ is reduced from 0.944 to 0.472. The results in Table 5 reveal the expected effect; there is a reduction in the calculated values of α under both policy rules, with the reduction being proportionately greater in the case of the myopic policy rule, and a sharp reduction in the difference between the values of the loss function for the two rules. This is to be expected, as the explicitly forward-looking rule is designed to deal with whatever structure is driving the inflation process. This would clearly be less important if the economy were truly linear.

Indeed, if the model were truly linear, then there would essentially be no benefit from a forward-looking policy rule of the kind used here. The same policy rules were optimized using stochastic simulations with gamma set equal to zero making the Phillips curve linear. The optimal rules in this case show greater similarity, but the IFB rule still gives more weight to the inflation rate and to interest rate smoothing. As a result of the latter property, the IFB rule damps movements in the interest rate somewhat more than the GTR rule, but otherwise there is no substantive difference between the two. This result is consistent with the findings of LWW.

A Backward-Looking Asymmetric Policy Reaction Function

We have seen that the IFB reaction function performs significantly better than the GTR reaction function because the IFB rule uses forecasts of inflation and therefore takes into account the asymmetric effects of excess demand on inflation in the nonlinear model. With the IFB rule, interest rates respond more aggressively to overheating than with the backward-looking GTR rule, which responds symmetrically to inflation and output gaps. To contrast the effects of a forward-looking rule with one that allows for a stronger response to excess demand, we considered an alternative backward-looking reaction function, where interest rates can respond asymmetrically to levels of the output gap.[24] This reaction function is written as

$$rs_t = \rho rs_{t-1} + (1 - \rho)[\omega_\pi \pi 4_t + \omega_{gap}\, gap_t + \omega_{gappos}\, gappos_t]\,, \tag{10}$$

where *gappos* represents the positive gaps and ω_{gappos} is the weight on these positive gaps.

When the coefficients of the asymmetric rule are also obtained by minimizing the loss function (9), there is a very large coefficient of 5.9 on *gappos*. This rule produces much better macroeconomic performance than the linear GTR rule. This finding is consistent with the analysis by Schaling (1998), who finds that an asymmetric monetary policy reaction function is optimal in a model with a convex Phillips curve. Nonetheless, despite this improved performance, the forward-looking IFB rule still leads to better overall macroeconomic performance.

24. The table with these results are not reported here but can be obtained by contacting one of the authors.

4. BOOM-AND-BUST CYCLES: SOME ILLUSTRATIVE SIMULATIONS

The previous section used stochastic simulations to derive the implications of alternative monetary policy reaction functions for the average level of performance of the economy, and in particular, how the average level of output depends on the policy rule. Here we consider the dynamic effects on output and inflation of a shock to aggregate demand. The shock is a change in the disturbance term in the excess demand equation that raises output by 1.0 percent relative to the control value in the first quarter. The shock is "on" for just one quarter so that the behavior of the economy from then on reflects solely the dynamics of the model.

We compare two scenarios in which there are different monetary responses to the shock, as described by the two reaction functions in Table 4. In these simulations all variables are initially set at their deterministic steady-state equilibrium values. In this deterministic mode, the unconditional variance of output is zero and $\alpha = 0$, so that $y = y^*$, that is, there is no difference between the equilibrium level of output and the notional level of output at which there is no tendency for inflation to rise or fall. As in the stochastic simulations, the inflation expectations of both private agents and the monetary authority are model consistent, that is, they are the solution values of the model for the current and all future periods. There is no uncertainty regarding the data-generating process, and all agents take full account of the consequences for inflation of the asymmetric Phillips curve and the propagating mechanisms in the dynamic equation for output. Thus, since the current level of inflation depends on private inflation expectations, demand shocks that persist into the future affect today's inflation rate through expectations, as well as directly through the output gap.

Inflation expectations, and therefore actual inflation, are influenced importantly by the nature of the monetary policy reaction function. While the parameters of the behavioral equations are assumed invariant to the different monetary policy response functions, the behavior of agents takes account of the response of the authorities to inflation through the expectations formation process; in this sense our simulations are less subject to the Lucas critique than would be the case with fixed-parameter, backward-looking representations of expectations.

The simulation in Figure 1 shows the results using the forward-looking IFB rule. The shock to demand—which is not anticipated by the monetary authorities—raises aggregate demand initially by 1.0 percent of baseline. Inflation rises in the first quarter by a little over 0.25 percentage points on a year-over-year basis (left middle panel) or by somewhat over 1.0 percentage point at an annual rate on a quarterly basis (right middle panel). With the forward-looking policy reaction function the nominal interest rate rises about 4 percentage points in the first quarter. This policy action has no direct effect on aggregate demand in the first two quarters because of the lag in the response of demand to the real interest rate, and output rises by more than 1.0 percent above control in the second quarter as a result of the estimated propagation effects. Starting in the third quarter, however, the higher real interest rate dampens aggregate demand and by the fifth quarter output falls below control (po-

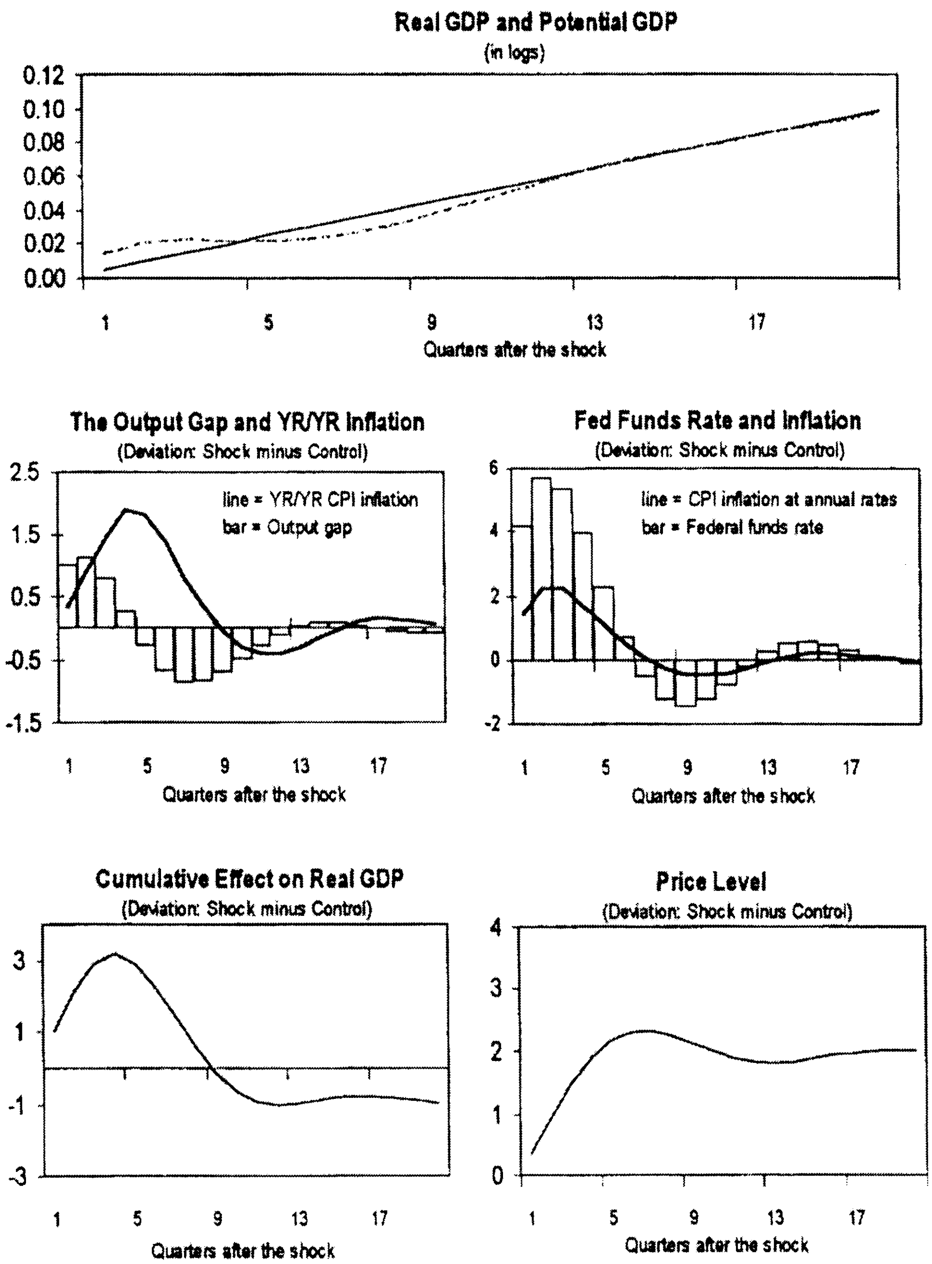

FIG. 1. Aggregate Demand Shock with an Optimized Inflation-Forecast-Based Rule

tential). Output must remain below potential for a period of eight quarters to bring inflation back to the target level. By the end of the third year, output and inflation are back to control with very little overshooting. In the end, the price level is up by just under 2 percent, and the cumulative effect on output is negative, but only slightly, that is, the contraction phase reverses the initial effects of the shock.

The behavior of the economy when the policymaker follows the GTR rule is shown in Figure 2. The initial increase in the Federal funds rate is about the same, but then it must be increased even more and held higher longer to bring inflation under control. This response induces cycles in output and inflation and leads to a much larger cumulative upward drift in the price level (about three times the result in Figure 1) and a significantly larger cumulative loss in output. Indeed, the final result is a cumulative decline in output of close to 6 percent of one year's potential output, which mirrors the result for the average level of output shown in Table 4.

The key difference between the two reaction functions is that forward-looking policy action dampens excess demand pressures sooner, which essentially avoids overshooting. The myopic rule, by contrast, results in periods of overshooting and as a result of the nonlinear Phillips curve there are increases in inflation above control over and above that associated with the positive demand shock in the first quarter. These increases in future inflation become embodied in inflation expectations, which leads to greater persistence of inflation above target. Consequently a longer period of excess supply is needed to bring inflation eventually back to the target level.

The basic lesson to be drawn from these two deterministic simulations is that a forward-looking monetary policy reaction function, which takes into consideration the implications of asymmetry and the lags in the transmission mechanism, will lead to a smoother path of output and limit the cycles that result from a demand shock. By contrast, a myopic response to a demand shock results in cycles in output and in demand overshooting capacity output. Although our example is cast in terms of asymmetry in the Phillips curve, an explicitly forward-looking rule is likely to have similar advantages in any case where there is a nonlinearity in model dynamics. A major advantage of the explicit leads in the control rule is that whatever is driving the model's dynamic response, the rule picks up their effects appropriately from a policy perspective, making that rule more robust to alternative shocks and assumptions about the timing and size of shocks and to the initial conditions of the experiment.

5. CONCLUSIONS

This paper explores the implications of alternative monetary policy reaction functions using a simple stylized model of the U.S. output-inflation nexus that has two important features. First, there are significant lags between changes in interest rates and their effects on aggregate demand and inflation. Second, the Phillips curve is asymmetric, reflecting the effects of short-term capacity constraints, as is suggested by a growing body of recent empirical evidence.

The asymmetry has important implications for the conduct of monetary policy. In

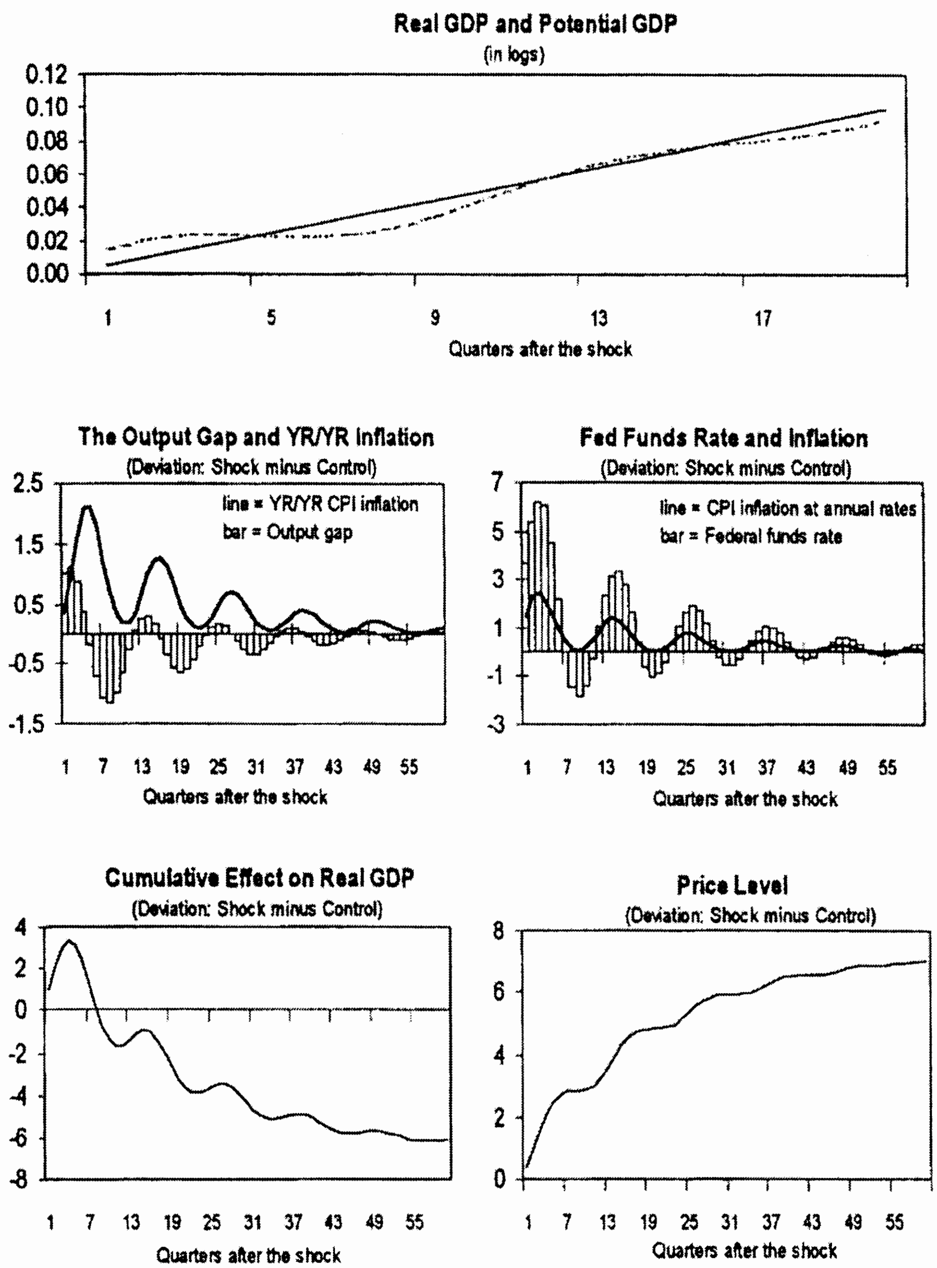

FIG. 2. Aggregate Demand Shock with an Optimized Generalized Taylor Rule

the case of a linear Phillips curve, positive and negative shocks to demand will have symmetric effects on inflation so that the overall impact will average to zero, regardless of the response of monetary policy. By contrast, in the case of an asymmetric (convex) Phillips curve, positive shocks to demand raise inflation to a greater extent than negative shocks of the same magnitude lower it. This property implies that early action to counteract emerging inflation pressures can reduce the need to take stronger action later. Moreover, to the extent that a prompt monetary policy response can succeed in stabilizing output, it will also raise the average level of output. These points are illustrated in the results of stochastic simulations of the model.

The results illustrate also that making the policy reaction function explicitly forward looking, by using leads of the variable to be controlled, provides a transparent and effective way to implement these ideas in a simulation model. The asymmetry in the Phillips curve is but one example of possible nonlinearity in dynamics. An advantage of an explicitly forward-looking rule is that the policy response and resulting cyclical properties of the economy will be more robust to alternative assumptions about dynamic structure and the nature of shocks than will a contemporaneous or backward-looking formulation. The robustness claimed by Levin, Wieland, and Williams (1999) for their generalized Taylor rule is shown to be entirely dependent on their presumption of a linear economy.

While we cannot claim too much from such a simple model in terms of explaining history, we would argue that these results do illustrate an aspect of the U.S. experience with inflation. Mussa (1994, pp. 89–93) has described Federal Reserve behavior during periods when inflation escalated sharply as "falling behind the curve" in that interest rates were not raised fast enough or soon enough to get on top of inflationary pressures before they became entrenched in expectations. Our results illustrate this risk. Based on illustrative but plausible estimates of the monetary transmission mechanism for the United States, we show that a myopic (or constrained) policy rule that delays necessary changes in interest rates can result in higher volatility in the economy and a permanent loss in output.

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