A Forward-Looking Monetary Policy Reaction Function

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The Federal Reserve's reaction function, which summarizes how the Federal Reserve (Fed) alters monetary policy in response to economic developments, plays an important role in macroeconomic and policy analyses. It can be helpful in predicting actual policy actions, thereby serving as a benchmark for assessing the current stance and the future direction of monetary policy. Also, in macro models, the reaction function is central in evaluating Fed policy and determining effects of other macro policies or economic shocks, implying macroeconomic performance may itself depend upon the conduct of monetary policy. Consequently, there is considerable interest in identifying the nature of actual policy pursued by the Fed and determining whether the estimated reaction function fostered or hindered macroeconomic stability.[1]

Although numerous monetary policy reaction functions have been estimated, in this article I estimate one that sheds new evidence on the nature of Fed policy since 1979. In particular, I present and estimate a forward-looking

The views expressed are the author's and not necessarily those of the Federal Reserve Bank of Richmond or the Federal Reserve System.

[1] See, for example, Clarida, Gali, and Gertler (1998b) and Taylor (1998). Clarida, Gali, and Gertler estimate a forward-looking version of the Taylor rule for the post–World War II U.S. economy and find that the interest rate policy in the Volcker-Greenspan period was more responsive to changes in expected inflation than it had been in the pre-Volcker period. They then embody these estimated policy rules within a standard business cycle model and analyze the statistical properties of inflation and output. They show that the estimated pre-Volcker rule permits larger fluctuations in inflation and real output (and therefore greater macroeconomic instability) than does the Volcker-Greenspan rule. Similarly, Taylor (1998) argues that U.S. interest rate policy during the period 1986 to 1997 is well predicted by the Taylor rule and that this period in U.S. monetary policy had the greatest degree of economic stability. Both inflation and real output had smaller fluctuations during this period. He then identifies two other periods, 1879 to 1914 and 1960 to 1979, when policy deviated significantly from the Taylor rule in that the nominal interest rate was not very responsive to both inflation and real output fluctuations. During those periods macroeconomic performance was not as good.

monetary policy reaction function that predicts the actual path of the funds rate during most of the period from 1979 to 1997. The distinguishing characteristic of this policy reaction function is that policy responds to movements in long-term inflationary expectations as evidenced by the behavior of the bond rate, an issue discussed first in Goodfriend (1993) but ignored in the recent empirical work on estimated monetary policy rules.[2] I also examine whether the policy reaction function has changed significantly during the 1990s, especially during Alan Greenspan's tenure as Fed Chairman. Finally, since this reaction function predicts actual policy actions fairly well, I discuss whether policy during the most recent period 1997Q1 to 1998Q2 is consistent with prior Fed behavior. This period is of interest because during this period the Fed did not adjust the funds rate in response to above-trend real growth.

The policy reaction function that I consider here has both backward- and forward-looking components. It assumes that the funds rate responds to actual inflation, increases in expected future inflation, expected output gap, and the bond rate. The funds rate response to the bond rate captures the influence of long-term inflationary expectations on policy. The empirical work here, which focuses on the behavior of the funds rate over two sample periods, 1960Q2 to 1979Q2 and 1979Q3 to 1998Q2, broadly supports this specification. However, policy responses differ across these sample periods. The most significant difference is that the funds rate has responded to movements in the bond rate after 1979 but not before. This indicates that since 1979 the Fed has been very sensitive to long-term expected inflation; so much so that for most of this period the nominal funds rate has moved more than one-for-one with actual inflation. Hence the real as well as the nominal funds rate increased in response to inflation. That is not the case in the pre-1979 period, when the nominal funds rate did not adjust one-for-one with actual inflation. In that period the real funds rate declined in response to actual inflation.

The policy reaction function given here tracks the actual behavior of the funds rate more closely since 1979 than it does in the period before. The sample period 1979Q3 to 1998Q2 spans the tenures of Paul Volcker and Alan Greenspan as Fed Chairmen. The results, however, indicate that the policy reaction function has not changed much between the Volcker and Greenspan periods. Finally, policy during the most recent subperiod 1997Q1 to 1998Q2 is consistent with prior Fed behavior. While the U.S. economy has grown at a very strong rate during this period, actual inflation has fallen steadily and

[2] Clarida, Gali, and Gertler (1998a) and Clarida, Gali, and Gertler (1998b) estimate forward-looking versions of the Taylor rule for G7 countries including the United States, but they do not examine the role of the bond rate. Nor do they examine issues relating to the stability of the reaction function and the ability to predict actual policy. Mehra (1997), on the other hand, does consider the response of policy to the bond rate and finds that the bond rate is significant in the reaction function.

long-term inflationary expectations as measured by the behavior of the bond rate have remained well behaved. Furthermore, there is also some evidence that the economy's underlying trend growth rate may have increased somewhat during the '90s. Once we consider together the influences of all these economic factors on the funds rate target, then the actual funds rate, which hovered around 5.5 percent during this subperiod, is not too different from the value predicted by the policy reaction function. On a more intuitive level, the surprisingly good performance of the economy on the inflation front combined with well-behaved long-term inflationary expectations and higher estimates of trend growth worked to neutralize the tighter policy response indicated by above-trend growth. Accordingly, the absence of any policy move during this subperiod is not out of line with prior Fed behavior.

1. THE MODEL AND THE METHOD

A Forward-Looking Specification

The policy reaction function considered here builds upon the work in Taylor (1993), Mehra (1997), and Clarida, Gali, and Gertler (1998b). The particular specification estimated here can be derived using the following two equations:

$$FR_t^* = \overline{rr} + a_{11} INFL_{t-1} + a_{12}(INFL_{t-1} - INFL^*) + a_{21}(EINFL_{t+1} - INFL_{t-1}) + a_{31}(BR_t - EINFL_{t+k}) + a_{41} EGAP_{t+k}, \text{ and} \tag{1}$$

$$FR_t = (1-\rho)FR_t^* + \rho FR_{t-1} + v_t;\ 0 \le \rho \le 1, \tag{2}$$

where FR_t is the actual funds rate; FR_t^* is the Fed's nominal funds rate target for period t; $INFL$ is the inflation rate; $INFL^*$ is the Fed's inflation target; GAP is the output gap; BR is the bond rate; $\overline{rr}$ is the economy's underlying equilibrium real interest rate; v_t is a stochastic disturbance term; and E is the expectations operator. Equation (1) specifies the economic determinants of the funds rate target. It assumes that the Fed has a target for inflation and a target for the level of output. It also assumes that the Fed pays attention to actual inflation as well as to the expected change in its future direction. Equation (1) thus hypothesizes that the funds rate target each period is determined as a function of the real rate of interest, actual inflation, and gaps between actual inflation and expected output and their respective target levels. Since the Fed is concerned with the expected future direction of inflation, equation (1) also posits that the funds rate target depends upon the change in expected future inflation and the bond rate. The other important assumption implicit in (1) is that the economy's underlying real rate of interest and the Fed's short-term target for inflation are constant in the short run.

Equation (2) specifies the actual funds rate as a weighted average of the last-period funds rate and the current-period funds rate target. It assumes the Fed smoothes short-run changes in interest rates and hence the actual funds rate adjusts gradually to the target implied by economic fundamentals specified in (1) (Goodfriend 1991). The magnitude of the parameter ρ measures the degree of interest rate smoothing in Fed behavior. In equation (2) there is also a shock term v_t, indicating that the Fed may deviate transitorily from its systematic rule in (1). I, however, assume these transitory deviations from the policy rule are not serially correlated, as in true "policy shocks." If we substitute (1) into (2), we get (3), which is the policy reaction function investigated here.

$$\begin{aligned} FR_t = {} & (1-\rho)(\overline{rr} - a_{12}INFL^*) + \rho FR_{t-1} + (a_{11} + a_{12})(1-\rho)INFL_{t-1} \\ & + a_{21}(1-\rho)(EINFL_{t+1} - INFL_{t-1}) + a_{41}(1-\rho)(EGAP_{t+1}) \\ & + a_{31}(1-\rho)(BR_t - EINFL_{t+1}) + v_t, \end{aligned} \tag{3}$$

where all variables are defined as before. Equation (3) is the short-run policy reaction function where the funds rate in period t is determined in part by its actual value in the previous period and in part by previous, current, and expected future values of economic factors. The reaction function indicates that the funds rate rises if actual inflation increases, if future inflation is expected to increase, if the bond rate moves relative to its value consistent with the Fed's current forecast of near-term expected future inflation, or if the expected future output gap is positive. The parameters $a_{ij}(1-\rho), i = 2, 3, 4, j = 1, 2$, measure these short-run responses, their magnitudes being determined in part by the degree of interest rate smoothing in Fed behavior. If the Fed does not smooth interest rates, then ρ is zero and the funds rate adjusts each period in response to changes in its economic determinants. The coefficients $a_{ij},\ i = 2, 3, 4,\ j = 1, 2$, then measure the responses of the funds rate target to economic fundamentals within each period. Consequently, the period t responses are the long-term responses.

The key feature of the short-run reaction function (3) is that the funds rate is assumed to respond to long-term inflationary expectations imbedded in the bond rate. Goodfriend (1993) has convincingly argued that in order to establish and maintain credibility to low inflation, the Fed has reacted to the long bond rate. However, since an expected future inflation variable is already included in the reaction function, the bond rate should influence the funds rate only if it contains information beyond that which is already imbedded in the Fed's current forecasts of the future inflation rate. As a result, the funds rate target is assumed to respond to deviations of the bond rate as measured from the expected future inflation rate.

We define the steady state as the one in which the Fed has achieved its short-term objectives for inflation and real output and in which the public's expectations of inflation are stabilized whereby long-term expected inflation equals the constant inflation target. Clearly the bond rate has no role in the steady state because the long-term expected inflation also equals the constant target inflation. Under this definition of the steady state (with $EGAP_{t+1} = 0$, $EINFL_{t+1} = INFL_{t-1} = INF^*, a_{31} = 0, a_{11} = 1$), the policy reaction function (1) has the property that the nominal funds rate target equals the inflation rate plus the economy's underlying real rate of interest, i.e., $\bar{rr} + INFL_t$.[3] The policy reaction function (3) has thus embedded in it the Fisher relation as applied to the nominal funds rate target, indicating that economic fundamentals such as the inflation rate and the real rate of interest are the steady-state determinants of the funds rate target.

The component $\bar{rr} + (a_{11} + a_{12})INFL$ in (1) is of interest, however, for one more reason. It provides information about the long-run response of the nominal funds rate to inflation.[4] In particular, the estimated coefficient $(a_{11} + a_{12})$ that appears on the level of actual inflation in (1) measures the net response of the funds rate to three inflation variables.[5] If its estimated value is above unity during a given sample period, it indicates that, as a result of the Fed's short-term reactions to inflation indicators, both the nominal and real funds rate target rose in response to inflation. On the other hand, if the estimated value is less than unity, then it indicates the real funds rate target declined in response to inflation. This information can be useful in assessing whether or not monetary policy is neutral during a given sample period.

It is also worth pointing out that the short-term policy reaction function (3) studied here is similar in some respects to the Taylor rule recently estimated in Taylor (1998). The policy rule estimated there is given in (4):

$$FR_t^* = \bar{rr} + INF_t + d_1(INF_t - INF^*) + d_2 GAP_t; FR_t = FR_t^*, \qquad (4)$$

where INF is measured by the average inflation rate over the past four quarters and all other variables are defined as before. First note that the reaction function (3) studied here collapses to the policy rule (4) if we substitute actual for expected output gap and set $\rho = 0,\ a_{11} = 1.0,\ a_{12} = d_1,\ a_{21} = a_{31} = 0,\ a_{41} = d_2$. In other words, according to the policy rule (4), the Fed does not smooth interest rates, responds only to actual inflation and the output gap, and ignores altogether the behavior of forward-looking inflation indicators in setting the funds rate target. Therefore one can interpret the policy rule estimated here as one that relaxes the restrictions implicit in the estimated Taylor rule.

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[3] I am implicitly assuming that the bond rate has been stripped of its assumed constant real rate component. In the empirical work, the bond rate variable $(BR - EINFL_{t+1})$ used has been demeaned.

[4] This is the long-run funds rate equation estimated in Mehra (1997) and is also the steady-state component of the Taylor rule (Taylor 1993).

[5] To see this result, rewrite equation (1) so that all three inflation variables are in levels. Then the coefficients that appear on levels of these three variables $(INFL, EINFL, BR)$ sum to $(a_{11} + a_{12})$.

Estimating the Forward-Looking Reaction Function

The reaction function (3) contains unobserved expected values of inflation and output gap. In estimating (3), I replace unobserved expected values with actual values and assume that the Fed's expectations of these variables are rational and hence uncorrelated with time $t-1$ information known to the central bank as in (5):

$$\begin{aligned} INFL_{t+1} &= E(INFL_{t+1}/I_{t-1}) + vp_{t+1} \\ GAP_{t+1} &= E(GAP_{t+1}/I_{t-1}) + vy_{t+1}, \end{aligned} \tag{5}$$

where vp_{t+1} and vy_{t+1} are forecast errors that are uncorrelated with $t-1$ dated information used by the central bank to forecast inflation and the output gap. If we eliminate the unobserved expected values from (3), we can rewrite (3) as (6):

$$\begin{aligned} FR_t = {} & (1-\rho)(\overline{rr} - a_{12}INF^*) + \rho FR_{t-1} + (a_{11} + a_{12})(1-\rho)INFL_{t-1} \\ & + a_{21}(1-\rho)(INFL_{t+1} - INFL_{t-1}) + a_{41}(1-\rho)GAP_{t+1} \\ & + a_{31}(1-\rho)(BR_t - INFL_{t+1}) + vv_t, \end{aligned} \tag{6}$$

where $vv_{t+1} = v_t - (a_{21} - a_{31})(1-\rho)vp_{t+1} - a_{41}(1-\rho)vy_{t+1}$. The composite error term, vv_t, is serially uncorrelated as both vp_{t+1} and vy_{t+1} are serially uncorrelated. But it is correlated with period $t+1$ values of actual inflation and output gap. That is, the disturbance term in (5) is correlated with the right-hand side explanatory variables. However, it can be verified that vv satisfies orthogonality conditions expressed in (7):

$$E(vv_t/I_{t-1}) = 0. \tag{7}$$

That is, the composite error term vv_t is uncorrelated with $t-1$ dated information used by the central bank to forecast one-period-ahead inflation and the output gap. That suggests equation (5) can be estimated by instrumental variables, using variables in the information set I_{t-1} as instruments. In particular, I follow Clarida, Gali, and Gertler (1998b) and estimate (5) using Hansen's (1982) generalized method of moments estimator. Under the identifying assumptions (7), this procedure produces efficient instrumental variables estimates. Furthermore, the procedure generates a test of identifying restrictions (7) used to estimate the model parameters.[6]

[6] I performed the generalized method of moments (GMM) estimation using the statistical package Regression Analysis for Time Series (version 4). The GMM is an efficient instrumental variables estimator. If we specify the list of instruments that are assumed to be uncorrelated with the disturbance term (vv_t in [7]) and if we know exactly the covariance matrix of this disturbance term, then the GMM estimator is in fact the generalized instrumental variables estimator of the form given below:

$$\beta = [(X'Z)(Z'\Omega Z)^{-1}(Z'X)]^{-1}(X'Z)(Z'\Omega Z)^{-1}Z'y, \tag{a}$$

Data, Definition of Economic Variables, and Empirical Specifications of the Funds Rate Equation

The empirical work here estimates the reaction function over two sample periods, 1960Q2 to 1979Q2 and 1979Q3 to 1998Q2. It is widely believed that in the second subperiod the Fed made serious efforts to reduce the trend rate of inflation and contain inflationary expectations and that this deflationary policy was set in motion when Paul Volcker became Fed Chairman in late 1979. It is also believed that such policy has continued through the current regime of Alan Greenspan. Hence the estimated monetary policy reaction function is likely to differ between pre- and post-1979 periods.[7]

With regard to data and definitions, the funds rate variable (*FR*) is the average quarterly value of the effective funds rate. Inflation (*INFL*) is measured by the behavior of the (chain-weighted) GDP deflator. The output gap variable (*GAP*) is measured as the excess of actual over potential GDP. I consider two alternatives about the Fed's estimate of potential GDP. In one I follow the evidence in Hodrick and Prescott (1997) that potential GDP has a smoothly varying trend and that this trend is well approximated by passing real GDP through the Hodrick-Prescott (HP) filter with the smoothness parameter λ set at 1600.[8] Taylor (1998) also estimates policy rules with series on the potential output generated with the HP filter. Alternatively, following Clarida, Gali, and Gertler (1998b), I also consider results using potential GDP estimated from a fitted quadratic function of time. This specification assumes that trend GDP is

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where X is the matrix of observations on the explanatory variables, Z is the matrix of observations on instruments, Ω is the covariance matrix of the disturbance term, and y is the vector of observations on the dependent variable. In the special case where $\Omega = \sigma^2 I$, so that the disturbance term vv_t is both homoscedastic and serially uncorrelated, the estimator (a) reduces to the simple instrumental variables estimator. However, in practice we do not know the form of Ω. But as Hansen (1982) shows, it is possible to compute consistent estimators using a procedure that imposes little structure on the matrix Ω. In particular, the estimates here are generated using a two-step procedure. In step one, the policy reaction function is estimated using the instrumental variables with $\Omega = \sigma^2 I$, and the residuals are computed. In step two, the matrix $(Z'\Omega Z)$ is estimated using residuals as suggested in Hansen (1982) and the GMM estimator is computed replacing the component $(Z'\Omega Z)^{-1}$ in (a) by its estimated value. In addition to specifying the list of instruments, one has to specify the length of lags on the instruments. Moreover, if the model suggests the presence of serial correlation, then one can take that into account in specifying the matrix Ω. The empirical work here is performed using four lags of instruments. Since the policy reaction function focuses on one-step-ahead expected values, the disturbance term under that assumption is serially uncorrelated.

[7] The empirical work in previous research also indicates that policy responses differ significantly across these two sample periods (Mehra 1997; Clarida, Gali, and Gertler 1998b; and Taylor 1998).

[8] The magnitude of the smoothness parameter λ determines the variability of the trend component. The larger the value of λ, the smaller the variability of its trend component. If λ is chosen to be infinity, then the filtered series approaches the least squares fit of a linear trend model. Hodrick and Prescott (1997), however, show that small changes in the value of the smoothness parameter chosen ($\lambda = 1600$) do not much alter the business cycle properties of real GDP.

deterministic as opposed to being stochastic. The long-term bond rate (*BR*) is measured here by the nominal yield on ten-year U.S. Treasury bonds.

In some previous studies, including Mehra (1997), lagged money growth is significant when included in the reaction function. In order to investigate this issue, I also include money growth in the policy reaction function. As in previous studies, money is defined by M1 until 1982Q3 and by M2 thereafter. Moreover, as in previous studies, money growth for the period 1979Q3 to 1982Q3 is included interacting with a slope dummy variable that is defined to be unity over this subperiod and zero otherwise. This formulation is consistent with the popular view that the Fed's "new operating procedures" paid considerable attention to M1, and consequently such procedures may have been a source of movements in the funds rate target during this period. McCallum and Nelson (1998) also report that the New Operating Procedure dummy is generally significant when included in policy rules estimated there.[9] Given the above-noted considerations, the policy reaction function estimated here is expressed in the following form:

$$\begin{aligned} FR_t = {} & (1-\rho)a_0 + \rho FR_{t-1} + a_1(1-\rho)INFL_{t-1} + a_2(INFL_{t+1} - INFL_{t-1}) \\ & + a_3(BR_t - INFL_{t+1}) + a_4 GAP_{t+1} + a_5 M1_{t-1} + vv_t, \end{aligned} \tag{8}$$

where $a_0 = \overline{rr} - a_{12}INFL^*, a_1 = (a_{11} + a_{12}), a_2 = a_{21}(1-\rho), a_3 = a_{31}(1-\rho)$, and $a_4 = a_{41}(1-\rho)$. $M1$ in (8) is money growth measured by the behavior of M1 nd all other variables are defined as before. The instrument list consists of a constant and four lagged values of the funds rate (*FR*), the inflation rate (*INFL*), the output gap (*GAP*), the bond rate (*BR*), and the growth rate of real GDP. For the subperiod 1960Q2 to 1979Q2, the instrument list also included four lagged values of M1 growth. For the other sample period the instrument list includes money growth interacting with a slope dummy that is defined to be 1 over 1979Q3 to 1982Q3 and zero otherwise.[10]

2. EMPIRICAL RESULTS

Estimates of the Forward-Looking Reaction Function

Table 1 presents GMM estimates of the short-run monetary policy reaction function (8) for two sample periods, 1960Q2 to 1979Q2 and 1979Q3 to 1998Q2.

[9] In their empirical work, the New Operating Procedure dummy is simply an intercept dummy, defined to be unity over 1979Q3 to 1982Q3 and zero otherwise. Here, the New Operating Procedure dummy is a slope dummy on M1 growth.

[10] The choice of instruments is motivated by the view that the Fed's forecast of expected inflation and the output gap depends upon the past history of inflation, the output gap, real growth, monetary growth, and the bond rate. In addition, the history of policy actions measured by the past behavior of the funds rate is also relevant. As is clear, many of the economic variables included in the Fed's information set are consistent with the Phillips curve and monetarist views of the inflation process.

Table 1 GMM Estimates of the Forward-Looking Reaction Function

Sample Period	a_1	a_2	a_3	a_4	a_5	ρ	a_0	x_1^2	J
Panel A: HP Trend									
1960Q2–1979Q2	0.71	0.34	−0.11	0.20	−0.04	0.76	2.6	2.3	24.0
	(3.8)	(3.3)	(1.0)	(3.6)	(1.0)	(9.6)	(2.9)	(0.13)	(0.15)
1979Q3–1998Q1	0.64	0.26	0.27	0.41	0.28	0.69	4.6	5.3	17.9
	(4.2)	(2.2)	(7.4)	(4.8)	(7.5)	(13.5)	(11.7)	(0.02)	(0.27)
Panel B: Quadratic Time Trend									
1960Q2–1979Q2	0.70	0.32	−0.06	0.12	−0.05	0.77	2.5	1.8	22.4
	(3.2)	(2.6)	(0.5)	(4.1)	(1.0)	(8.5)	(2.5)	(0.17)	(0.21)
1979Q3–1998Q1	1.2	0.40	0.46	0.26	0.26	0.59	2.9	2.8	13.1
	(8.7)	(4.2)	(7.1)	(7.2)	(6.9)	(12.1)	(7.4)	(0.09)	(0.60)

Notes: The coefficients (t-values in parentheses below) reported above are from the funds rate equation (8) of the text:

$$FR_t = (1-\rho)a_0 + \rho FR_{t-1} + (1-\rho)a_1 INFL_{t-1} + a_2(INFL_{t+1} - INFL_{t-1}) + a_3(BR_t - INFL_{t+1}) + a_4 GAP_{t+1} + a_5 M1_{t-1},$$

where *FR* is the federal funds rate; *INFL* is the inflation rate; *M*1 is M1 growth; *GAP* is the output gap; and *BR* is the bond rate. For the sample period 1979Q3–1998Q1, money growth is included interacting with a slope dummy variable D^*M1, where *D* is a dummy that is 1 over 1979Q3–1982Q3 and 0 otherwise. The instrument set consists of a constant, four lagged values of the funds rate, inflation, the bond rate, money growth, output gap, and real *GDP* growth. *J* is the test of overidentifying restrictions and is distributed Chi-squared. x_1^2 is the Chi-squared statistic that tests the null hypothesis $a_1 = 1$. Significance levels of these statistics are reported in parentheses below. The constant term a_0 is $(rr - a_{12}INF^*)$, where *rr* is the real rate of interest and INF^* is the Fed's inflation target.

Panel A in Table 1 contains results that occur when potential output is measured with the HP trend, and Panel B contains results that occur when instead the quadratic trend is used. For all variables the coefficients reported are the short-run coefficients, with the exception of the one for actual inflation. For that variable the coefficient reported is the long-run coefficient a_1; the short-run coefficient can be recovered by multiplying the reported coefficient by $(1-\rho)$, i.e., $a_1(1-\rho)$ in (8).[11] The J-statistic reported there tests the null hypothesis that

[11] As noted before, the policy reaction function (8) is nonlinear in parameters, with ρ appearing in front of many variables including FR_{t-1}. One could estimate (8) with or without imposing these nonlinear restrictions. If restrictions are imposed, then one gets estimates of the long-term coefficients and the short-term smoothness parameter ρ. Given long-term estimates, the short-term coefficients are recovered by multiplying the estimated long-term coefficients by $(1-\rho)$. Alternatively, one may ignore these nonlinear restrictions and estimate directly the following version of equation (8):

$$FR_t = d_0 + d_1 FR_{t-1} + d_2 INFL_{t-1} + d_3(INFL_{t+1} - INFL_{t-1}) + d_4(BR_t - INFL_{t+1}) + d_5 GAP_{t+1} + d_6 M1_{t-1} + vv_t,$$

orthogonality restrictions imposed under GMM estimation are consistent with data. If this statistic is small, then it indicates the restrictions are not rejected by the data; therefore GMM estimates are consistent.

If one focuses on post-1979 estimates, one can see that all estimated coefficients have expected signs and are generally statistically significant (see t-values in parentheses below estimates in Panels A and B, Table 1). Those estimates indicate that the funds rate rises if actual inflation rises, if future inflation is expected to increase, if output is expected to be above trend, or if the current-period bond rate moves relative to the expected future inflation rate. The estimated short-run coefficients (a_2, a_3) that appear on two future inflation indicators are positive, indicating the funds rate target responded to expected changes in the future direction of actual inflation. In particular, the estimated short-run coefficient (a_3) on the bond rate is 0.3 to 0.4, which indicates the funds rate increases 30 to 40 basis points in response to 1 percentage point increase in the bond rate.[12] The M1 growth dummy is significant, which shows the influence of "new operating procedures" on the funds rate. The point-estimate of the coefficient that appears on the lagged funds rate (ρ) is between 0.6 to 0.8, which indicates the presence of considerable interest rate smoothing in Fed behavior. Finally, the reported J-statistic is small, which indicates the restrictions imposed in deriving GMM estimates are consistent with data.[13]

The results do not change qualitatively between two alternative measures of potential output used here. However, magnitudes of individual coefficients that measure responses of the funds rate target to different economic fundamentals are sensitive to the measure of trend used. The one difference to highlight is the long-run, estimated coefficient (a_1) that appears on the level of actual inflation. This coefficient is greater than unity if output gap is estimated with the quadratic trend, suggesting that in the post-1979 period, the real funds rate target rose in response to inflation. However, the point estimate of a_1 falls below unity if output gap is estimated instead with the HP trend (compare estimates of a_1 in Panels A and B, Table 1). Nonetheless, as discussed later, the point

where all variables are defined as before. The estimated coefficients $d_i, i = 0,1,2,3,4,5,6$, are then estimates of short-term coefficients. The long-term coefficients can then be recovered by multiplying the short-term estimates by $[1/(1 - d_1)]$. Both these procedures yield qualitatively similar results. The empirical work reported here is based mostly on estimates generated using nonlinear restrictions.

[12] Since the Fed smoothes interest rates in the short run, the long-term estimated response measured by $a_3/(1 - \rho)$ is stronger. In the HP trend case, the estimated long-run response is $0.26/(1 - 0.69)$, i.e., 0.87.

[13] The overall fit of the regression as measured by the standard error of estimate is better when four lagged values of the instruments are used in estimation than it is when two or three lagged values are used. The results, however, do not change qualitatively if the policy reaction function is instead estimated using two to three lagged values of the instruments. In particular, the bond rate remains significant in the post-1979 period. The J-statistic continues to confirm the condition in (7) that the error term is not correlated with instruments.

estimate of a_1 has remained above unity in most other subperiods ending in the '90s (see estimates of a_1 in Tables 3 and 4 for various subperiods). Together these estimates indicate that during most of the Volcker-Greenspan period the real funds rate target increased in response to actual inflation.[14]

If one focuses on pre-1979 estimates, one can see that, like the post-1979 estimates, these estimates indicate that the funds rate target rises in response to actual inflation, to increases in expected future inflation, and to the positive expected output gap. But pre-1979 estimates differ significantly from post-1979 estimates in several ways. First, the bond rate is not significant, indicating that in the pre-1979 period the Fed did not adjust the target in response to movements in the bond rate. This result on the absence of long-term inflationary expectations on policy is robust to changes in the measure of trend used. Second, money growth is also not significant.[15] Third, the long-run, estimated coefficient (a_1) that measures the response of the funds rate to inflation is economically less than unity, indicating that the funds rate did not adjust one-for-one with inflation. That is, the real funds rate declined in response to actual inflation prior to 1979. This decline occurred despite the evidence here that in the pre-1979 period the funds rate is responsive to movements in near-term expected future inflation (see estimates of a_2 in Table1). The absence of response to the bond rate may explain why the real funds rate target declined in response to actual inflation during the pre-Volcker period.

Assessing the Predictive Content of the Policy Reaction Function: Pre- and Post-1979

The key hypotheses posited about Fed behavior here are that the fund rate responds to economic fundamentals specified in (3). The estimates discussed above lend support to these hypotheses. In order to assess further the empirical plausibility of these hypotheses, I examine how well the policy reaction function predicts the actual behavior of the funds rate during the two sample periods. The predictive content is evaluated with the following regression:

$$FR_t = c + dPFR_t + ee_t, \tag{9}$$

[14] Table 1 also reports estimates of the constant term $a_0 = \overline{rr} - a_{12}INFL^*$ in (8). But, as is obvious, it is not possible to recover estimates of the assumed constant real rate $\overline{rr}$ without information about the Fed's constant inflation target.

[15] In the forward-looking reaction function estimated here, money growth, when included, is generally not significant, with the exception of the brief "new operating procedures" period 1979Q3 to 1982Q3. This result is in contrast with the one reported in many previous studies, where money growth is significant. One explanation of these different results is that the reaction functions in these studies are backward-looking. Hence money growth may be significant in these studies not because the funds rate responds to money growth but because past money is giving information about future economic factors that are omitted from the reaction function.

where *PFR* is the funds rate predicted by the policy reaction function and *ee* is the disturbance term. The predicted values used in (9) are the dynamic within-sample simulated values of the policy reaction function (8), generated using actual values of explanatory variables. However, in order to highlight the importance of the effect of interest rate smoothing on the funds rate target, I also generate predictions of the funds rate with the smoothing parameter ρ in (8) set to zero. The predicted funds rate is an unbiased predictor of the actual funds rate if $c = 0$ and $d = 1$.[16]

Table 2 reports estimates of the regression (9) for two sample periods, 1961Q1 to 1979Q2 and 1981Q1 to 1998Q1. The results are reported for both measures of the output gap and with and without accounting for the effect of interest rate smoothing (see Panels A and B). (Figures 1 through 4 chart predicted and actual values of the funds rate for the HP filtered output gap.) If one focuses on post-1979 sample results with smoothing, one can see that the coefficient that appears on the predicted fund rate variable *PFR* in (9) is close to unity. x_1^2 is the Chi-squared statistic that tests the null hypothesis that $(c, d) = (0, 1)$. This statistic is not significant at the 5 percent level, suggesting the predicted funds rate is an unbiased predictor of the actual funds rate. The result is not sensitive to the measure of trend used or to the presence of interest rate smoothing in Fed behavior (compare results in Panels A and B, Table 2). Figures 2 and 4 tell the same story, which is that the funds rate moves closely with the level determined by economic fundamentals as specified in (1). The results, however, are different in the pre-1979 period. When the focus is on results without smoothing, the coefficient that appears on the predicted funds rate *PFR* is significantly below unity and this result is not sensitive to the measure of the output gap. If one allows for the effect of interest rate smoothing on the funds rate, the coefficient that appears on the predicted funds rate does however move closer to unity (compare Figure 1 with Figure 3). But the predicted funds rate is still a biased predictor of the actual funds rate in one specification of the output gap (compare estimates in Panels A and B, Table 2). Hence the hypothesis that the funds rate target is a function of economic variables as specified in the policy reaction function (1) is a better description of Fed policy in the post-1979 period than it is in the previous period.

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[16] The result that the predicted funds rate may be a biased predictor of the actual funds rate in (9) does not imply that the stochastic disturbance term in the estimated policy reaction function (8) is biased and the estimation procedure used here is therefore invalid. The reason is that the result above—that the predicted funds rate is a biased predictor—may arise because the predicted values used in regression (9) are dynamic, not static. The policy reaction function (8) instead is estimated using actual values of explanatory variables including the lagged funds rate. Hence the disturbance term, though unbiased in (8), may appear biased in (9) if predicted values used are dynamic.

Table 2 In-Sample Predictability of the Forward-Looking Reaction Function

Panel A: Actual and Predicted Funds Rate, Without Smoothing

Sample Period	HP Trend			Quadratic Trend		
	c	***d***	$x_1^2(2)$	***c***	***d***	$x_1^2(2)$
1961Q1–1979Q2	2.7	0.46	38.5*	2.2	0.53	25.9*
	(3.5)	(4.9)		(3.5)	(5.7)	
1981Q1–1998Q1	1.0	0.89	1.8	0.64	0.93	2.6
	(1.3)	(10.1)		(1.6)	(20.9)	
Panel B: Actual and Predicted Funds Rate, With Smoothing						
1961Q1–1979Q2	0.4	0.89	5.3**	0.2	0.88	4.3
	(1.2)	(18.9)		(0.2)	(8.2)	
1981Q1–1998Q1	−0.27	1.0	0.5	0.2	0.96	0.8
	(0.5)	(16.7)		(0.6)	(22.7)	

*Significant at the 5 percent level.

**Significant at the 10 percent level.

Notes: The coefficients (t-values in parentheses below) reported above are from regressions of the form $FR_t = c + dPFR_t$, where FR is the actual funds rate, and PFR_t is the predicted funds rate. The predicted values are generated using the policy rule (8) of the text, with ρ set to zero (see Panel A) and with ρ set to its estimated value (see Panel B). The predicted values used in Panel B regressions are within-sample but dynamic. x_1^2 is the Chi-squared statistic that tests the null hypothesis $(c, d) = (0, 1)$.

Has the Reaction Function Changed during the Greenspan Period?

It is commonly believed that the Fed under Alan Greenspan has maintained an anti-inflationary stance set in motion when Paul Volcker became the Fed Chairman. In fact, as discussed above, the forward-looking reaction function (8) estimated here is consistent with the actual path of the funds rate over the Volcker-Greenspan period, indicating the policy reaction function may not have changed much over this period. Nevertheless, I investigate this issue further by comparing the reaction function between Volcker and Greenspan periods, 1979Q4 to 1987Q3 and 1987Q3 to 1998Q2. The main problem with estimating separate reaction functions over the Volcker and Greenspan periods is that those estimates may be subject to the small sample bias. In fact, during the Greenspan period both the bond rate and inflation have not varied much. In view of these considerations I estimate the reaction function using the technique of rolling regressions, which generates somewhat larger subsamples. In particular, I begin with estimating the reaction function over the Volcker period 1979Q4 to 1987Q3 and then continually reestimate it advancing the end date by four quarters, keeping the start date fixed. The resulting estimates of key coefficients

Figure 1 Actual and Predicted Funds Rate, With Smoothing; HP Trend Pre 1979

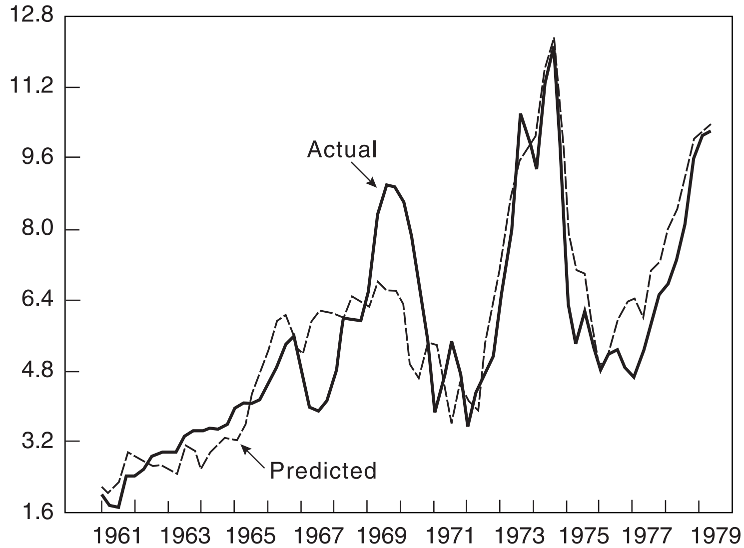


Figure 2 Actual and Predicted Funds Rate, With Smoothing; HP Trend Post 1979

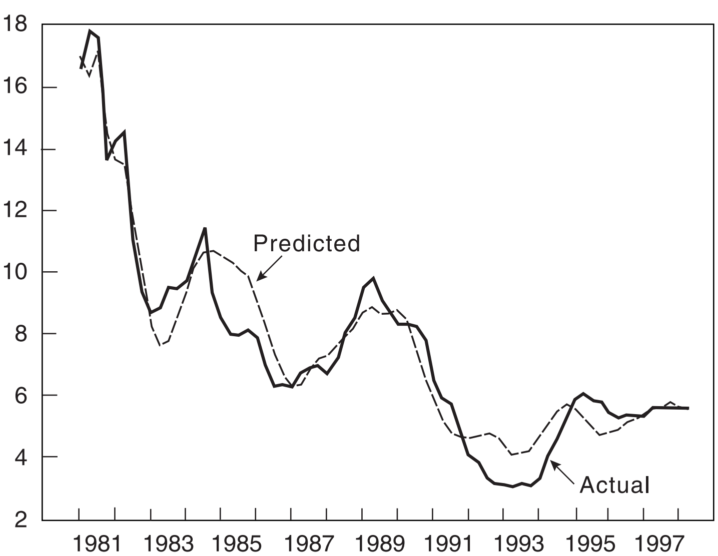


Figure 3 Actual and Predicted Funds Rate, Without Smoothing; HP Trend Pre 1979

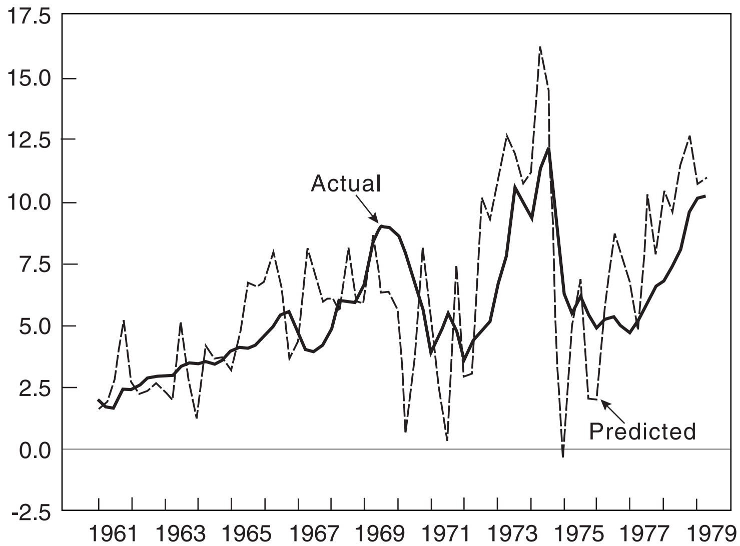
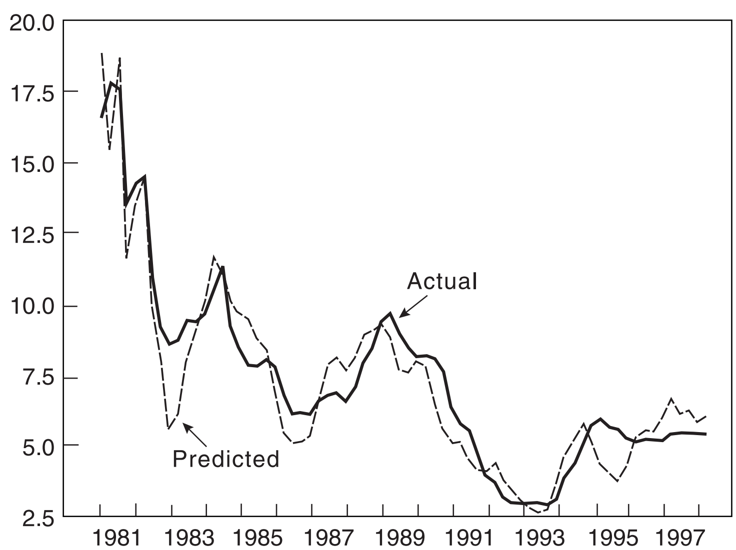


Figure 4 Actual and Predicted Funds Rate, Without Smoothing; HP Trend Post 1979



are reported in Tables 3 and 4. Table 3 reports estimates using the HP filtered output gap, and Table 4 gives estimates using the quadratic trend output gap.

If we focus on short-run estimated coefficients, $a_i, i = 2, 3, 4$, they all have theoretically expected signs in all subsamples considered here and are generally statistically significant (t-values not reported). The estimated sizes of the individual coefficients are relatively stable over different subsamples, with few exceptions. Of particular interest is the long-run, estimated coefficient a_1 that appears on the level of actual inflation. It is mostly above or close to unity in all subsamples, with the exception of those ending in 1996 and 1997. In those two subsamples the magnitude of the estimated coefficient is sensitive to the measure of the output gap used: it falls below unity if the output gap is estimated with the HP trend (compare estimates of a_1 in Tables 3 and 4). These estimates thus suggest that the Fed during most of the Greenspan period has responded aggressively enough to expected inflation indicators that the real funds rate has increased in response to actual inflation.

Predicting the Funds Rate during the Greenspan Period

The results discussed in the previous section indicate that estimates of the individual coefficients that measure responses of the funds rate to economic fundamentals do display considerable subsample variability during the Volcker-Greenspan period. But despite such variability, a cursory look at Figure 2 indicates that the policy reaction function here tracks the actual behavior of the funds rate fairly well in the ’80s and the ’90s. In this section I provide additional evidence on this issue by examining the out-of-sample predictive performance of the reaction function over the period 1988Q1 to 1998Q2, which for the most part spans the current tenure of Alan Greenspan as the Fed Chairman.

Table 5 presents the predicted values of the funds rate. The predicted values are the dynamic one-year-ahead forecasts of the funds rate that are conditional on actual values of the economic fundamentals and are generated using rolling regressions over the forecast period. Panel A in Table 5 presents the predicted values generated with the HP trend and Panel B presents the predicted values with the quadratic trend. (Figures 5 and 6 chart the quarterly values for this period.) Actual values of the funds rate, prediction errors, and summary error statistics are also presented. As shown, the reaction function tracks the actual funds rate fairly well over the forecast period. The mean value of the prediction error is very small and the root mean squared error is about 0.4 of a percentage point. The average annual prediction errors are not statistically significant, with the exception of the year 1995. In 1995 the prediction error is positive, and it is more than twice the root mean squared error. During that year real growth decelerated from its rapid pace of the previous year, but the Fed did not lower the funds rate in response to such a slowdown. Nevertheless, since 1995 the magnitude of the prediction error has steadily declined.

Table 3 Rolling Regression Estimates of the Reaction Function during Volcker-Greenspan Periods, GDP Deflator and HP Trend

Sample Period Ends in	a_1	a_2	a_3	a_4	ρ	a_0	$J(sl)$
1987Q4	1.0	0.6	0.48	0.25	0.42	3.6	17.4 (0.29)
1988Q4	1.0	0.6	0.45	0.28	0.43	3.4	21.6 (0.12)
1989Q4	1.1	0.5	0.37	0.40	0.50	3.5	19.3 (0.20)
1990Q4	1.2	0.6	0.35	0.32	0.50	3.1	16.0 (0.38)
1991Q4	1.2	0.6	0.35	0.36	0.51	3.1	14.1 (0.52)
1992Q4	1.2	0.6	0.35	0.41	0.56	2.7	15.0 (0.45)
1993Q4	1.4	0.7	0.39	0.39	0.57	1.9	16.1 (0.37)
1994Q4	1.5	0.7	0.39	0.38	0.59	1.6	15.5 (0.41)
1995Q4	1.1	0.5	0.33	0.38	0.61	3.2	14.7 (0.47)
1996Q4	0.8	0.4	0.29	0.41	0.64	4.1	16.1 (0.38)
1997Q4	0.7	0.4	0.28	0.32	0.66	4.5	17.1 (0.31)
1987Q3–1998Q1	0.7	0.1	0.28	0.35	0.81	4.7	17.8 (0.27)

Notes: The coefficients above are GMM estimates of the forward-looking reaction function given in Table 1. Unless stated otherwise the estimation period for all regressions begins in 1979Q3 and ends in the year as shown in the first column above. All reported coefficients have significant t-values (not reported), with one exception: a_2 is not significant over 1987Q3–1998Q2.

Table 4 Rolling Regression Estimates of the Reaction Function during Volcker-Greenspan Periods, GDP Deflator and Quadratic Trend

Sample Period Ends in	a_1	a_2	a_3	a_4	ρ	a_0	$J(sl)$
1987Q4	1.2	0.7	0.54	0.17	0.39	3.3	14.6 (0.49)
1988Q4	1.2	0.7	0.54	0.17	0.39	3.1	15.4 (0.42)
1989Q4	1.1	0.6	0.47	0.25	0.50	3.6	14.3 (0.50)
1990Q4	1.3	0.6	0.47	0.23	0.48	3.2	14.5 (0.48)
1991Q4	1.3	0.7	0.49	0.26	0.50	3.0	14.1 (0.52)
1992Q4	1.4	0.7	0.48	0.29	0.54	2.6	15.3 (0.43)
1993Q4	1.5	0.7	0.49	0.30	0.54	2.3	14.3 (0.50)
1994Q4	1.5	0.7	0.49	0.29	0.54	2.2	14.1 (0.52)
1995Q4	1.3	0.5	0.43	0.30	0.59	3.1	13.7 (0.55)
1996Q4	1.2	0.5	0.44	0.31	0.59	3.3	12.6 (0.63)
1997Q4	1.3	0.5	0.45	0.28	0.57	2.9	12.1 (0.60)
1987Q3–1998Q1	1.4	0.2	0.28	0.20	0.73	2.5	17.5 (0.15)

Notes: See notes for Table 3.

Table 5 Actual and Predicted Funds Rate: 1988Q1–1998Q2

		Panel A: HP Trend		Panel B: Quadratic Trend	
Year	**Actual Funds Rate**	**Predicted**	**Error**	**Predicted**	**Error**
1988	7.6	7.8	−0.20	7.9	−0.30
1989	9.2	8.7	0.50	8.6	0.60
1990	8.1	8.2	−0.01	8.1	0.00
1991	5.7	6.0	−0.30	6.0	−0.30
1992	3.5	4.3	−0.80	4.1	−0.60
1993	3.0	3.1	−0.01	2.9	0.10
1994	4.2	4.2	0.00	4.2	0.00
1995	5.8	4.9	0.90*	5.1	0.70
1996	5.3	5.1	0.20	5.4	−0.10
1997	5.5	5.4	0.10	5.9	−0.40
1997Q1	5.3	5.3	0.0	5.9	−0.60
1997Q2	5.5	5.3	0.2	6.5	−1.0
1997Q3	5.5	5.5	0.0	6.7	−1.2
1997Q4	5.5	5.6	−0.1	6.2	−0.7
1998Q1	5.5	5.3	0.2	5.7	−0.2
1998Q2	5.5	5.2	0.3	5.9	−0.04
Mean Error (1988–1997)			0.00		−0.02
Root Mean Squared Error			0.44		0.41

*The prediction error is twice the root mean squared error.

Notes: The predicted values above are generated using the forward-looking reaction functions reported in Tables 3 and 4. The predicted values are the dynamic, one-year-ahead forecasts, generated using rolling regressions over sample periods that all begin in 1979Q3 but end in the year before the forecast period.

Table 5 also presents the quarterly values of the predicted funds rate for the most recent period 1997Q1 to 1998Q2. During this period the U.S. economy has grown at an above-trend growth rate, while inflation has steadily declined. The Fed, however, did not adjust the funds rate target during this subperiod, which remained at 5.5 percent. The funds rate predicted by the reaction function is 5.4 percent if the Fed's estimate of trend GDP is generated with the HP filter, and it is 6.2 percent if instead the quadratic trend is used. There is a difference in prediction because in this subperiod the Fed's estimate of trend GDP is 3.0 percent if the HP trend is used and 1.9 percent if instead the quadratic trend is employed to estimate the output gap. Consequently, the magnitude of the positive output gap is smaller with the HP trend than with the quadratic, thereby suggesting a less tight response to observed above-trend growth. If one believes the popular view that the economy's underlying trend growth rate

Figure 5 Actual and Predicted Funds Rate, Out-of-Sample; HP Trend

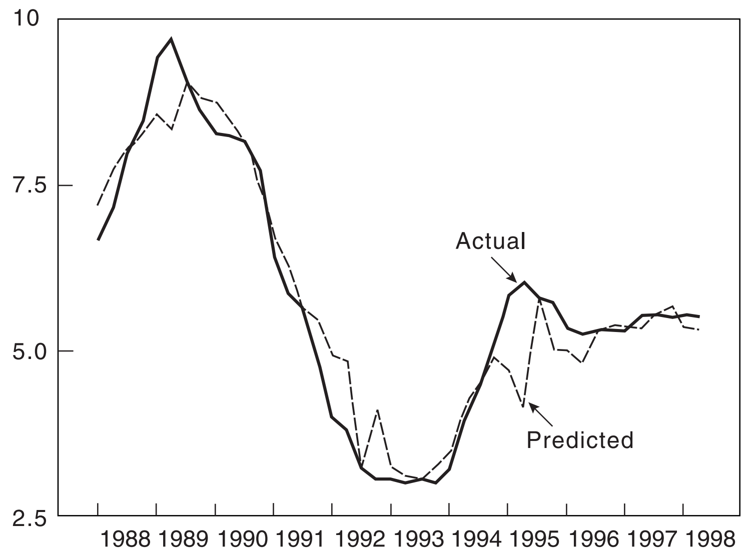
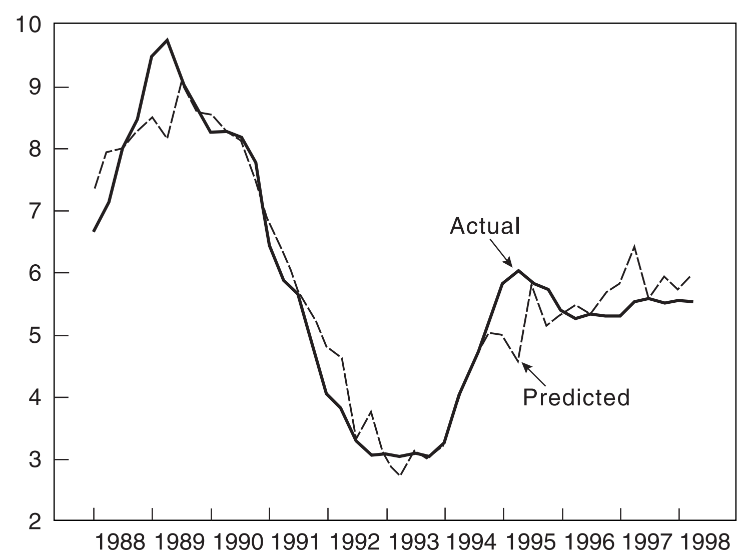


Figure 6 Actual and Predicted Funds Rate, Out-of-Sample; Quadratic Trend



may have increased in the '90s, then one may have more confidence in the reaction function estimated with the HP filtered output gap than in the one with the quadratic. Therefore, the absence of policy response to recent above-trend growth is not inconsistent with prior Fed behavior if one takes seriously the proposition that the economy's trend growth in recent years may be higher than 2 percent estimated using the quadratic trend.

3. CONCLUDING OBSERVATIONS

In this article I estimate a forward-looking monetary policy reaction function that quite accurately predicts the actual behavior of the federal funds rate since 1979. The key property of the estimated reaction function in the Volcker-Greenspan period is that the funds rate target is responsive to movements in long-term inflationary expectations evidenced by the behavior of the bond rate. During this period the Fed has responded aggressively enough to future inflation indicators that the real funds rate target increased in response to actual inflation. Such is not the case in the pre-1979 period, when the real funds rate target declined in response to inflation.

It has been suggested that the U.S. economy experienced macroeconomic stability in the Volcker-Greenspan period because the interest rate policy pursued during this period was very responsive to expected inflation; so much so that the real funds rate increased in response to inflation (Clarida, Gali, and Gertler 1998b; Taylor 1998). The results here indicate that the Fed's willingness to move the funds rate preemptively to react to movements in the bond rate may explain why the funds rate was more responsive to inflation in the Volcker-Greenspan period than it had been in the previous period.

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