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A Taylor Rule and the Greenspan Era

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There is considerable interest in determining whether monetary policy actions taken by the Federal Reserve under Chairman Alan Greenspan can be summarized by a Taylor rule. The original Taylor rule relates the federal funds rate target to two economic variables: lagged inflation and the output gap, with the actual federal funds rate completely adjusting to the target in each period (Taylor 1993).[1] The later assumption of complete adjustment has often been interpreted as indicating the policy rule is "non-inertial," or the Federal Reserve does not smooth interest rates. Inflation in the original Taylor rule is measured by the behavior of the GDP deflator and the output gap is the deviation of the log of real output from a linear trend. Taylor (1993) shows that from 1987 to 1992 policy actions did not differ significantly from prescriptions of this simple rule. Hence, according to the original Taylor rule, the Federal Reserve, at least during the early part of the Greenspan era, was backward looking, focused on headline inflation, and followed a non-inertial policy rule.

Recent research, however, suggests a different picture of the Federal Reserve under Chairman Greenspan. English, Nelson, and Sack (2002) present evidence that indicates policy actions during the Greenspan period are better explained by an "inertial" Taylor rule reflecting the presence of interest rate smoothing.[2] Blinder and Reis (2005) state that the Greenspan Fed focused on

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[1] Taylor (1993) did not estimate the policy rule but chose specific values for the policy response coefficients, the real rate, and the inflation target.

[2] English, Nelson, and Sack (2002) provide empirical evidence for the hypothesis that the Greenspan Fed smoothed interest rates. Woodford (2005) suggests the Federal Reserve under Greenspan, in fact, communicated its interest-smoothing intentions to financial markets by including descriptive, forward-looking sentences in its policy statements to ensure that policy expectations of the financial sector remain aligned with its own outlook for policy. For example, in order to

a "core" measure of inflation in adjusting its federal funds rate target. Clarida, Galí, and Gertler (2000), among others, have shown that a forward-looking Taylor rule that relates the current funds rate target to "expected" inflation and output developments appears to fit the data quite well over the period spanning the tenures of Chairmen Paul Volcker and Alan Greenspan. Orphanides (2001) argues that policy evaluations using policy rules estimated with the final revised data may be misleading.

This article estimates a Taylor rule that address three key features of the Greenspan period highlighted in recent research: the Federal Reserve under Greenspan was forward looking, focused on core inflation, and smoothed interest rates. Furthermore, this article uses the real-time data for economic variables and investigates whether results based on the final, revised data change when the real-time data are used. We also examine whether the use of real-time data leads to a better explanation of policy actions during the Greenspan period.

A Taylor rule incorporating the above-noted three features is shown below in equation (1.3).

$$\begin{aligned} FR_t^* &= \alpha_0 + \alpha_\pi \pi_{t,j}^c + \alpha_y (ln\ y_{t,k} - \ ln\ y_{t,k}^*), && (1.1) \\ FR_t &= \rho FR_{t-1} + (1-\rho) FR_t^* + v_t, && (1.2) \\ FR_t &= \rho FR_{t-1} + (1-\rho)\{\alpha_0 + \alpha_\pi \pi_{t,j}^c && (1.3) \\ & \quad + \alpha_y (ln\ y_{t,k} - ln y_{t,k}^*)\} + v_t, && \end{aligned}$$

where FR_t is the actual federal funds rate, FR_t^* is the federal funds rate target, $\pi_{t,j}^c$ is the j-period ahead forecast of core inflation made at time t, $ln\ y$ is the log of actual output, $ln\ y^*$ is the log of potential output, and v_t is the disturbance term. Thus, the term $(ln\ y_{t,k} - \ ln\ y_{t,k}^*)$ is the k-period ahead forecast of the output gap. Equation (1.1) relates the federal funds rate target to expected values of two economic fundamentals: core inflation and the output gap. The funds rate target is hereafter called the policy rate. The coefficients α_π and α_y measure the long-term responses of the funds rate target to the expected inflation and the output gap. They are assumed to be positively signed, indicating that the Federal Reserve raises its funds rate

deal with the threat of deflation in 2003, policy statements in that year included sentences such as "...policy accommodation can be maintained for a considerable period of time," meaning the Federal Reserve would not raise its funds rate target in response to increases in real growth given the threat of deflation. The intent was to hold long-term interest rates low by quashing expectations that the Fed was on the verge of increasing the funds rate. In 2004, policy statements included phrases such as "...the Committee believes that it can be patient in removing policy accommodation," and "...the Committee believes that policy accommodation can be removed at a pace that is likely to be measured." The latter came to mean 25 basis points at each FOMC meeting. These considerations suggest the Greenspan policy rule should be estimated allowing for the presence of interest-rate smoothing. Blinder and Reis (2005) also argue that the Greenspan Fed used frequent small changes in the funds rate to hit its target for the policy rate suggested by economic fundamentals such as inflation and unemployment.

target if inflation rises and/or the output gap is positive. Equation (1.2) is the standard partial adjustment equation, expressing the current funds rate as a weighted average of the current funds rate target FR_t^* and last quarter's actual value FR_{t-1}. If the actual funds rate adjusts to its target within each period, then ρ equals zero, which suggests that the Federal Reserve does not smooth interest rates. Equation (1.2) also includes a disturbance term, indicating that in the short run, the actual funds rate may deviate from the value implied by economic determinants specified in the policy rule. If we substitute equation (1.1) into (1.2), we get (1.3), a forward-looking "inertial" Taylor rule.[3]

This article estimates the Taylor rule (1.3) using final as well as real-time data. The real-time data consists of the Greenbook forecasts of core CPI inflation and the Congressional Budget Office (CBO) estimates of the output gap.[4] The policy rule estimated using the final data covers all of the Greenspan period from 1987:1 to 2005:4, whereas the rule estimated using the Greenbook forecasts spans part of the Greenspan period from 1987:1 to 2000:4, given the five-year lag in release of the Greenbook forecasts to the public.[5]

The empirical work presented here suggests several conclusions. First, policy response coefficients in the estimated inertial Taylor rule (α_π, α_y, ρ) are all positively signed and statistically significant. The key points to note are: (a) the estimated long-term inflation response coefficient α_π is well above unity, which suggests that the Greenspan Fed responded strongly to expected inflation; (b) the estimated output gap response coefficient α_y is generally below unity, suggesting the presence of a relatively weak response to the output gap; and (c) the estimated partial adjustment coefficient ρ is well above zero, indicating the presence of interest-rate smoothing. The conclusion suggested by the estimated Taylor rule, namely, the Greenspan Fed responded strongly to expected inflation developments ($\alpha_\pi > 1$) but relatively weakly to the output gap ($\alpha_y < 1$), is in line with the recent work by Boivin (2006), who, using a different estimation methodology, reports time-varying estimates of inflation and the output gap response coefficients from 1970 to 1995. For the period

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[3] As is well known, the constant term in the Taylor rule has embedded in it the Federal Reserve's estimates of the short-term real rate and the inflation target. For further explantion, rewrite equation (1.1) of the text as $FR_t^* = rr^* + \pi^* + \alpha_\pi(\pi_{t,j}^c - \pi^*) + \alpha_y(ln\ \ y_{t,k} - ln\ \ y_{t,k}^*)$ where $rr^*$is the real rate and π^* is the inflation target. If we substitute the above equation into equation (1.2) of the text, we get equation (1.3) of the text, where the constant term is now defined as $\alpha_0 = rr^* + (1 - \alpha_\pi)\pi^*$. However, one cannot recover estimates of both $rr^*$and π^*without bringing some additional information. See footnote 17.

[4] The preferred measure of real economic activity (say, the output gap) should be the one used in generating the Greenbook forecasts. However, for a major part of the sample period covered here, the Greenbook has not published estimates of the output gap. Hence, it is quite common in this literature to estimate the policy rules using the CBO estimates of the output (or unemployment) gap.

[5] We lose observations at the beginning and end of the sample period due to leads and lags of inflation in the policy rule. The effective sample period is 1988:1 to 2004:4.

since the mid-1980s, the reported estimated policy coefficients are stable and close to values as reported in this article.[6]

Second, the hypothesis that the Greenspan Fed paid attention to expected inflation and output gap developments is supported by additional test results. Those tests favor a forward-looking inertial Taylor rule over the one in which the Federal Reserve focuses on lagged inflation and the output gap. Furthermore, the results somewhat support the hypothesis that the Greenspan Fed was focused on core rather than on headline inflation.

Third, the Taylor rule estimated using the Greenbook core CPI inflation forecasts and the CBO's estimates of real-time output gap has a lower standard error of estimate and predicts policy actions better than the Taylor rule estimated using actual future inflation and the final, revised data on the output gap. However, there still remain several periods during which policy actions differ significantly from prescriptions of the simple Taylor rule. Hence, despite its better fit, the forward-looking inertial Taylor rule estimated here may not be considered a complete description of policy actions taken by the Greenspan Fed.

The rest of the article is organized as follows. Section 1 discusses estimation of the Greenspan policy rule and the real-time data that underlie the estimated policy rule. Section 2 discusses estimation results, and concluding observations are in Section 3.

1. EMPIRICAL METHODOLOGY

Estimation of the Forward-Looking Inertial Taylor Rule

One key objective of this article is to investigate whether monetary policy actions taken by the Federal Reserve under Chairman Greenspan can be summarized by a Taylor rule according to which the Federal Reserve was forward looking, focused on core inflation, and smoothed interest rates. We model the forward-looking nature of the policy rule by relating the current value of the funds rate target to the four-quarter-average expected inflation rate and the contemporaneous output gap. The policy rule incorporating these features is reproduced below in equation (2.3).

[6] In Boivin (2006), the main objective is to investigate whether policy coefficients have changed over time. For expected inflation, the Greenbook forecasts of GNP and GDP deflator are employed. The level of economic activity is proxied using the difference between the natural unemployment rate and the Greenbook forecast of the unemployment rate. The article, however, also uses the real-time output gap measure constructed by Orphanides (2001). For the period 1985 to 1995, the point estimates of the long-run inflation response coefficients are well above unity and those for the long-run output gap response coefficient are well below unity.

$$\begin{aligned} FR_t &= \rho\ FR_{t-1} + (1-\rho)\{\alpha_0 + \alpha_\pi \overline{\pi}^c_{t,\overline{4}} + \alpha_y(ln\ y_t - ln\ y^*_t)\}, \quad (2.3) \\ &+ v_t \end{aligned}$$

where $\overline{\pi}^c_{t,\overline{4}}$ is the average of one-to-four-quarter-ahead forecasts of core CPI inflation made at time t and other variables as previously defined.[7]

The estimation of the policy rule in equation (2.3) raises several issues. The first issue relates to how we measure expected inflation and the output gap. The second issue relates to the nature of data used in estimation, namely, whether it is the real-time or final, revised data. As discussed earlier, the use of revised as opposed to the real-time data may affect estimates of policy coefficients and may provide a misleading historical analysis of policy actions (Orphanides 2001, 2002). The third issue is an econometric one, arising as a result of the potential presence of serial correlation in the error term v_t. Rudebusch (2006) points out that the Federal Reserve may respond to other economic factors besides expected inflation and the output gap, and hence a Taylor rule estimated omitting those other factors is likely to have a serially correlated error term. The presence of serial correlation in the disturbance term, if ignored, may spuriously indicate that the Federal Reserve is smoothing interest rates.

To further explain that a serially correlated disturbance term may mistakenly indicate the presence of partial adjustment, note first that if the funds rate does partially adjust to the policy rate as shown in (1.2) and the disturbance term has no serial correlation, then the reduced-form policy rule in (1.3 or 2.3) has the lagged funds rate as one of the explanatory variables. Hence, the empirical finding of a significant coefficient on the lagged funds rate in the estimated policy rule may be interpreted as indicating the presence of interest-rate smoothing. Now assume that there is no partial-adjustment, $\rho = 0$ in (2.3), but instead the disturbance term is serially correlated as shown below in equation (3.1).

$$v_t = s v_{t-1} + \varepsilon_t, \quad (3.1)$$

$$\begin{aligned} FR_t &= sFR_{t-1} + \{\alpha_0 + \alpha_\pi \overline{\pi}^c_{t,\overline{4}} + \alpha_y(\ln y_t - \ln y^*_t)\} \\ &\quad - s\{\alpha_0 + \alpha_\pi \overline{\pi}^c_{t-1,\overline{4}} + \alpha_y(\ln y_{t-1} - \ln y^*_{t-1})\} + \varepsilon_t. \quad (3.2) \end{aligned}$$

If we substitute equation (3.1) into (2.3), it can be easily shown that we get the reduced-form policy rule in equation (3.2), in which among other variables lagged funds rate also enters the policy rule. Hence, the empirical finding of

[7] In particular, the four-quarter-average inflation forecast is defined as $\pi^c_{t,\overline{4}} = \frac{(\pi^c_{t,1}+\pi^c_{t,2}+\pi^c_{t,3}+\pi^c_{t,4})}{4}$. We have also dropped the subscript 0 in the output gap term ($ln\ y_{t,0} -\ ln\ y^*_{t,0}$).

a significant coefficient on the lagged funds rate in the estimated policy rule may be interpreted arising as a result of interest rate smoothing when in fact, it is not present. In view of these considerations, this policy rule is estimated allowing for the presence of both interest rate smoothing and serial correlation, namely, we allow both partial adjustment and a serially correlated disturbance term. It can be easily shown that the policy rule incorporating both partial adjustment and serial correlation can be expressed as in equation (4).

$$\begin{aligned} FR_t \;=\;& \alpha_0(1-s)(1-\rho) + (s+\rho)FR_{t-1} + (1-\rho) \\ & \{\alpha_\pi \overline{\pi}^c_{t,\overline{4}} + \alpha_y(\ln y_t - \ln y^*_t)\} - s\{(1-\rho)\alpha_\pi \overline{\pi}^c_{t-1,\overline{4}} \\ & + (1-\rho)\alpha_y(\ln y_{t-1} - \ln y^*_{t-1})\} - s\rho FR_{t-2} + \varepsilon_t. \end{aligned} \tag{4}$$

Note that if there is no serial correlation ($s = 0$ in [4]), we get the reduced-form policy rule shown in equation (2.3), and if there is no partial adjustment ($\rho = 0$ in [4]), we get the policy rule shown in (3.2). Of course, if both s and ρ are not zero, we have a policy rule with both partial adjustment and serial correlation.

In previous research, the forward-looking policy rule similar to the one given in equation (2.3) has often been estimated assuming rational expectations and using a generalized method of moments procedure (Clarida, Galí, and Gertler 2000). We follow this literature and estimate the policy rule assuming rational expectations; namely, we substitute actual future core inflation and actual current output gap for the expected inflation and output gap terms and use an instrumental variables procedure to estimate policy coefficients. However, we also estimate the policy rule using the Greenbook inflation forecasts as proxy for expected inflation. In contrast to previous work, we estimate the policy rule allowing for the presence of both interest-rate smoothing and serial correlation as in equation (4). We use a nonlinear instrumental variables procedure when rational expectations are assumed and nonlinear ordinary least squares procedure when the Greenbook forecasts are used. The instruments used are three lagged values of inflation, the federal funds rate, levels and first differences of the output gap, and the spread between the ten-year Treasury bond yield and the federal funds rate.

In previous work, as in Boivin (2006), ordinary least squares have been employed to estimate the Taylor rule that uses the Greenbook forecasts. However, the use of ordinary least squares requires the assumption that the Greenbook forecasts are contemporaneously uncorrelated with the policy shock ε_t. As noted in Boivin (2006), while some casual arguments can be made to support this assumption,[8] they cannot be directly verified, and hence would not be

[8] Reifschneider, Stockton, and Wilcox (1997) provide some information about the conditioning assumptions of the Greenbook forecasts over the last ten years. The first feature is that these forecasts are made under the typical assumption that the federal funds rate will remain unchanged

enough to convince a skeptic that the Greenbook forecasts may potentially be correlated with the policy surprise. This correlation may arise if the Greenbook forecasts reflect some contemporaneous information and the FOMC also reacts to such information by adjusting the policy rate, as argued in Rudebusch (2006). This endogeneity could introduce some bias in parameter estimates. In view of this consideration, we check the robustness of our results to the presence of potential endogeneity, using instrumental variables. In particular, we also estimate the Taylor rule, using the Greenbook forecasts made in previous quarters as instruments. We find our main results are robust with respect to this change in the estimation procedure.

Data

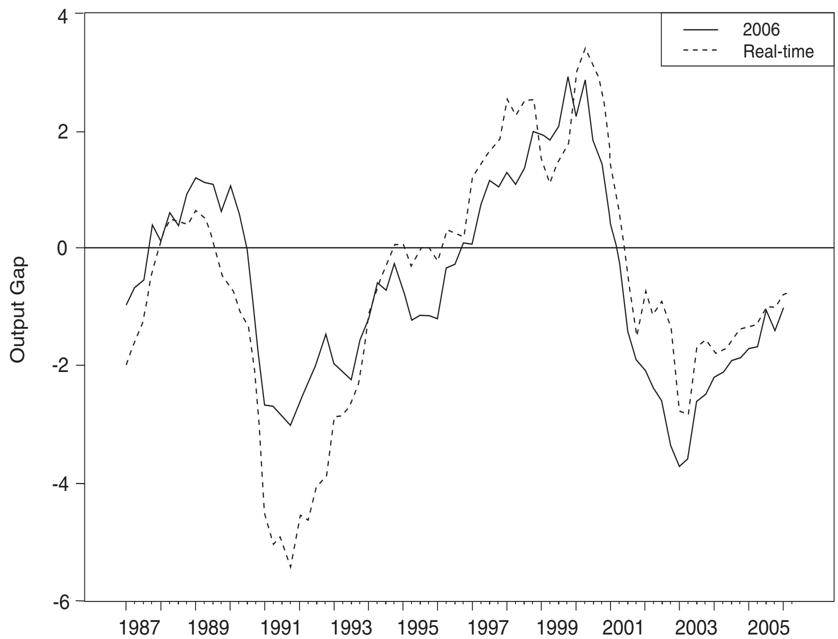
We estimate the policy rule in equation (4) over the period from 1987:1 to 2005:4 using the data on core CPI inflation and the output gap. For expected inflation, we also use the Greenbook inflation forecasts of core CPI inflation, prepared by the Board staff for the Federal Open Market Committee (FOMC) meeting held near the second month of the quarter. There is considerable evidence that the Greenbook forecasts are most appropriate in capturing policymakers' real-time assessment of future inflation developments. Romer and Romer (2000) show that the Federal Reserve has an informational advantage over the private sector, producing relatively more accurate forecasts of inflation than does the private sector. Bernanke and Boivin (2003) argue one needs a large set of conditional information to properly model monetary policy. In that respect, the Greenbook forecasts include real-time information from a wide range of sources, including the Board staff's "judgment," not otherwise directly measurable. The policy rule that uses the Greenbook forecasts is estimated over the period from 1988:1 to 2000:4.

Unlike inflation forecasts the Board staff's estimates of the output gap are not readily available. Here we follow the previous research using estimates of potential output prepared by the Congressional Budget Office (CBO).[9]

during the next six to eight quarters. This neutral assumption about the path of monetary policy may reflect the desire of the Board staff to avoid being construed as making policy recommendations, suggesting that for most of that period, the forecasts were not conditioned on the policy surprise. The second feature of these forecasts is a large "judgmental" component, making it hard for these forecasts to be mechanically reproduced by any particular forecasting model, thereby lessening the probability of a contemporaneous correlation between forecasts and the policy surprise.

[9] Potential output is defined as *trend in the productive capacity* of the economy and is estimated by the level of GDP attainable when the economy is operating at a high rate of resource use. The CBO estimates potential output for the economy, using a production function approach applied to each of five major sectors (nonfarm business, government, farm, household and nonprofit institutions, and residential housing) and then aggregating sectoral estimates of potential output. For example, for the nonfarm business sector CBO uses a neoclassical production function that relates output produced in that sector to labor (hours worked), capital, and total factor productivity. Potential output in nonfarm business sector is an estimate of output attainable when labor, capital,

Figure 1 Vintage 2006 and Real-Time Output Gap (Congressional Budget Office)



However, we also construct a real-time series on the output gap using the Congressional Budget estimates of actual and potential output series available in real time.[10] Unlike the data on the output gap, the data on CPI is not significantly revised, and hence we use the 2006 vintage dataset for core CPI.

Figure 1 charts real-time estimates of the output gap from 1987 to 2005. The most recent vintage (2006) estimates of the output gap are also charted. The main observation is that the real-time estimates of the output gap are not too different from their recent vintage estimates with the exception of periods 1990 to 1993 and 1995 to 1998. The real-time estimates of the output gap during the period surrounding the 1990–1991 recession indicate the presence of considerably more slack in the economy than what is indicated by current

and total factor productivity variables in the production function are set at their cyclically adjusted levels (Congressional Budget Office 2001).

[10] In January of each year from 1991 to 2006, the Congressional Budget Office has released the historical data on actual and potential output. For the period 1987 to 1990, the output gap is constructed using the series on actual and potential output given in the 1991 vintage data file. For 1991, we have used the pertinent series on actual and potential output from the 1992 vintage data file and for each year thereafter. So, the potential output estimate for 2005 is constructed using the data file released in January 2006.

Figure 2 Greenbook Forecasts and Actual Core CPI Inflation (Four-Quarter Average)

estimates. Hence, a policy rule that uses the real-time estimates of the output gap is likely to prescribe a lower funds rate target than what is indicated by the use of revised estimates. Similarly, real-time estimates of the output gap from 1995 to 1998 indicate far less slack in the economy than what is suggested by the current vintage estimates, due to the ongoing productivity acceleration that was not recognized by most economists at the time. Hence, for the subperiod 1995 to 1998 the funds rate target prescribed by the policy rule with the real-time output gap is higher than what is suggested by the current vintage estimate of the output gap, ceteris paribus. Given the size of output gap revisions, policy evaluation is likely to be affected whether one uses the real-time or revised data on the output gap.

Figure 2 charts the actual and Greenbook forecasts of the four-quarter-average core CPI inflation rate. As shown, the Greenbook forecasts track actual inflation fairly well, with the exception of periods, 1988:2 to 1989:2 and 1995 to 1997. In both these subperiods, the Greenbook was “too pessimistic” about future inflation. As some analysts have noted, during the first subperiod the Board staff may have worried about future inflation because the Greenspan Fed had kept interest rates low following the stock market crash of October

1987. During the second subperiod, productivity acceleration was underway, and most economists, including the Board staff, were slow in recognizing the favorable effects of productivity acceleration on inflation.

2. EMPIRICAL RESULTS

This section presents and discusses estimates of a Taylor rule fitted over the Greenspan period.

Estimates of Policy Response Coefficients

Table 1 presents estimates of policy response coefficients (α_π, α_y, ρ) from the Taylor rule in equation (4) estimated using the final as well as the real-time data on core CPI inflation and the output gap. Row 1 contains estimates derived using the current vintage data on the output gap, whereas row 2 contains estimates derived using the real-time data on the output gap. Row 3 contains ordinary least squares estimates using the Greenbook core CPI inflation forecasts and the real-time data on the output gap. We also present estimates of the first-order serial correlation coefficient s. The estimates in rows 1 through 3 of Table 1 suggest the following observations. First, all estimated policy response coefficients are correctly signed and statistically significant. In particular, the inflation response coefficient α_π is generally well above unity and the output response coefficient α_y is below unity, which suggests that the Greenspan Fed responded strongly to expected inflation and relatively weakly to output.

Second, the estimated serial correlation coefficient s is generally positive and statistically significant, indicating the presence of serially correlated errors in the estimated policy rules. As noted in Rudebusch (2006), the presence of serial correlation may reflect influences on the policy rate of economic variables to which the Federal Reserve may have responded but which are omitted from the estimated policy rule.

Third, even after allowing for the presence of serial correlation, the estimated partial adjustment coefficient ρ is positive and well above zero, which suggests the continued role of partial adjustment in generating a significant coefficient on the lagged value of the funds rate. This result is similar to that of English, Nelson, and Sack (2002). However, the magnitude of the estimated partial adjustment coefficient ρ reported here is somewhat smaller than what is found in previous research. As discussed later in this article, the point estimates of the partial adjustment coefficient range from .5 to .7 when the Taylor rule is alternatively estimated using the Greenbook forecasts of headline CPI and GDP inflation rates.

Table 1 Estimated Taylor Rules: Core CPI Inflation

Row	Period	Gap	Inflation	Estimation	α_π	α_y	ρ	s	$\overline{R}^2$	*SER*
1	2005:4	Revised	(Actual, FW)	IV	1.5	.78	.73	.59	.98	.326
					(3.7)	(3.2)	(6.7)	(4.3)		
2	2005:4	Real-time	(Actual, FW)	IV	2.2	.68	.66	.49	.98	.315
					(8.2)	(5.5)	(6.4)	(3.6)		
3	2000:4	Real-time	(GB, FW)	OLS	1.7	.64	.70	.35	.98	.257
					(8.8)	(6.4)	(13.1)	(2.5)		
4	2000:4	Real-time	(Actual, BW)	OLS	1.0	.73	.75	.59	.97	.329
					(1.8)	(2.6)	(5.9)	(3.5)		
5	2005:4	Real-time	(Actual, BW)	OLS	0.71	.51	0.66	.84	.98	.345
					(0.8)	(1.5)	(2.8)	(3.9)		

Notes: Rows 1 and 2 contain nonlinear instrumental variables (IV) estimates of policy coefficients from the forward-looking (FW) policy rule given below in (a) and use revised or real-time data on the output gap.

$$FR_t = \rho FR_{t-1} + (1-\rho)\{\alpha_0 + \alpha_\pi \overline{\pi}^c_{t,\overline{4}} + \alpha_y(ln\ y_t - ln\ y^*_t)\} + v_t. \tag{a}$$

Row 3 contains nonlinear ordinary least squares estimates (OLS) of policy coefficients from the forward-looking (FW) policy rule given below in (b) and use the Greenbook (GB) inflation forecasts of core CPI inflation and real-time CBO estimates of the output gap.

$$FR_t = \rho FR_{t-1} + (1-\rho)\{\alpha_0 + \alpha_\pi GB\overline{\pi}^c_{t,\overline{4}} + \alpha_y(ln\ y_t - ln\ y^*_t)\} + v_t. \tag{b}$$

Row 4 contains nonlinear ordinary least squares (OLS) estimates of policy coefficients from the backward-looking (BW) policy rule given below in (c).

$$FR_t = \rho FR_{t-1} + (1-\rho)\{\alpha_0 + \alpha_\pi \overline{\pi}^c_{t-1} + \alpha_y(ln\ y_{t-1} - ln\ y^*_{t-1})\} + v_t. \tag{c}$$

The instruments used are three lagged values of the inflation rate, the funds rate, the output gap (final or real-time), the growth gap, and the spread between nominal yields on ten-year Treasury bonds and the federal funds rate. Parentheses contain t-values. *SER* is the standard error of estimate. Estimation was done allowing for the presence of first-order serial correlation in v_t, and s is the estimated first-order serial correlation coefficient. The sample periods begin in 1988:1 and end in the year shown in the column labeled "period."

These estimates indicate a faster convergence of the funds rate to its desired level over this sample period (see Panels A and B in Table 3).[11]

Forward- Versus Backward-Looking Specifications

The maintained hypothesis in this article is that the Greenspan Fed was forward looking, responding to expected inflation rather than lagged inflation. As noted at the outset, the original Taylor rule relates the actual federal funds rate to lagged inflation and the output gap. In order to investigate which specification better explains the Greenspan period, we also estimate the backward-looking specification. Rows 4 and 5 in Table 1 contain estimates of policy response coefficients from this backward-looking specification, using core CPI inflation and the real-time data on the output gap. Row 4 reports estimates for the subperiod 1988:1 to 2000:4, as does row 5 for the complete sample period 1988:1 to 2005:4.

One key feature of the backward-looking specifications reported in Table 1 is that the estimated inflation response coefficient α_π is close to or below unity and not always statistically significant. These estimates suggest that the Greenspan Fed did not respond strongly to inflation.[12] This conclusion is in sharp contrast to the one suggested by forward-looking specifications, according to which the Greenspan Fed responded strongly to inflation.

How does one decide which one of these two alternative specifications better describes the Greenspan period? The first to note is that the forward-looking specification better fits the data, because the forward-looking specification based on the Greenbook forecasts has a lower standard error of estimate than the backward-looking specification, (compare SERs across rows 3 and 4 in Table 1). We investigate this issue further by testing the validity of alternative specifications, using a general specification that nests both backward- and forward-looking specifications. In particular, consider a general specification

[11] As illustrated in Rudebusch (2006), the typical estimate of the partial adjustment coefficient ρ for this sample period is .8, suggesting that if in response to changed economic conditions the Federal Reserve wanted to raise the funds rate by one percentage point, it would raise it by about 20 basis points in the first three months and by about 60 basis points after one year. Focusing on the Taylor rule, which is estimated using Greebook forecasts and real-time data on the output gap, the mid-point of the estimated range of the partial adjustment coefficient is .6, suggesting the adjustment of the actual funds rate to its desired level will be complete well before a year. See also English, Nelson, and Sack (2002), in which the use of real-time data in a forward-looking policy rule yields an estimate of the partial adjustment coefficient that is also quite low.

[12] Blinder and Reis (2005) report a similar finding. For the period from 1987:3 to 2000:1, they estimate a Taylor rule that relates the funds rate target to current inflation and the unemployment gap. The inflation response coefficient estimated during that time is .57, leading them to conclude that the Greenspan Fed did not respond strongly to inflation.

given in equation (5.1).

$$
\begin{aligned}
FR_t^* &= a + \alpha_\pi GB\overline{\pi}^c_{t,\bar{j}} + \alpha_y(\ln y_t - \ln y_t^*) + \alpha_{\pi 2}\overline{\pi}^c_{t-1} \qquad (5.1)\\
&\quad +\alpha_{y2}(\ln y_{t-1} - \ln y_{t-1}^*),\\
FR_t &= \rho FR_{t-1} + (1-\rho)FR_t^* + v_t, \text{ and} \qquad (5.2)\\
v_t &= s v_{t-1} + \varepsilon_t \ ,
\end{aligned}
$$

where all variables are defined as before. Equation (5.1) relates the federal funds rate target to variables suggested by both the specifications. The key assumption underlying the general specification (5.1) is that lagged inflation and the output gap may directly influence the current federal funds rate target, in addition to influencing it indirectly through the Greenbook inflation forecast. The backward-looking specification allows for the direct influence of lagged inflation and the output gap on the current funds rate target. If α_π and α_y are zero in (5.1), we get the backward-looking specification, and if $\alpha_{\pi 2}$ and α_{y2} are zero, we get the forward-looking specification.

Table 2 contains nonlinear ordinary least squares estimates of policy response coefficients from the general policy rule (5) estimated over the period from 1988:1 to 2000:4. In addition to using the four-quarter-average Greenbook inflation forecast, we also report estimates using the one-quarter and two-quarter-average inflation forecasts. As shown, estimated coefficients on the Greenbook forecast α_π and the current output gap α_y are correctly signed and statistically significant, whereas estimated coefficients on lagged inflation $\alpha_{\pi 2}$ and lagged output gap α_{y2} are not. The p-value of the null hypothesis that $\alpha_{\pi 2}$ and α_{y2} are zero is .89 to .94, leading to the conclusion that the data favors the forward-looking specification.[13]

Robustness Issues: Core Versus Headline Inflation and Ordinary Least Squares Versus Instrumental Variables

Another key aspect of the maintained hypothesis is that the Greenspan Fed was focused on core rather than headline inflation. Furthermore, the analysis using the Greenbook forecasts used ordinary least squares to estimate the Taylor rule. We now investigate the robustness of our results to a few changes in the specification of the Taylor rule and the choice of the estimation procedure.

Table 3 presents the Taylor rule estimated using the Greenbook forecasts of three alternative measures of inflation: core CPI, headline CPI, and the GDP implicit deflator. The measure of real-time output gap used is from

[13] The results do not change if the general specification is estimated including current values of inflation and the output gap, instead of lagged values of inflation. That is, the estimated coefficient on expected inflation remains significant and that on current inflation is not.

Table 2 Estimates of Policy Response Coefficients From a General Policy Rule: Core CPI Inflation

Row	GB Forecasts	α_π	α_y	ρ	$\alpha_{\pi 2}$	α_{y2}	*SER*	$\overline{R}^2$	p-value
1	1-q average	1.49	.91	.75	.29	-.1	.284	.97	.89
		(1.9)	(1.9)	(8.4)	(.3)	(.2)			
2	2-q average	1.85	0.86	0.75	.16	-.1	.275	.97	.94
		(2.0)	(1.9)	(8.5)	(.1)	(.3)			
3	4-q average	1.99	0.71	0.72	0.33	-.1	.262	.97	.93
		(2.5)	(2.0)	(8.3)	(.3)	(.3)			

Notes: The coefficients reported are nonlinear least squares estimates of the policy rule given below in (a) and use the Greenbook forecasts (GB) and real-time data on the output gap.

$$FR_t^* = a + \alpha_\pi GB\overline{\pi}^c_{t,\bar{4}} + \alpha_y(\ln\ y_t - \ln\ y_t^*) + \alpha_{\pi 2}\overline{\pi}_{t-1} + \alpha_{y2}(\ln\ y_{t-1} - \ln\ y_{t-1}^*), \qquad (a.1)$$

$$FR_t = \rho FR_{t-1} + (1-\rho)FR_t^* + v_t, \qquad (a.2)$$

where all variables are defined as in Table 1. Parentheses below coefficients contain t-values. The p-value reported is for the test of the null hypothesis that $\alpha_{\pi 2}$ and α_{y2} are zero. The sample period is from 1988:1 to 2000:4. We do not report the estimated serial correlation coefficient, though the equations are estimated assuming the presence of serial correlation.

the Congressional Budget Office and remains the same across these three inflation specifications. Panel A presents ordinary least squares estimates and Panel B, instrumental variables estimates. For a comparison, Panel C reports the Taylor rule estimated using actual future inflation and the final data on the output gap. The estimates presented in Table 3 indicate three main observations. First, focusing on the Taylor rule with the Greenbook forecasts, the hypothesis—the Greenspan Fed responded strongly to expected inflation and relatively weakly to the output gap—is robust with respect to the use of headline inflation forecasts and the instrumental variables procedure. The estimated inflation response coefficient is well above unity and the output gap response coefficient is below unity for all three measures of inflation. The instrumental variables estimates of key policy response coefficients yield conclusions that are qualitatively similar to those based on ordinary least squares estimates (compare estimates across Panels A and B). These results suggest that the bias in ordinary least squares estimates, introduced as a result of the potential endogeneity of the Greenbook forecasts, may be very small.

Second, as expected, the fit of the estimated Taylor rule as measured by the standard error of regression (SER) is somewhat worse if instrumental variables are used. However, the Taylor rule estimated with the Greenbook forecasts always has a lower standard error of regression than the Taylor rule estimated using actual future inflation and the revised data on inflation and on the output gap (compare the SERs across Panels A, B, and C).

Table 3 Estimated Taylor Rules

Sample Period	Inflation	α_0	α_π	α_y	ρ	s	$\overline{R}^2$	*SER*
		Panel A: Greenbook Forecasts/Ordinary Least Squares						
1988:1–2000:4	Core CPI	0.12	1.7	.64	.69	.35	.98	.257
		(0.20)	(8.8)	(6.4)	(13.1)	(2.5)		
1988:1–2000:4	CPI	-0.80	2.1	.81	.74	.46	.98	.253
		(0.70)	(6.4)	(5.5)	(14.4)	(3.3)		
1988:1–2000:4	GDP	0.70	1.9	.66	.66	.45	.98	.252
		(1.20)	(8.5)	(6.5)	(10.9)	(3.3)		
		Panel B: Greenbook Forecasts/Instrumental Variables						
1988:1–2000:4	Core CPI	-0.20	1.8	.62	.60	.45	.98	.270
		(0.30)	(9.3)	(6.6)	(6.9)	(3.2)		
1988:1–2000:4	CPI	-1.50	2.3	.78	0.64	.60	.98	.273
		(1.20)	(6.0)	(5.5)	(7.8)	(4.3)		
1988:1–2000:4	GDP	0.29	2.1	.64	.51	.55	.97	.278
		(0.40)	(9.0)	(7.2)	(4.5)	(4.1)		
		Panel C: Actual Future Inflation/Instrumental Variables						
1988:1–2000:4	Core CPI	2.70	1.0	.85	.80	.60	.97	.314
		(1.30)	(1.5)	(1.9)	(5.6)	(3.2)		
1988:1–2000:4	CPI	1.80	1.3	.80	.78	.61	.98	.324
		(1.00)	(2.2)	(2.0)	(7.3)	(3.4)		
1988:1–2000:4	GDP	1.30	1.9	.67	.72	.63	.96	.332
		(0.80)	(2.9)	(1.8)	(4.3)	(2.7)		

Notes: Panels A, B, and C contain nonlinear estimates of policy coefficients from the policy rule given below in (a). Panels A and B use the Greenbook inflation forecasts and the CBO real-time estimates of the output gap. Panel C uses actual future inflation and the final revised data on the output gap.

$$FR_t = \rho FR_{t-1} + (1-\rho)\{\alpha_0 + \alpha_\pi \overline{\pi}^c_{t,\overline{4}} + \alpha_y(\ln\ y_t - \ln\ y_t^*)\} + v_t. \tag{a}$$

The instruments used are three lagged values of the pertinent inflation variable: the federal funds rate, the output gap (real-time or final), the growth gap, and the spread between nominal yields on ten-year Treasury bonds and the federal funds rate. See notes in Table 1.

Third, regarding core versus headline inflation, the results are mixed. When the Greenbook forecasts are used, instrumental variables estimates favor the core CPI, whereas ordinary least squares estimates favor the headline GDP inflation (compare the SERs across Panels A and B in Table 3). However, as reported in the next section, when we compare the relative accuracy of the within-sample dynamic forecasts of the funds rate generated by these different Taylor rules, the Taylor rule with core CPI inflation forecasts yields slightly more accurate forecasts of the funds rate than the Taylor rule with headline inflation forecasts, supporting the maintained hypothesis that the Greenspan Fed was focused on core inflation.[14]

Predicting the Actual Path of the Federal Funds Rate Using the Greenbook Inflation Forecasts and the Real-Time Output Gap

In order to evaluate how well the forward-looking inertial Taylor rule estimated here predicts actual policy actions, we focus on the policy rule estimated using Greenbook core CPI inflation forecasts and the real-time CBO estimates of the output gap from 1987:4 to 2000:4. For this exercise we focus on ordinary least squares estimates. We carry out this evaluation in two alternative ways. According to the inertial Taylor rule estimated here, expected inflation (approximated by Greenbook inflation forecasts) and the output gap are two major determinants of the federal funds rate target. In order to see how well the actual funds rate is predicted by these two economic fundamentals, we generate the within-sample dynamic predictions of the funds rate from 1987:4 to 2000:4, using the estimated policy rule shown in equation (6).

$$FR_t^p = \hat{\rho} FR_{t-1}^p + (1-\hat{\rho})\{\hat{\alpha}_0 + \hat{\alpha}_\pi GB\overline{\pi}_{t,\overline{4}}^c + \hat{\alpha}_y(\ln y_t - \ln y_t^*)\}, \qquad (6)$$

where FR^p is the predicted funds rate and other variables are defined as before. The key feature of the prediction equation (6) is that in generating the current-quarter predicted value of the funds rate, we use last quarter's predicted, but not actual value of the federal funds rate, in addition to using current-period values of two other economic fundamentals.

Figure 3 charts the within-sample dynamic predictions of the funds rate.[15] Actual values of the funds rate and the prediction errors are also charted. Two observations need to be highlighted. First, the actual funds rate has generally moved in the direction suggested by these two economic fundamentals (see Panel A). Second, the estimated policy rule predicts very well the actual level of the funds rate. The mean absolute error is .29 percentage points and the root mean squared error is .40 percentage points. Despite this good fit, however, there are few periods when the actual funds rate is far away from the value prescribed by economic fundamentals. Significant deviations, at least twice the root mean squared error, occur in 1988 and 1995 (see Panel B, Figure 3).

[14] We did not consider the consumption expenditure deflator (PCE) in this comparison, because the Federal Reserve only recently started focusing on core PCE. In fact, the Greenbook started producing forecasts of core PCE beginning in 2000, suggesting the Greenspan Fed was focused on core CPI for most of the period covered.

[15] The predictions begin in 1987:4. For generating the prediction for 1987:4, we use the preceding quarter's actual funds rate. For later periods, the predicted values are generated using the preceding period's predicted value and the current period estimates of expected inflation and the output gap.

Figure 3 Predicting the Actual Funds Rate

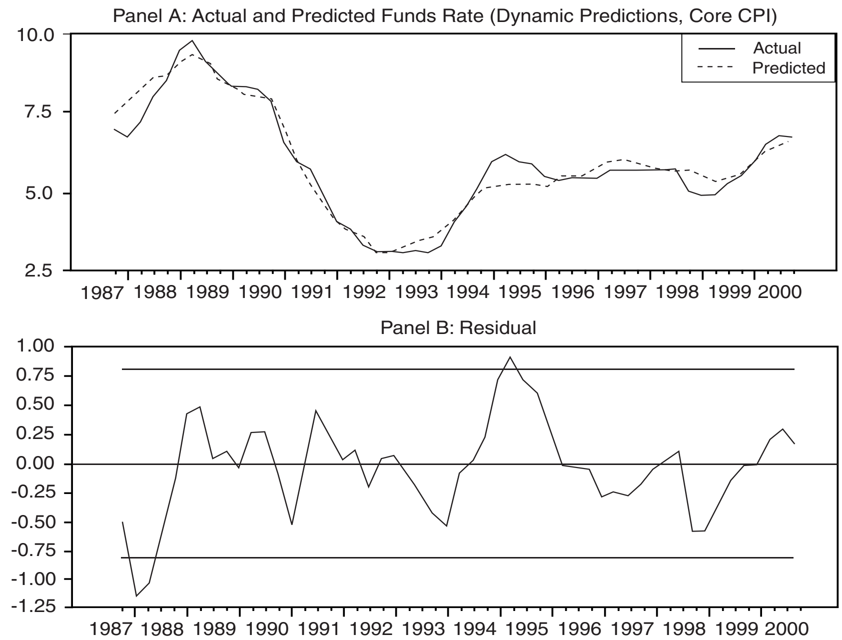


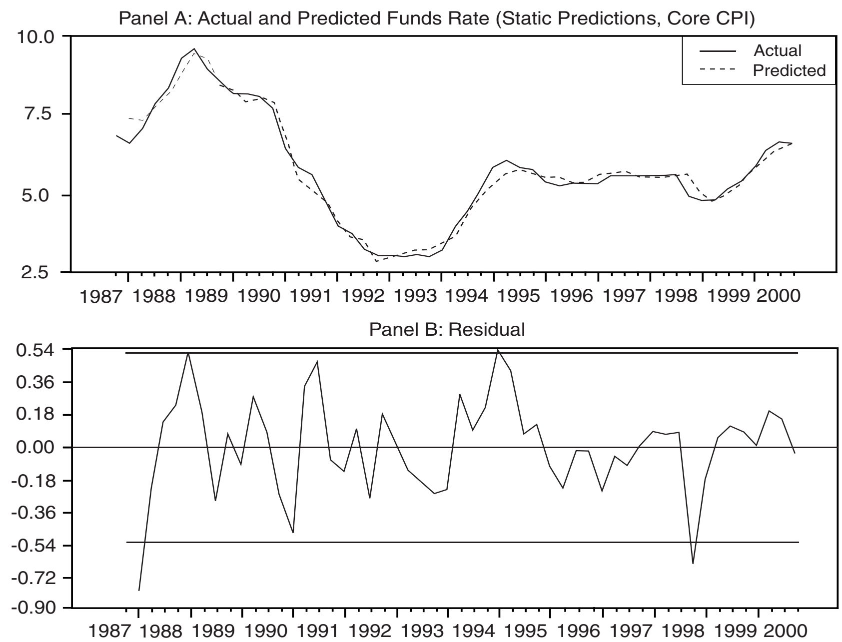
Figure 4 charts the static predictions of the federal funds rate, generated using the same policy rule but feeding in last quarter's actual value of the funds rate as shown below in equation (7).

$$FR_t^p = \hat{\rho} FR_{t-1} + (1 - \hat{\rho})\{\hat{\alpha}_0 + \hat{\alpha}_\pi GB\overline{\pi}^c_{t,\overline{4}} + \hat{\alpha}_y(\ln y_t - \ln y_t^*)\}. \quad (7)$$

In static forecasts the current-period forecast of the funds rate is determined, in part, by the current-period value of the desired policy rate suggested by economic fundamentals and, in part, by the one-period lagged value of the actual funds rate. So, in the static exercise the current forecast is influenced, in part, by actual policy actions, with the magnitude of the influence of policy on the forecast being determined by the size of the partial adjustment coefficient $\hat{\rho}$. Hence, the actual funds rate is likely better predicted by static than dynamic forecasts, because the latter are generated ignoring the recent history of actual funds rate changes.

A visual check of actual values of the funds rate and its static predictions charted in Figure 4 is consistent with the estimated policy rule. The mean absolute error is now .20 percentage points and the root mean squared error is

Figure 4 Predicting the Actual Funds Rate



.26 percentage points. Panel B charts the residuals. As shown, there are still a few periods of significant deviations. We see deviations at least as large as twice the root mean squared error occurring in 1988, 1989, 1995, and 1998:4. Thus, Figures 3 and 4 suggest that the Taylor rule estimated using Greenbook inflation forecasts and the real-time data on the output gap well predict actual policy actions, with the caveat that few episodes remain when the actual funds rate is significantly far from what is prescribed by this policy rule.

Using Actual Future Core Inflation and the Revised Output Gap

It is worth pointing out that in the prediction exercise the Taylor rule estimated using the Greenbook inflation forecasts and the real-time data on the output gap predicts actual policy actions better than the Taylor rule estimated using actual future inflation (core CPI) and the current vintage estimate of the output gap. In particular, we re-estimate the Taylor rule over the period from 1988:1 to 2000:4 and generate the within-sample, static and dynamic predictions of the funds rate, using the current vintage estimate of the output gap. For static predictions, the mean absolute error and root mean squared error are .30 and .37 percentage points, respectively. For dynamic predictions, the corresponding mean absolute error and the root mean squared errors are .72 and .84 percentage points. These prediction errors are substantially higher than those generated using the Greenbook inflation core CPI forecasts and the real-time output gap.

Core Versus Headline Inflation

The use of core inflation forecasts in the estimated Taylor rule produces slightly more accurate forecasts of the funds rate than those based on the headline inflation. For dynamic predictions of the funds rate generated using alternatively the Taylor rules based on core CPI, CPI, and GDP inflation forecasts, the mean absolute errors are .29, .35, and .33 percentage points, respectively. The corresponding root mean squared errors are .40, .44, and .41 percentage points. These summary statistics do favor core CPI, though the Taylor rule based on GDP inflation forecasts is a serious contender.[16,17]

Policy Residuals: Role of Additional Factors in the Estimated Taylor-Type Rule

As stated above, even though the use of Greenbook inflation forecasts and real-time data on the output gap enables the estimated policy rule to predict policy actions very well, there remain few periods when the actual funds rate is significantly away from values prescribed by the rule, with significant deviations occurring in 1988, 1989, 1995, and 1998:4. Many analysts contend that

[16] If the Taylor rules based on the Greenbook forecasts of three alternative measures of inflation—core CPI, CPI, and GDP—are estimated with instrumental variables, then the root mean squared errors generated by the dynamic prediction exercise are .46, .59, and .49 percentage points, respectively.

[17] It will be interesting to derive an estimate of the Greenspan Fed's inflation target under the additional assumption that the Fed's estimate of the short-term real rate can be approximated by the sample mean of the ex post real yield on three-month Treasury bills over a longer sample period, the latter defined as the nominal yield minus the lagged value of the four-quarter-average GDP inflation rate. By this metric, the short-term real rate is 1.9 percent if we use the sample period 1961:1–2005:4, and 2.1 percent if we use only the Greenspan period 1987:1–2005:4. These calculations suggest it is reasonable to assume that the Greenspan Fed's estimate of the short-real rate is approximately 2.0 percent. Given $rr^* = 2.0$ percent and given an estimate of the constant term from the estimated Taylor rule based on the Greenbook forecasts of core CPI inflation, the Greenspan Fed's inflation target calculated using the relationship $\hat{\alpha}_0 = rr^* + (1 - \hat{\alpha}_\pi)\pi^* \rightarrow .12 = 2.0 + (1 - 1.7)\pi^*$ is 2.7 percent. The result above—the Greenspan Fed's inflation target is 2.7 percent—may at first appear at odds with the 2.0 percent value assumed in the original Taylor rule, where inflation is measured by the behavior of GDP inflation. During the Greenspan era, GDP inflation has exhibited a somewhat different trend behavior than the core CPI inflation measure. Using the metric of comparing means, the sample mean of GDP inflation rates over 1987:1–2005:4 is 2.4 percent, which is lower compared with the value 3.0 percent computed using core CPI inflation over the same period. If we were to adjust the inflation targets for the presence of different means, then the Greenspan Fed having an inflation target of 2.7 percent based on the behavior of the core CPI inflation measure is equivalent to its having, instead, an inflation target of 2.1 percent based on the GDP inflation measure. The latter value is close to 2.0 percent assumed in the original Taylor rule.

significant deviations represent episodes when the Greenspan Fed responded to a variety of macroeconomic developments that are not included in the simple policy rule (Blinder and Reis 2005, Rudebusch 2006). To illustrate this point, consider the following narrative history of those developments.

The first episode occurs in 1988 and 1989. Following the stock market crash of October 1987, the Greenspan Fed kept interest rates low as an insurance against the heightened risk of a recession, so that in 1988 the actual funds rate is below what is prescribed by the Taylor-type rule. Inflation worries then may have led the Greenspan Fed to tighten more in 1989, which suggests that greater-than-policy-rule tightening in 1989 followed a somewhat looser policy of the previous year. Some support for this view emerges if we examine the Greenbook inflation forecasts in the period leading to 1989. As shown in Figure 2, for the period surrounding mid-to-late 1988 and early 1989, the Greenbook inflation forecasts turned out to be too pessimistic.

The second episode occurs in 1995 when the actual funds rate is higher than what is prescribed by the rule. The reasons for this greater-than-policy-rule tightening are not very clear. Taylor (2005) notes this may reflect preemptive policy tightening that began in 1994, whereas Rudebusch (2006) attributes it to an inflation scare that occurred at the end of 1994 evidenced by a rapid rise in long-term interest rates. Some limited support for the inflation scare argument appears in Figure 2, which shows that beginning in 1994:3, the Greebook inflation forecasts turned somewhat pessimistic about inflation.[18]

Finally, in 1998:4 the actual funds rate is below what is prescribed by the policy rule. This is the period when the international financial system was rocked by the Russian default and the demise of the Long-Term Capital Management (LTCM), which led the Greenspan Fed to lower interest rates. Together, these episodes suggest that the particular Taylor rule estimated in this article may not be considered a complete description of policy actions taken by the Greenspan Fed.

[18] Another factor that explains the greater-than-policy tightening in 1995 and in 1996–1997, as in some previous work that uses actual future inflation and the current vintage output gap measure, is the remarkable increase in productivity and potential output. At the time, most economists did not recognize these changes and, hence, may have overestimated the degree of utilization in product and labor markets, which likely reflected in tighter policy. However, a visual check of Figures 1 and 2 suggests that productivity acceleration may not be relevant in explaining the greater-than-policy tightening in 1995. As shown in Figure 1, real-time estimates of the output gap indicate far less slack in the economy than what is suggested by its 2006-vintage-only data in the subperiod following the year 1995. Similarly, the Greenbook forecasts become significantly pessimistic only in the years 1996–1997. Thus, these considerations suggest that while productivity acceleration may be relevant in explaining the post-1995 greater-than-policy tightenings documented in some previous work, its role in explaining the 1995 policy episode is in doubt.

3. CONCLUDING OBSERVATIONS

The main objective of this article is to investigate whether monetary policy actions taken by the Greenspan Fed can be summarized by a Taylor rule. Recent research highlights three aspects of the policy rule followed by the Greenspan Fed; namely, the Greenspan Fed was forward looking, focused on core inflation, and smoothed interest rates. The empirical work presented here supports the above-noted general characterization of the policy rule followed by the Greenspan Fed.

Using the Greenbook inflation forecasts and real-time Congressional Budget estimates of the output gap, this article reports evidence indicating that the Greenspan Fed reacted strongly to expected inflation and relatively weakly to the output gap. The evidence also indicates the Greenspan Fed smoothed interest rates, though the degree of interest-rate smoothing exhibited is considerably less than what is documented in previous research. The hypothesis that the Greenspan Fed was focused on core CPI inflation receives some support, as the Taylor rule based on the Greenbook forecasts of core CPI inflation does produce slightly more accurate forecasts of the funds rate than the Taylor rule that uses the Greenbook forecasts of headline CPI or GDP inflation.

This article finds that a Taylor rule estimated using the Greenbook core CPI inflation forecasts and real-time Congressional Budget estimates of the output gap predicts very well the actual path of the federal funds rate from 1987 to 2000. The Taylor rule estimated alternatively with the Greenbook GDP inflation forecasts seems to do as well. However, there are few periods when the Greenspan Fed is off the estimated rule, arising perhaps as a result of the Federal Reserve response to special macroeconomic developments not captured by the simple rule.

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