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Inflation Measure, Taylor Rules, and the Greenspan-Bernanke Years

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Recent research has highlighted several aspects of monetary policy under Chairman Alan Greenspan, noting that the Federal Reserve was forward looking, smoothed interest rates, and focused on core inflation.[1] Some analysts have estimated Taylor rules that incorporate these salient features of monetary policy, and have shown that monetary policy actions taken by the Federal Reserve in the Greenspan era can broadly be explained by these estimated Taylor rules. Using a core measure of consumer price inflation (CPI), Blinder and Reis (2005) estimate a Taylor rule over 1987:1–2005:1, showing that the estimated policy rule tracks actual policy actions fairly well. Using Greenbook forecasts of core CPI inflation, Mehra and Minton (2007) estimate a forecast-based Taylor rule that shows this estimated policy rule also fits the data over 1987:1–2000:4.[2] More recently however, Taylor (2007, 2009) has argued that monetary policy was "too loose" during most of the period from 2002–2006, in the sense that the actual federal funds rate was too low relative to the level simulated by a smoothed version of the original Taylor rule.[3] In this simulation exercise, Taylor (2007) assumes response coefficients

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[1] Blinder and Reis (2005) have hailed Chairman Greenspan's focus on core, rather than headline, inflation as a "Greenspan innovation." The measure of core inflation used excludes food and energy prices.

[2] The sample period used in Mehra and Minton (2007) ends in 2000, given the five-year lag in the release of the Greenbook forecasts to the public.

[3] 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

of 1.5 and .5 on inflation and the output gap, as in the original Taylor rule, but instead uses headline CPI as a measure of inflation.[4]

This article highlights another aspect of monetary policy in the Greenspan era: The measure of inflation used in monetary policy deliberations has also been refined over time. This can be seen in the semiannual monetary policy reports to Congress (Humphrey-Hawkins reports), where inflation forecasts by the members of the Federal Open Market Committee (FOMC) have been presented using different measures of inflation over time. Thus, through July 1988, inflation forecasts used the implicit deflator of the gross national product, thereafter switching to the CPI. In February 2000, the CPI was replaced by the personal consumption expenditures (PCE) deflator measure of inflation and from July 2004 onward inflation forecasts employed the core PCE deflator that excludes food and energy prices.

Though these different measures of inflation may move together in the long run, over short periods these inflation measures may behave differently because of factors such as energy prices and changes in coverage and definitions. As a result, the Fed's inflation target may vary depending on the measure of inflation used, thereby affecting the desired setting of the federal funds rate.[5] Previous empirical work has not paid much attention to this issue, as most analysts estimate Taylor rules under the assumption that the measure of inflation used in policy deliberations did not change during the Greenspan years.[6]

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target each period as shown below (Taylor 1993):

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\begin{aligned}
FR_t &= rr^* + \alpha_\pi \left(\pi_{t-1} - \pi^*\right) + \alpha_y \left(y_t - y_t^*\right)_{t-1} \\
FR_t &= 2.0 + 1.5 \left(\pi_{t-1} - 2.0\right) + .5 \left(y_t - y_t^*\right)_{t-1},
\end{aligned}
$$

where rr^* is the real interest rate (assumed to be 2 percent), π is actual inflation, π^* is the Fed's inflation target (assumed to be 2 percent), $\left(y_t - y_t^*\right)$ is the output gap, α_π is the inflation response coefficient (assumed to be 1.5), and α_y is the output response coefficient (assumed to be .5). Inflation in the original Taylor rule was measured by the behavior of the gross domestic product (GDP) deflator, and the output gap is the deviation of the log of real output from a linear trend. According to the original Taylor rule, the Federal Reserve is backward looking, focused on headline inflation, and follows a "non-inertial" policy rule.

[4] Using the policy response coefficients from the original Taylor rule and headline CPI as a measure of inflation, Poole (2007) also shows that the actual federal funds rate is too low relative to the level prescribed for most of the period from 2000:1–2006:4 (see Figure 1 in Poole [2007]). Poole, however, does not conclude that policy was too easy because he alludes to the change in the measure of inflation used in monetary policy deliberations during this subperiod.

[5] Kohn (2007) has highlighted these considerations.

[6] While Blinder and Reis (2005) and Mehra and Minton (2007) estimate Taylor rules using a core measure of CPI inflation, the measure of inflation used in Taylor (2007, 2009) is headline CPI and the one used in Smith and Taylor (2007) is the implicit deflator for GDP. An exception is the paper by Orphanides and Wieland (2008), in which a forecast-based Taylor rule is estimated using the semiannual Humphrey-Hawkins inflation forecasts. More recently, Dokko et al. (2009) and Bernanke (2010) have highlighted the issue of the measurement of inflation used in monetary policy deliberations.

This article re-examines the issue of whether monetary policy actions taken during the Greenspan years can be described by a stable Taylor rule. It considers two Taylor rules that differ with respect to the measure of inflation used in implementing monetary policy. According to both these rules, the Greenspan Fed was forward looking, smoothed interest rates, and linked the federal funds rate target to expected inflation and the unemployment gap. However, according to one Taylor rule, the Federal Reserve used headline CPI inflation, and, according to the other, it used core CPI until 2000 and core PCE thereafter. The later specification departs from the usual assumption that a Taylor rule has to be estimated using a single measure of inflation.[7] Both the policy rules employ real-time data on economic fundamentals such as the pertinent inflation measure and the unemployment gap. As noted by Orphanides (2001, 2002), in evaluating historical monetary policy actions using estimated Taylor rules, the use of ex post revised, as opposed to real-time, data on economic variables can give misleading inferences about the stance of monetary policy.

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

$$FR_t^* = \alpha_0 + \alpha_\pi E_t \pi_{t+j}^c + \alpha_u \left(ur_t - ur_t^* \right), \tag{1.1}$$

$$FR_t = \rho FR_{t-1} + (1-\rho) FR_t^* + \nu_t, \tag{1.2}$$

$$FR_t = \rho FR_{t-1} + (1-\rho) \left\{ \alpha_0 + \alpha_\pi E_t \pi_{t+j}^c + \alpha_u \left(ur_t - ur_t^* \right) \right\} + \nu_t, \tag{1.3}$$

where FR_t is the actual federal funds rate, FR_t^* is the federal funds rate target, $E_t \pi_{t+j}^c$ is the expectation of the j-period-ahead core inflation rate made at time t conditional on period $t-1$ dated information, ur is the actual unemployment rate, ur^* is the non-accelerating inflation unemployment rate (NAIRU), and ν_t is the disturbance term. Thus, the term $\left(ur_t - ur_t^* \right)$ is the current unemployment gap. Equation (1.1) relates the federal funds rate target to two economic fundamentals, expected inflation and the current unemployment gap. Hereafter, the funds rate target is called the policy rate. The coefficients α_π and α_u measure the long-term responses of the funds rate target to expected inflation and the unemployment gap; the inflation response coefficient is assumed to

[7] The estimation of a Taylor rule using an inflation series that employs two or more measures of inflation may mean that the intercept term in the estimated Taylor rule is no longer a constant. This may happen if different measures of inflation exhibit different trend behaviors during the course of the estimation period and, hence, the Fed's inflation target expressed in these different inflation measures is no longer similar in magnitude.

be positive and the unemployment gap response coefficient is assumed to be negative, indicating that the Federal Reserve raises its funds rate target if it expects inflation to rise and/or the unemployment gap to fall. Equation (1.2) is the standard partial adjustment equation, which expresses the current funds rate as a weighted average of the current funds rate target, FR_t^*, and the last quarter's actual value, FR_{t-1}. If the actual funds rate adjusts to its target within each period, then ρ equals zero, suggesting 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 (1.1) into (1.2), we get (1.3)—a forward-looking "inertial" Taylor rule.

As in Clarida, Gali, and Gertler (2000), the Taylor rules are estimated assuming rational expectations and using instrumental variables over 1987:1–2004:4; this sample period spans most of the Greenspan era.[8] The key feature of the estimation procedure used here is that the instrument set includes, among other variables, Greenbook inflation forecasts based on different inflation measures. This strategy differs from the one used in Boivin (2006) and Mehra and Minton (2007), where forward-looking Taylor rules are estimated directly using Greenbook forecasts. Given the five-year lag in the release of Greenbook forecasts to the public, the current strategy enables one to estimate the Taylor rules over most of the Greenspan era (1987:1–2004:4) and then examine their predictive content for the longer sample period (1987:1–2006:4) that includes the Bernanke years.[9] We end the sample in 2006 in order to compare results in previous research that indicate monetary policy was too loose over 2002–2006.

The empirical work presented here suggests several observations. First, a Taylor rule that is estimated using a time-varying measure of core inflation

[8] There is considerable evidence that the policy rule followed by the Greenspan Fed differed from the one followed by the Volcker Fed in one important way. In its attempts to build credibility, the Volcker Fed responded strongly to long-term inflationary expectations imbedded in long bond yields, in addition to responding to inflation and unemployment, the two fundamental variables suggested by a Taylor rule (Mehra 2001). The long bond rate is generally not significant if the Taylor rule is estimated using data from the Greenspan era because the Greenspan Fed had by then achieved credibility. For this reason we estimate the Taylor rule using observations only from the Greenspan era. This strategy is also consistent with the observation that in criticizing the Greenspan Fed, Taylor (2007) uses a policy rule that includes only inflation and unemployment (output) gap variables.

[9] We, however, do compare the robustness of our results to this alternative method of estimating the Taylor rule using Greenbook inflation forecasts. Although estimates of policy response coefficients differ, the estimates yield qualitatively similar conclusions about the relevance of the inflation measure. In particular, the Taylor rule that is estimated using Greenbook forecasts of core CPI until 2000 and core PCE thereafter tracks actual policy well over 2000:1–2006:4 and passes the test of parameter stability. That is not the case if the Taylor rule is estimated using Greenbook forecasts of headline CPI inflation. Furthermore, as measured by the root mean squared error criterion, the Taylor rule with Greenbook forecasts of the time-varying inflation measure fits the data better than the Taylor rule with Greenbook forecasts of headline CPI.

(CPI until 2000 and PCE thereafter) yields reasonable estimates of inflation and unemployment gap response coefficients. The estimated inflation response coefficient, α_π, is positive and way above unity, suggesting that the Greenspan Fed responded strongly to expected inflation. The estimated unemployment gap response coefficient, α_u, is negative and statistically significant, suggesting that the Federal Reserve also responded to slack. The Chow test of parameter stability does not indicate a shift in the estimated parameters around 2000 when the Federal Reserve switched from CPI to PCE.[10] Also, the estimated Taylor rule tracks the actual path of the federal funds rate fairly well, especially over the period from 2002–2006.

In contrast, a Taylor rule that is estimated using headline CPI inflation does not provide reasonable estimates of policy response coefficients and depicts parameter instability over 1988:1–2004:4. The estimated Taylor rule based on headline CPI inflation is consistent with the actual funds rate being too low relative to the level prescribed by the estimated Taylor rule over 2002–2006, as in Smith and Taylor (2007) and Taylor (2007). These results indicate that the choice of the measure of inflation used in estimated Taylor rules is not innocuous. Furthermore, one should employ real-time information for evaluating historical monetary policy actions.

Second, during most of the period from 2001–2006, inflation measured by headline CPI was higher than what would be indicated by core PCE data, reflecting in part the effects of the rise in oil prices on headline inflation. The tests of parameter stability here indicate that the Greenspan Fed did not adjust the federal funds rate target in response to increases in the headline measure of CPI inflation.[11] The lack of policy response to increases in headline CPI inflation reflected the Greenspan Fed's belief that oil price increases were transitory[12] and that core inflation is a better gauge of the underlying trend inflation.[13]

Third, the core measure of PCE inflation has been substantially revised over the years. In particular, real-time estimates of core PCE inflation over

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[10] Although the core PCE index was given prominence in Humphrey-Hawkins forecasts in July 2004, the hypothesis here that the Greenspan Fed in fact paid attention to core measures of inflation implies that the FOMC started paying attention to core PCE much earlier.

[11] Several analysts and policymakers have noted that the Greenspan Fed's policy of focusing on core inflation continued through the Bernanke years. See, for example, Kohn (2009) and Bernanke (2010).

[12] During this subperiod most other economists also thought oil price increases were transitory and hence did not expect the rise in oil prices to lead to persistent increases in headline inflation. For example, despite the actual increase in headline CPI inflation, the Survey of Professional Forecasters forecasts of headline CPI inflation did not increase appreciably over 2003:1–2006:4. See Dokko et al. (2009) for additional evidence on this issue.

[13] This belief is consistent with the empirical evidence documented by several analysts that, for the period since the early 1980s, it is core rather than headline inflation that better approximates the trend component of inflation. Some of that empirical evidence is reviewed in Mishkin (2007) and Kiley (2008) and updated in Mehra and Reilly (2009).

2002:1–2005:4 are substantially lower than those indicated by ex post revised data (vintage 2009). The counterfactual simulations of the federal funds rate generated using the ex post revised data do suggest that deviations of the policy rule are somewhat larger than those generated using the real-time data. However, it would be misleading to conclude from such evidence that the Greenspan Fed had followed an easier stance on monetary policy.

Our results complement the recent work of Orphanides and Wieland (2008), who argue that policy actions taken over 1988–2007 have been consistent with a stable Taylor rule and that policy was not too loose over 2001–2007. They, however, estimate a forecast-based Taylor rule using publicly available forecasts of inflation and unemployment contained in semiannual Humphrey-Hawkins reports. As indicated before, the Humphrey-Hawkins inflation forecasts used CPI until 1999, switching thereafter to the PCE measure. The evidence in this article implies that a forward-looking Taylor rule estimated using actual real-time inflation and unemployment data yields identical results, in particular the conclusion that policy actions are consistent with a stable Taylor rule, provided we allow for the change in the measure of inflation used in monetary policy deliberations.[14]

The rest of the paper is organized as follows. Section 1 discusses the empirical methodology and reviews the data on the behavior of different measures of inflation during the Greenspan era. Section 2 presents empirical results, reproducing the evidence in Taylor (2007, 2009) that the Greenspan Fed set a funds rate low relative to the Taylor rule. We show that the result in Taylor disappears if one uses the time-varying measure of inflation employed by the FOMC. Section 3 concludes.

1. EMPIRICAL METHODOLOGY

Estimation of the Forward-Looking Inertial Taylor Rule

The 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, smoothed interest rates, and refined the measure of inflation used in monetary policy deliberations. We model the forward-looking nature of the policy rule by relating the current value of the funds rate

[14] Using somewhat different approaches, Dokko et al. (2009) and Bernanke (2010) also show that actual policy is much closer to the one prescribed by the original Taylor rule if the measure of inflation used in the policy rule is the one employed by the FOMC in monetary policy deliberations and if real-time data are used. Bernanke (2010) generates the predictions of the policy rate using the Greenbook inflation forecasts until 2004 and the Humphrey-Hawkins forecasts thereafter. Dokko et al. (2009) generate the predictions of the policy rate employing real-time estimates of core PCE inflation.

target to the expected average annual inflation rate and the contemporaneous unemployment gap. The policy rule incorporating these features is reproduced below in equation (2.3):

$$FR_t = \rho FR_{t-1} + (1-\rho)\left\{\alpha_0 + \alpha_\pi E_t \bar{\pi}^c_{\bar{4}} + \alpha_u \left(ur_t - ur^*_t\right)\right\} + \nu_t, \quad (2.3)$$

where the expected average annual inflation rate, $E_t \bar{\pi}^c_{\bar{4}}$, is measured by the average of one-through-four-quarter-ahead expected values of core inflation made at time t, and other variables are defined as before.[15]

The estimation of the policy rule (2.3) raises several issues. The first issue relates to how we measure expected inflation and the unemployment 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 indicated earlier, the use of revised as opposed to real-time data may affect estimates of policy coefficients and may provide a misleading historical analysis of policy actions. The third issue is an econometric one, arising as a result of the potential presence of serial correlation in the error term ν_t. Rudebusch (2002, 2006) points out that the Federal Reserve may respond to other economic factors besides expected inflation and the unemployment gap and, hence, a Taylor rule estimated while 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 understand how 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. But 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 (3.1):

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

[15] In particular, the four-quarter average of expected inflation rates is defined as $\bar{\pi}^c_{t,\bar{4}} = \left(\pi^c_{t,1} + \pi^c_{t,2} + \pi^c_{t,3} + \pi^c_{t,4}\right)/4$, where $\pi^c_{t,j}\, j = 1, 2, 3, 4$ is the j-quarter-ahead expected value of core inflation made at time t.

$$FR_t = sFR_{t-1} + \left\{\alpha_0 + \alpha_\pi E_t \bar{\pi}^c_4 + \alpha_u \left(ur_t - ur^*_t\right)\right\}$$
$$-s\left\{\alpha_0 + \alpha_\pi E_{t-1}\bar{\pi}^c_4 + \alpha_u \left(ur_{t-1} - ur^*_{t-1}\right)\right\} + \varepsilon_t. \quad (3.2)$$

If we substitute (3.1) into (2.3), it can be easily shown that we get the reduced-form policy rule (3.2) in which, among other variables, the lagged funds rate also enters the policy rule. Hence, the empirical finding of a significant coefficient on the lagged funds rate in the estimated policy rule may be interpreted as arising as a result of interest rate smoothing when in fact it is not present. In view of these considerations, the policy rule here 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

$$FR_t = \alpha_0(1-s)(1-\rho) + (s+\rho)FR_{t-1}$$
$$+ (1-\rho)\left\{\alpha_\pi E_t\bar{\pi}^c_4 + \alpha_u\left(ur_t - ur^*_t\right)\right\}$$
$$-s\left\{(1-\rho)\alpha_\pi E_{t-1}\bar{\pi}^c_4 + (1-\rho)\alpha_u\left(ur_{t-1} - ur^*_{t-1}\right)\right\}$$
$$-s\rho FR_{t-2} + \varepsilon_t. \quad (4)$$

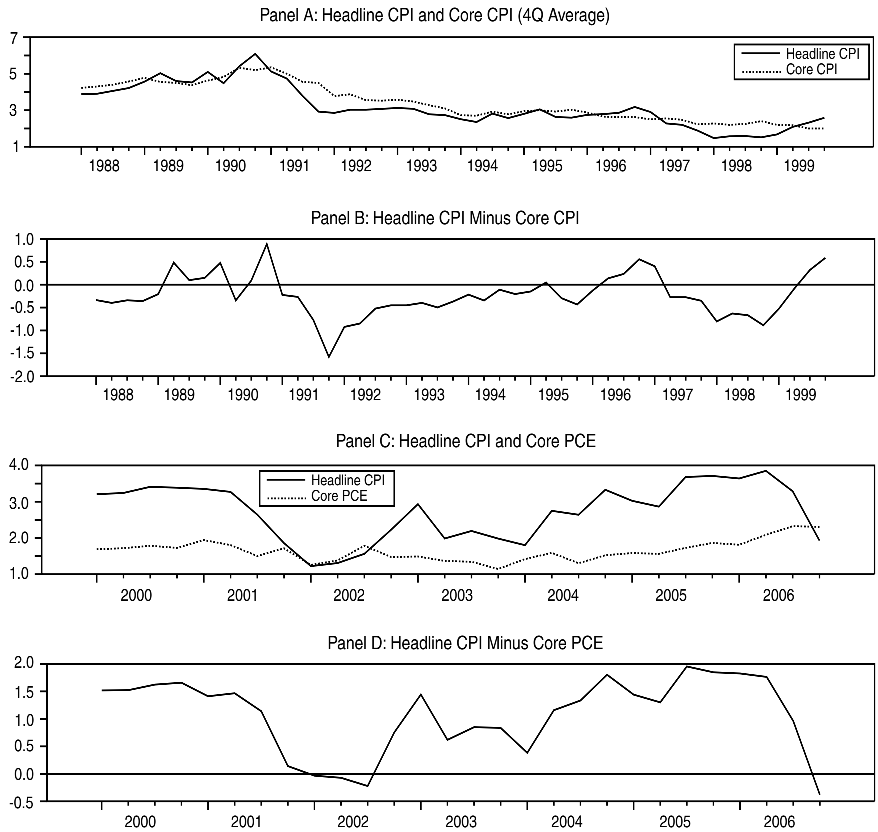
Note, if there is no serial correlation ($s = 0$ in [4]), we get the reduced-form policy rule shown in (2.3), and if there is no partial adjustment ($\rho = 0$ in [4]), we get the policy rule shown in (3.2). Of course, if both s and ρ are not zero, we have a policy rule with both partial adjustment and serial correlation.[16]

In previous research, a forward-looking policy rule such as the one given in (2.3) has often been estimated assuming rational expectations and using a generalized method of moments procedure (Clarida, Gali, and Gertler 2000). We follow this literature and estimate the policy rule assuming rational expectations, namely, we substitute actual future core inflation for the expected inflation term and use an instrumental variables procedure to estimate policy coefficients. Given the evidence that the Greenbook forecasts are most appropriate in capturing policymakers' real-time assessment of future inflation developments, we include the Greenbook forecasts in the instruments.[17] In

[16] Estimating the policy rule allowing for the presence of serial correlation produces more robust estimates of policy parameters including the partial adjustment coefficient. Moreover, the policy rule is estimated using the quasi-differenced data, as can be seen in equation (3.2). This quasi-differencing of data minimizes the spurious regression phenomenon noted in Granger and Newbold (1974).

[17] Romer and Romer (2000) have shown 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 that one needs a large set of conditional information to properly model monetary policy. In that respect, the Greenbook forecasts include

Figure 1 Actual Inflation (Real-Time)

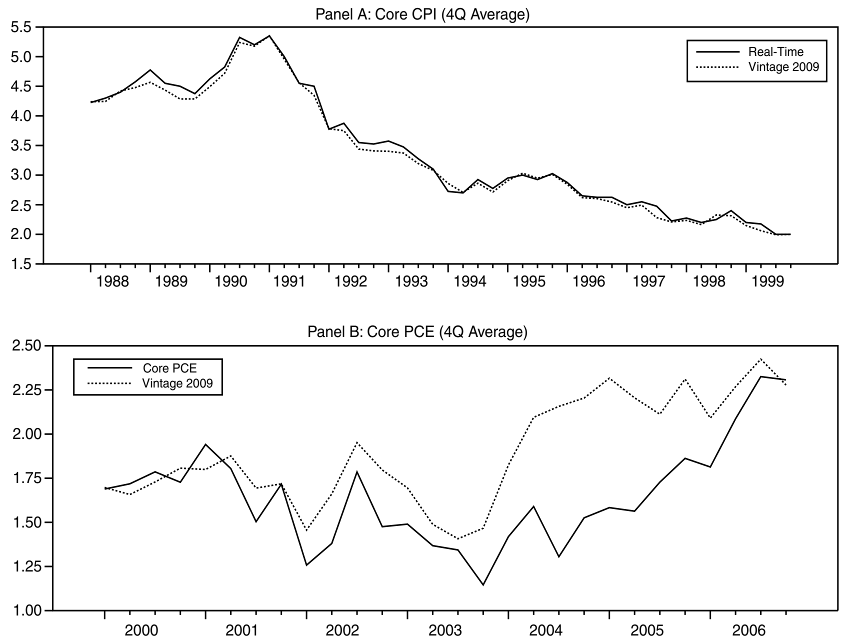


addition, we estimate the policy rule allowing for the presence of both interest rate smoothing and serial correlation as in (4) and use the nonlinear instrumental variables procedure. The instruments used are the three lagged values of Greenbook inflation forecasts, the federal funds rate, levels of the unemployment gap, and the spread between the 10-year Treasury bond yield and the federal funds rate. As indicated earlier, the policy rule is estimated over 1988:1–2004:4, given the five-year lag in the release of the Greenbook forecasts to the public.[18]

real-time information from a wide range of sources, including the Board staff's "judgment," not otherwise directly measurable.

[18] The estimation period begins in 1988:1 because the instrument set includes the lagged values of economic variables. As a check on the adequacy of the instruments variables procedure, we ran the first-stage regressions for the endogenous variables (expected inflation and the

Figure 2 Real-Time Versus Vintage 2009 Core Inflation



Data

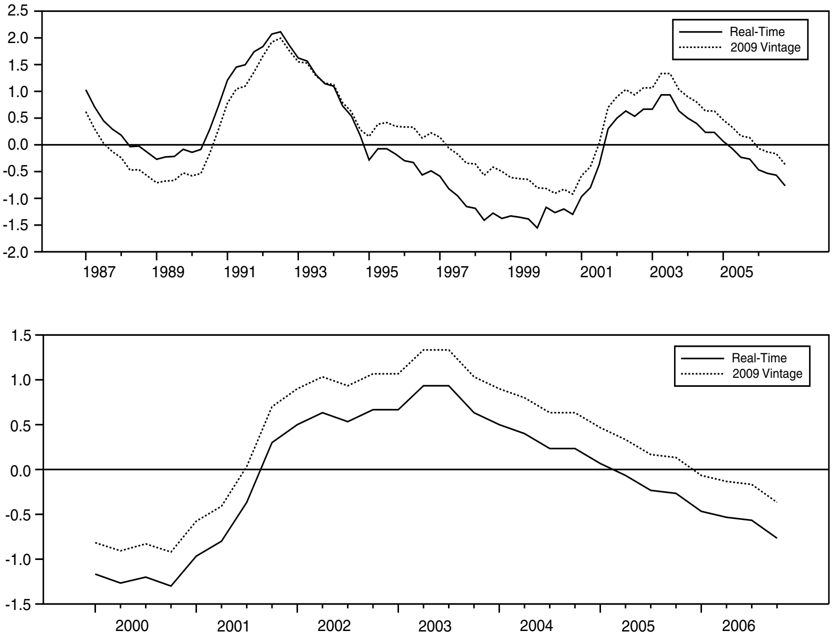
We estimate the policy rule in (4) using real-time data on core inflation and the unemployment gap. The data on core inflation came from the real-time data set maintained at the Philadelphia Fed.[19] The data on real-time estimates of the NAIRU were those prepared by the Congressional Budget Office (CBO).[20] The Greenbook forecasts of core inflation used in the instrument list are those prepared for the FOMC held near the second month of the quarter.

contemporaneous unemployment gap). In the first stage regressions, the R-squared statistics are fairly large, ranging from .45 to .97, suggesting the endogenous variables are highly correlated with the instruments.

[19] The empirical work used the preliminary estimates of core PCE inflation, usually released by the end of the first month of a quarter. The Greenbook forecasts used as instruments were the ones prepared for the FOMC meetings held near the second month of a quarter. This timing means that the Board staff preparing the Greenbook forecasts had information about the preliminary estimates of core inflation rates in previous quarters. However, none of the conclusions reported here would change if we had used third release estimates, usually reported by the end of the third month of the quarter.

[20] In January of each year from 1991–2006, the CBO released estimates of the NAIRU. For the period 1987–1990, the estimates used are those given in the 1991 vintage data file. For 1991, we used the pertinent series on the NAIRU from the 1992 vintage data file and so on for each year thereafter.

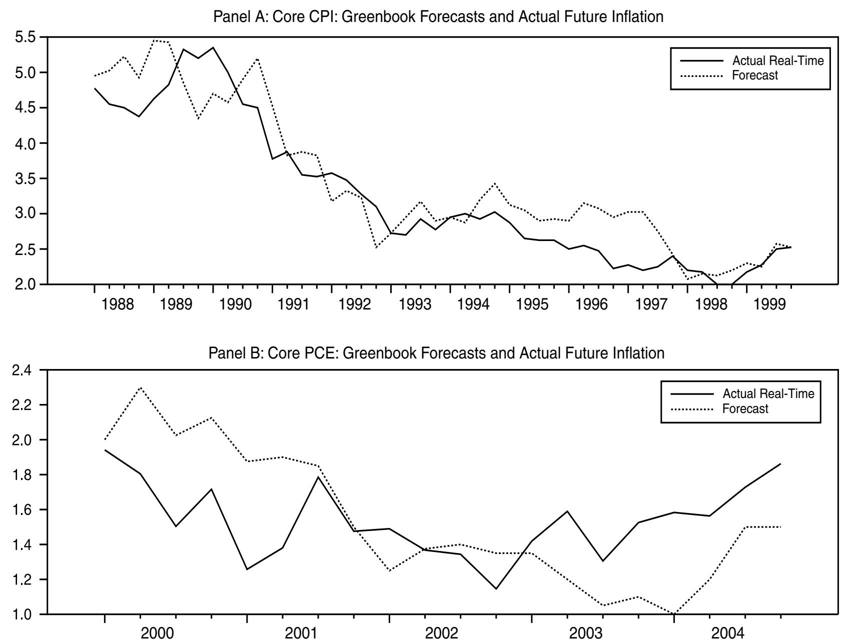
Figure 3 Unemployment Gap



Panel A in Figure 1 charts the four-quarter averages of real-time headline and core CPI inflation rates from 1988:1–1999:4, and Panel C charts the averages of headline CPI and core PCE inflation rates from 2000:1–2006:4. As can be seen, headline and core CPI inflation series stay together for most of the period before 2000 (see Panel B). However, over 2000:1–2006:4, headline CPI inflation remained above core PCE inflation (see Panel D), suggesting that a policy rule that relates the policy rate to headline CPI inflation is likely to prescribe a higher federal funds rate target than a policy rule that relates the policy rate to core PCE inflation, ceteris paribus. Hence, given the different behavior of headline CPI inflation and core PCE inflation rates over this subperiod, the measure of inflation used in the estimated Taylor rule will matter for predicting the stance of monetary policy.

Figures 2 and 3 chart real-time and 2009 vintage estimates of economic fundamentals that enter the Taylor rules; Figure 2 charts the four-quarter average of core CPI and core PCE inflation rates, whereas Figure 3 charts the unemployment gap. Two observations are noteworthy. First, core PCE inflation data have been extensively revised over the years, and there are big discrepancies between real-time and revised estimates of core PCE inflation. In particular, real-time estimates of the four-quarter average of PCE inflation

Figure 4 Greenbook Inflation Forecasts and Actual Future Inflation (4Q Average)



rates were substantially below the 2009 vintage estimates over 2002:1–2005:4 (see Figure 2, Panel B). Second, the unemployment gap data is also revised, but discrepancies between the real-time and 2009 vintage estimates are small and do not increase appreciably over 2001–2006 (see Figure 3).

Figure 4 charts Greenbook inflation forecasts and actual future inflation; Panel A charts inflation forecasts of core CPI inflation and Panel B charts those of core PCE. As can be seen, Greenbook inflation forecasts of core CPI inflation do track actual core CPI inflation, with the exception of the short period 1994–1997 when the Greenbook forecasts turned out to be too pessimistic. For the later period, the Greenbook forecasts of core PCE inflation do not fare as well in predicting actual core inflation. In particular, in 2003:1–2004:4, the Greenbook forecasts of core PCE inflation indicated deceleration in expected inflation, but actual core PCE inflation turned out to be much higher than what the Board staff predicted. The fear of expected deflation implicit in Greenbook forecasts of declining future inflation is used by some analysts to argue that the Greenspan Fed may have kept the federal funds rate target too low for too long during this subperiod. However, it is for a very short span that actual core inflation was higher than what the Board staff forecasted. The result

Table 1 Estimated Taylor Rules

Row	End Period	Inflation	α_π	α_y	ρ	s	SER
1	1999:4	Core CPI + PCE	1.6	−1.3	.56	.62	.322
			(5.3)	(4.3)	(3.3)	(2.9)	
2	2004:4	Core CPI + PCE	1.9	−1.4	.52	.67	.331
			(8.2)	(5.5)	(6.4)	(3.6)	
3	1999:4	Headline CPI	1.5	−1.0	.72	.61	.352
			(2.9)	(2.3)	(5.8)	(3.2)	
4	2004:4	Headline CPI	.1	−2.4	.40	.97	.347
			(.3)	(−4.9)	(2.6)	(3.3)	
5	1999:4	Core CPI	1.6	−1.3	.56	.62	.322
			(5.4)	(4.3)	(3.3)	(2.9)	
6	2004:4	Core CPI	1.6	−1.4	.60	.75	.324
			(3.1)	(3.0)	(4.3)	(4.4)	

Notes: Rows labeled 1 through 4 contain nonlinear instrumental variables estimates of policy coefficients from the forward-looking policy rule given below in (a) and use real-time data on inflation and the unemployment gap:

$$\begin{aligned} FR_t &= \alpha_0 (1-s)(1-\rho) + (s+\rho) FR_{t-1} + (1-\rho)\left\{\alpha_\pi E_t \bar{\pi}^c_4 + \alpha_u \left(ur_t - ur^*_t\right)\right\} \\ &\quad -s\left\{(1-\rho)\alpha_\pi E_{t-1}\bar{\pi}^c_4 + (1-\rho)\alpha_u\left(ur_{t-1} - ur^*_{t-1}\right)\right\} - s\rho FR_{t-2} + \varepsilon_t. \quad \text{(a)} \end{aligned}$$

The instruments used are three lagged values of Greenbook inflation forecasts, the funds rate, unemployment gap, the growth gap, and the spread between nominal yields on 10-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 ν_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 "End Period."

here—that a rational expectations version of the Taylor rule estimated using real-time data tracks the actual funds rate target well—implies that the fear of deflation may have played a limited role in keeping the funds rate target low during this subperiod.

2. EMPIRICAL RESULTS

This section presents and discusses policy response coefficients from Taylor rules that are estimated using different measures of inflation. It also examines the stability of policy response coefficients using the Chow test with the break data around 2000, when the Greenspan Fed switched from focusing on CPI to PCE inflation measure.

Estimates of Policy Response Coefficients

Table 1 presents estimates of policy response coefficients (α_π, α_u) from the Taylor rule in equation (4) for two sample periods, 1988:1–1999:4 and

1988:1–2004:4. Rows 1 and 2 present estimates using the time-varying measure of core inflation, and rows 3 and 4 present estimates for headline CPI inflation measure. Focusing first on estimates of the Taylor rule with the time-varying measure of core inflation, all estimated policy response coefficients are correctly signed and statistically significant. In particular, the inflation response coefficient α_π is generally well above unity, suggesting that the Greenspan Fed responded strongly to expected inflation. Furthermore, in both sample periods, estimated policy response coefficients remain correctly signed and are statistically significant, suggesting parameter stability.[21,22]

Focusing on estimates of the Taylor rule with headline CPI inflation, we find that estimated policy response coefficients are sensitive to the sample period. For the sample period ending in 1999:4, the estimated policy response coefficients are correctly signed and statistically significant. The estimated inflation response coefficient is 1.5, well above unity, and the estimated unemployment gap response coefficient is close to unity. However, the estimated policy response coefficients are not stable across the two sample periods. In particular, the estimated inflation response coefficient falls below unity and is no longer statistically significant when the policy rule is estimated over 1988:1–2004:4 (see Table 1, Row 4). This result is similar in spirit to the one in Smith and Taylor (2007), who estimate a Taylor rule over 1984:1–2005:4 and find that the estimated inflation response coefficient declined significantly in 2002, leading them to conclude that the Greenspan Fed had become less responsive to inflation.

Parameter Stability

We formally test for stability of policy response coefficients in the Taylor rule over 1988:1–2004:4 using the Chow test and treating the break date as unknown. Since the FOMC switched to the PCE measure of inflation in

[21] Other estimated coefficients of interest are also correctly signed. 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 that are omitted from the estimated policy rule. Furthermore, even after allowing for the presence of serial correlation, the estimated partial adjustment coefficient, ρ, is positive and well above zero, suggesting that the continued role of partial adjustment in generating a significant coefficient on the lagged value of the funds rate. This result is in line with the one in 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.

[22] The empirical work employed the inflation series using CPI until 2000:4 and PCE thereafter. The estimates of the policy response coefficients do not change much if the policy rule is alternatively estimated using CPI until 2000:1 and PCE thereafter. Furthermore, the test of parameter stability discussed in the next section was implemented for all break dates over 2000:1–2001:4. As discussed later, the estimated policy rule employing the time-varying measure of inflation did not indicate a break in policy response coefficients for any of the break dates.

Table 2 Test for Stability of Policy Coefficients in Policy Rules

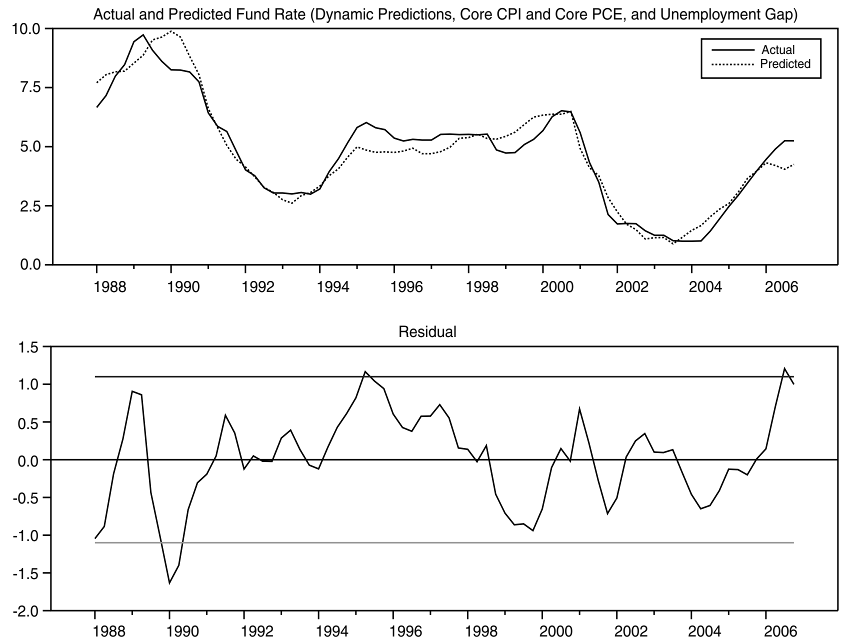
Breakpoint	**Policy Rule Core CPI + Core PCE (A)**	**Policy Rule Headline CPI (B)**	**Policy Rule Core CPI (C)**
2000Q1	.86	.04	.22
2000Q2	.95	.02	.19
2000Q3	.46	.01	.16
2000Q4	.30	.01	.17
2001Q1	.41	.00	.05
2001Q2	.17	.00	.01
2001Q3	.65	.00	.19
2001Q4	.75	.00	.35

Notes: The values reported are p-values of a test of the null hypothesis in which policy coefficients, including the intercept in the policy rule, were stable against the alternative in which coefficients changed at the indicated date. Since the test is implemented including dummy variables in the policy rule given in equation (a) in the Table 1 Notes, the reported p-values are a test of the null hypothesis in which coefficients on slope dummies, including the intercept, did not change at the indicated date.

2000, we look for a break in the estimated Taylor rule around that period. In particular, for each date between 2000:1–2001:4, we include intercept and slope dummies on policy response coefficients in the Taylor rule in equation (4) and test their joint significance for a possible break in the estimated relation. Table 2 reports the p-value for a test of the null hypothesis in which Taylor rule coefficients were stable against the alternative in which coefficients changed at the indicated date. The column labeled (A) reports p-values generated using the Taylor rule that employed the time-varying measure of core inflation, whereas the column labeled (B) does so for the Taylor rule with headline CPI inflation. As can be seen, there is no date in the interval 2000:1–2001:4 at which one could claim to find a statistically significant break in the Taylor rule if one uses a time-varying measure of core inflation. In contrast, there are several dates one could find the evidence of a break in relation if the Taylor rule is estimated using headline CPI inflation (see column B). The latter result is similar in spirit to the one in Smith and Taylor (2007).[23]

[23] The test for parameter stability was implemented using intercept and slope dummies. In the case of the policy rule that was estimated using the time-varying measure of inflation, both the intercept and slope dummy coefficients were not different from zero, suggesting that there was no shift in the intercept of the policy rule in response to change in the measure of inflation employed. In contrast, when the policy rule is estimated using headline CPI, the slope dummy coefficient on the inflation response coefficient is relatively small, suggesting that the Federal Reserve did not respond as aggressively to headline inflation as it did before. This result is in line with the inflation response coefficient becoming insignificant when the policy rule is estimated over 1988:1–2004:4 (compare estimates across rows 3 and 4, Table 1).

Figure 5 Forward-Looking Taylor Rule



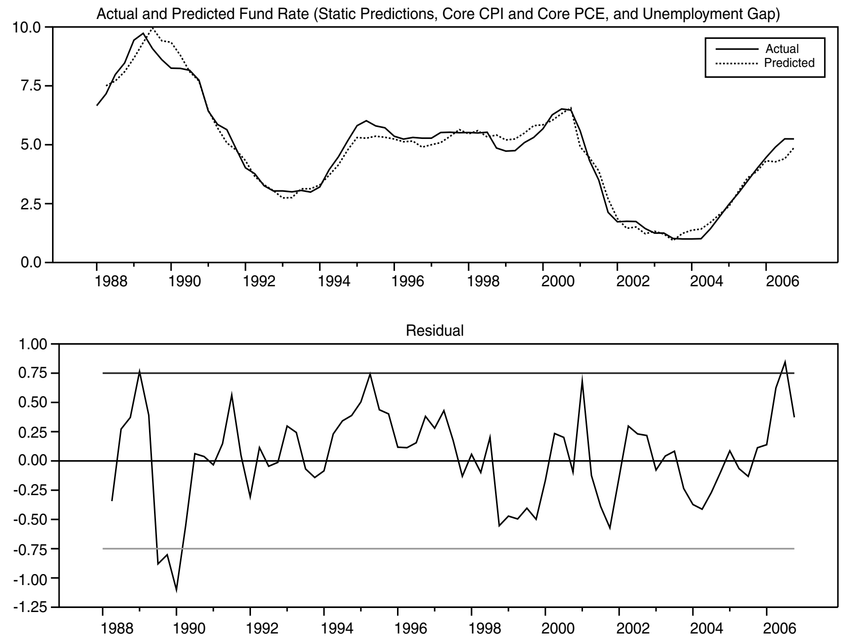
Predicting the Policy Rate Using a Taylor Rule based on Core Inflation: Was the Fed Off the Taylor Rule over 2001:1–2006:4?

In order to evaluate whether monetary policy actions over 2000:1–2006:4 can be explained by a Taylor rule, we generate predictions of the policy rate using the estimated Taylor rules. We consider two Taylor rules that differ with respect to the measure of inflation, and we generate both dynamic and static predictions. The dynamic predictions are generated using the policy rule as shown in (5):

$$FR_t^p = \hat{\rho} FR_{t-1}^p + \left(1-\hat{\rho}\right)\left\{\hat{\alpha}_0 + \hat{\alpha}_\pi \bar{\pi}^c_{t,\bar{4}} + \hat{\alpha}_u \left(ur_t - ur_t^*\right)\right\}, \qquad (5)$$

where FR^p is the predicted funds rate and the other variables are defined as before. As can be seen in the prediction equation given in (5), in generating the current quarter predicted value of the funds rate, we use last quarter's predicted value of the federal funds rate rather than the actual value, while using current-period values of the other two economic fundamentals. As a result, the current funds rate is a distributed lag on current and past values of expected inflation and the unemployment gap.

Figure 6 Forward-Looking Taylor Rule



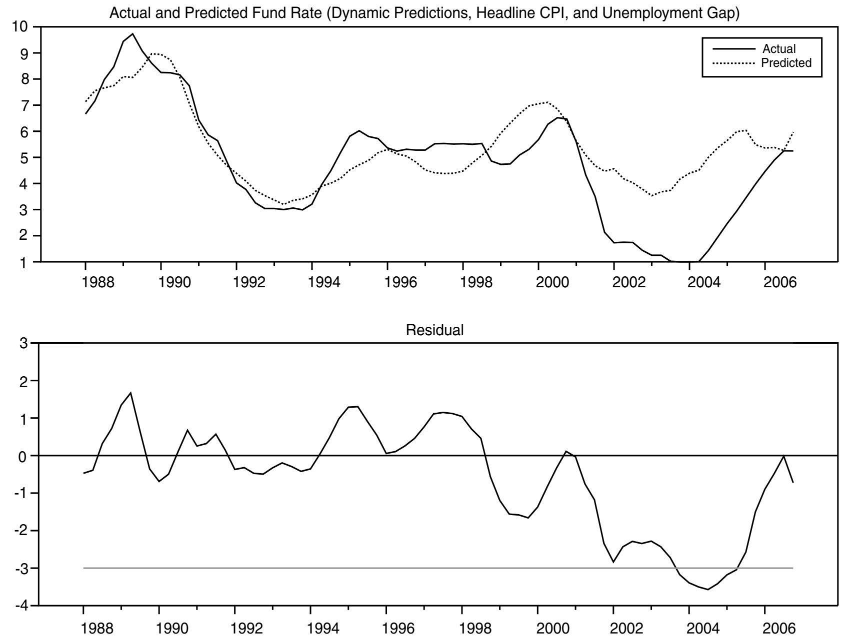
In contrast, the static predictions of the policy rate are generated while also paying attention to recent policy actions, in addition to economic fundamentals. In particular, the static predictions are generated using the estimated policy rule as shown in (6):

$$FR_t^p = \hat{\rho} FR_{t-1} + \left(1 - \hat{\rho}\right) \left\{\hat{\alpha}_0 + \hat{\alpha}_\pi \bar{\pi}^c_{t,\bar{4}} + \hat{\alpha}_u \left(ur_t - ur_t^*\right)\right\}. \quad (6)$$

The policy rule shown in (6) is similar to the one in (5) with the exception that (6) uses last quarter's actual value of the federal funds rate. Thus, in the static exercise the current forecast is influenced in part by actual policy actions, the magnitude of the influence of policy on the forecast being determined by the size of the partial adjustment coefficient, ρ.[24]

[24] Since the dynamic predictions are generated by paying attention only to expected inflation and the unemployment gap, they are better at revealing certain types of misspecification. In particular, if the federal funds rate equation is misspecified because it is estimated ignoring the influences of some other economic fundamentals, then the dynamic predictions generated using such a policy rule are likely to be poor proxies for the actual behavior of the federal funds rate. Hence, the dynamic predictions are better at gauging the fit of the estimated policy rule than are the static predictions.

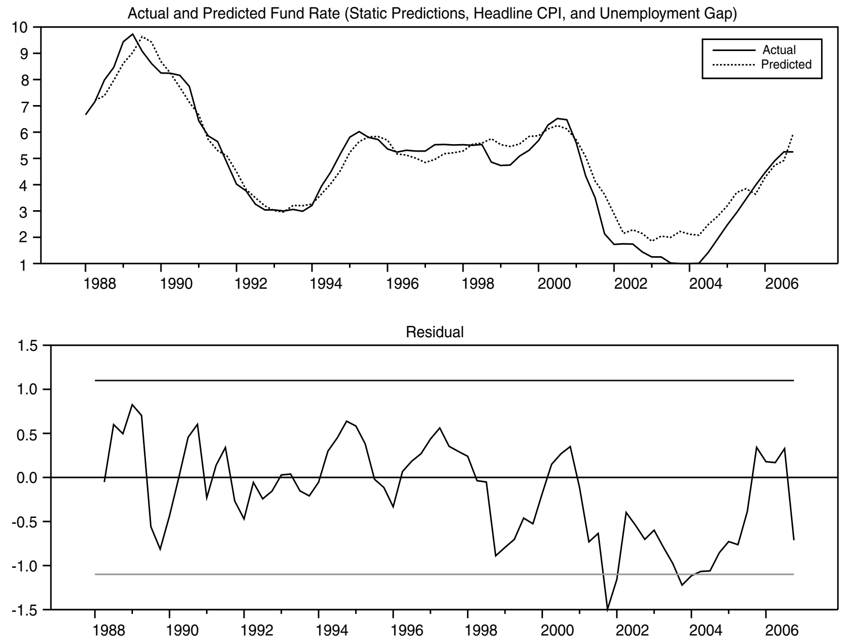
Figure 7 Forward-Looking Taylor Rule



Figures 5 and 6 respectively chart the dynamic and static predictions of the funds rate from the Taylor rule that is estimated using the time-varying measure of core inflation.[25] Actual values of the funds rate and the prediction errors are also charted there. Two observations need to be highlighted. First, the estimated policy rule predicts very well the broad contours of the policy rate over 1988:1–2006:4. The mean absolute error is .47 percentage points when dynamic predictions are used and .30 percentage points when static predictions are used. The root mean squared error is .60 percentage points when dynamic predictions are used, whereas it is only .38 percentage points when static predictions are used. Secondly, focusing on the period from 2000:1–2006:4, there is no evidence of persistently large prediction errors, and most prediction errors are small in magnitude (below twice the root mean squared error), suggesting that the actual funds rate is well predicted and, hence, that the Greenspan-Bernanke Fed was "on" a Taylor rule.

[25] The predictions begin in 1988:1. For generating the prediction for 1988:2, we use last quarter's actual funds rate. For later periods, the predicted values are generated using last period's predicted value and current period estimates of expected inflation and the unemployment gap.

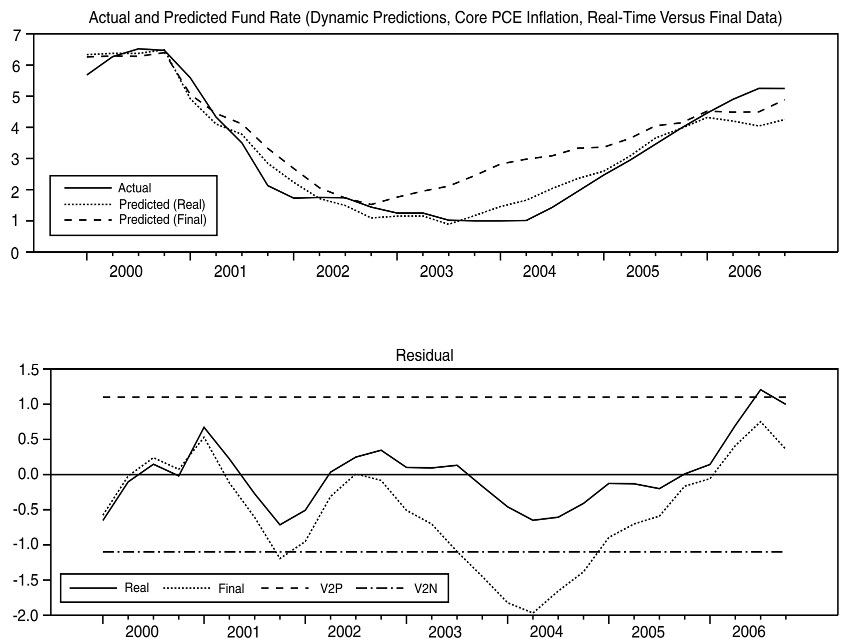
Figure 8 Forward-Looking Taylor Rule



Predicting the Policy Rate Using a Taylor Rule Based on Headline CPI Inflation: Was the Fed Off the Taylor Rule over 2001:1–2006:4?

Figures 7 and 8 respectively chart the dynamic and static predictions of the policy rate from the Taylor rule estimated using headline CPI inflation. Two observations are noteworthy. First, this Taylor rule does not predict well the broad contours of the policy rate. The mean absolute error is 1.1 percentage points and the root mean squared error is 1.5 percentage points, based on dynamic prediction of the policy rate. The summary measures of predictive performance improve somewhat when they are calculated using the static prediction errors—the mean absolute error is .46 percentage points and the root mean squared error is .56 percentage points. Secondly, focusing on the period from 2000:1–2006:4, there is clear evidence of persistently large negative prediction errors, and many of these prediction errors are large in magnitude (see lower panels, Figures 7 and 8). According to this Taylor rule, the actual funds rate remained consistently below the level prescribed, implying policy was too loose for most of the period over 2000:1–2006:4—a result that is in line with the ones in Smith and Taylor (2007) and Taylor (2007).

Figure 9 Counterfactual Simulations



Role of Data Revisions

Figure 2 shows that data on core PCE inflation have been extensively revised over the years, particularly for the period 2002–2005 when real-time estimates of core PCE inflation are substantially below the 2009 vintage estimates. Figures 9 and 10 chart, respectively, the counterfactual dynamic and static simulations of the policy rate generated using 2009 vintage data on economic fundamentals.[26] For a comparison, the predictions generated using real-time data are also charted. As can be seen, deviations of the policy rule using the 2009 vintage data are somewhat larger than those generated using real-time data. However, it would be misleading to conclude from such evidence that the Federal Reserve was too loose.[27]

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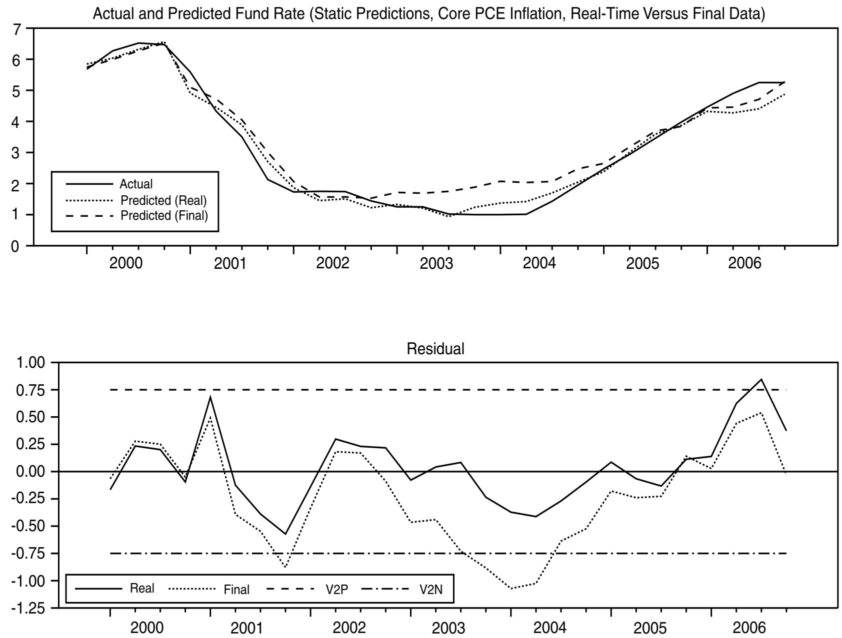
[26] The policy rule is estimated using real-time data over 1988:1–2004:4. The dynamic predictions are, however, generated using not real-time but 2009 vintage estimates of core PCE inflation and the unemployment gap.

[27] Many analysts have examined other indicators of inflation available in real time and conclude that monetary policy was not inflationary, despite the low level of the federal funds rate target. For example, Dokko et al. (2009) have examined the commercially available inflation forecasts of the private sector as well as the inflation forecasts made by the individual members the FOMC published in the Humphrey-Hawkins reports over 2003–2006. They concluded that all those inflation forecasts were consistent with the Federal Reserve's informal inflation target of between

Figure 10 Counterfactual Simulations

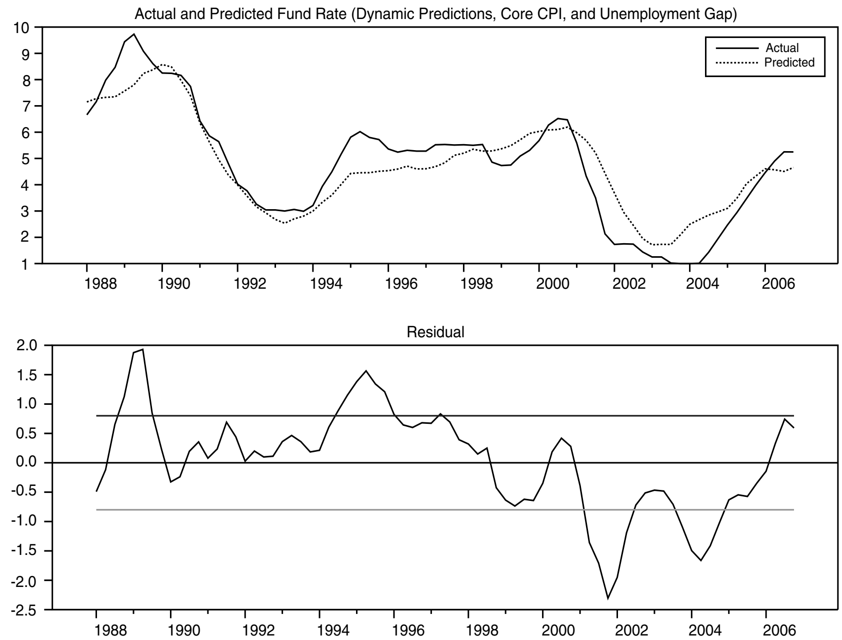


Role of Deflation Fears

Some analysts, focusing on the Taylor rule estimated using CPI inflation measure, contend that, over the period 2002:1–2005:4, the Greenspan Fed may have kept the federal funds rate too low for too long in order to avoid the consequences of a Japanese-style deflation. According to this explanation, internal forecasts of the U.S. inflation rate indicated the possibility of deflation, which led the Greenspan Fed to keep the short-term interest rate low for an extended period of time. There is some limited support for this view in Figure 4, which shows that the Greenbook forecasts of core PCE inflation indicated substantial deceleration of expected inflation for most of the period over 2002:1–2005:4. However, actual core PCE inflation did not decline to levels indicated by the Greenbook forecast. Also, as shown above, the actual funds rate is close to what is prescribed by a forward-looking Taylor rule estimated using real-time data on the fundamentals, namely, core PCE inflation

1.5 percent to 2 percent. Others focusing on the bond market measures of inflationary expectations point out that, over this subperiod, long-term rates exhibited considerable stability that is consistent with the presence of a noninflationary policy stance, despite the low level of the federal funds rate.

Figure 11 Forward-Looking Taylor Rule

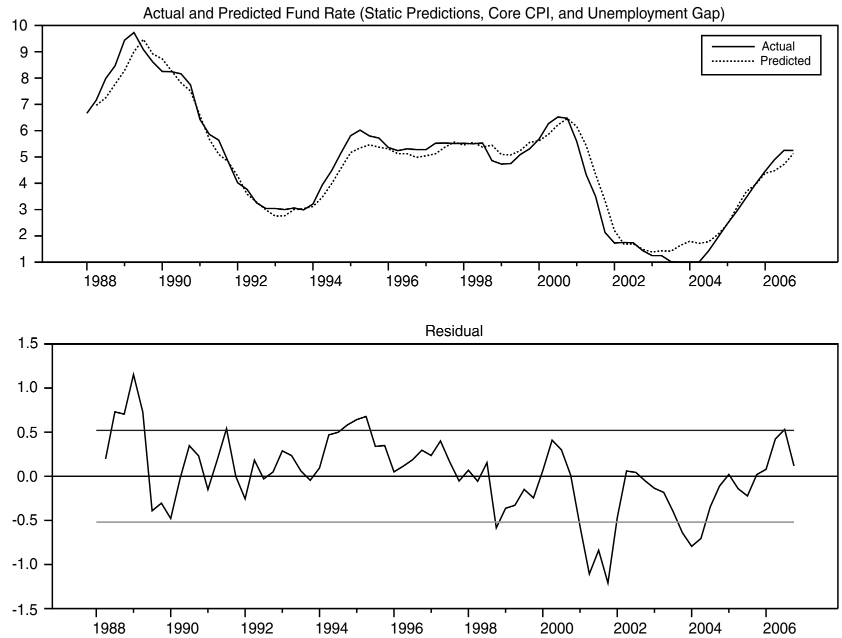


and the unemployment gap. The empirical work here suggests that, while the fear of deflation may have played some role, the actual funds rate remained low for fundamental reasons once we recognize that the Greenspan Fed was focused not on headline CPI but on a core measure of PCE inflation.

Headline CPI Versus Core CPI

The result here—that a forward-looking Taylor rule estimated using a headline measure of CPI inflation does not depict parameter stability during the Greenspan years—continues to hold if the Taylor rule is instead estimated using a core measure of CPI inflation. In fact, several analysts, including Blinder and Reis (2005), have estimated Taylor rules using a core measure of CPI inflation. But, as shown below, the use of a core measure of CPI inflation does generate reasonable estimates of policy response coefficients; the estimated policy rule, however, does not depict parameter stability in the Greenspan years. Table 1 presents policy response coefficients estimated using core CPI inflation data and Table 2 presents p-values of the Chow test of parameter stability (see column C). As can be seen, estimated policy response coefficients appear reasonable. However, the estimated policy rule still

Figure 12 Forward-Looking Taylor Rule

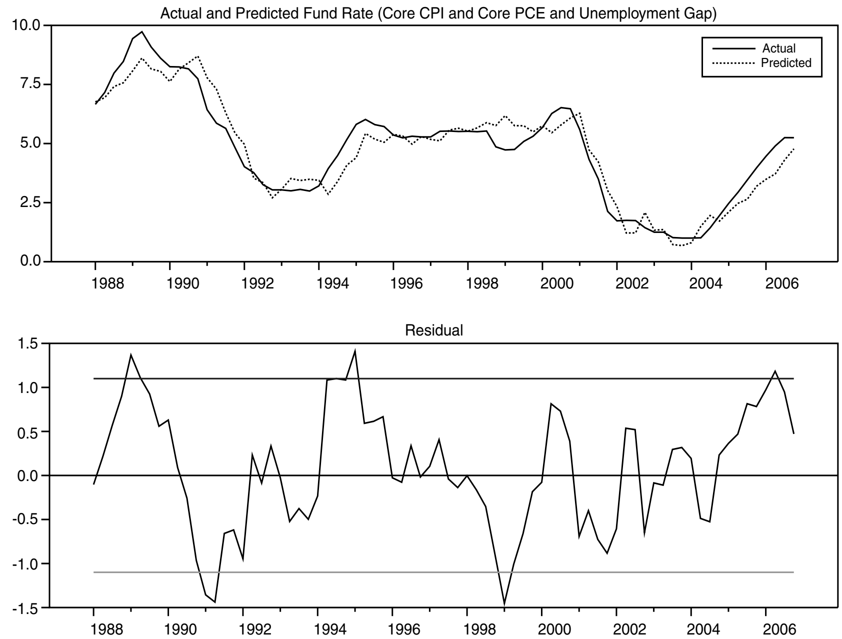


exhibits parameter instability in 2001; the test results indicate a reduction in the size of the inflation response coefficient, consistent with the observation in Taylor (2007) that the Greenspan Fed did not react strongly to inflation after 2001. Figures 11 and 12 chart the dynamic and static simulations of the federal funds rate using the estimated Taylor rule based on the core measure of CPI inflation. As can be seen, the actual funds rate is considerably below the value prescribed by this policy rule for most of the subperiod from 2001:1–2006:4. Using the metric of summary error statistics based on dynamic predictions, we calculate the mean absolute error as .70 percentage points and the root mean squared error as .86 percentage points. By this metric, the Taylor rule estimated using core CPI does better than the Taylor rule estimated using headline CPI inflation. However, neither of these Taylor rules depict parameter stability and both are consistent with policy by being "too loose" over most of the period 2002:1–2006:4.

Forward- Versus Backward-Looking Taylor Rules

The empirical work here has used forward-looking Taylor rules to show that the measure of inflation chosen matters for predicting actual policy actions

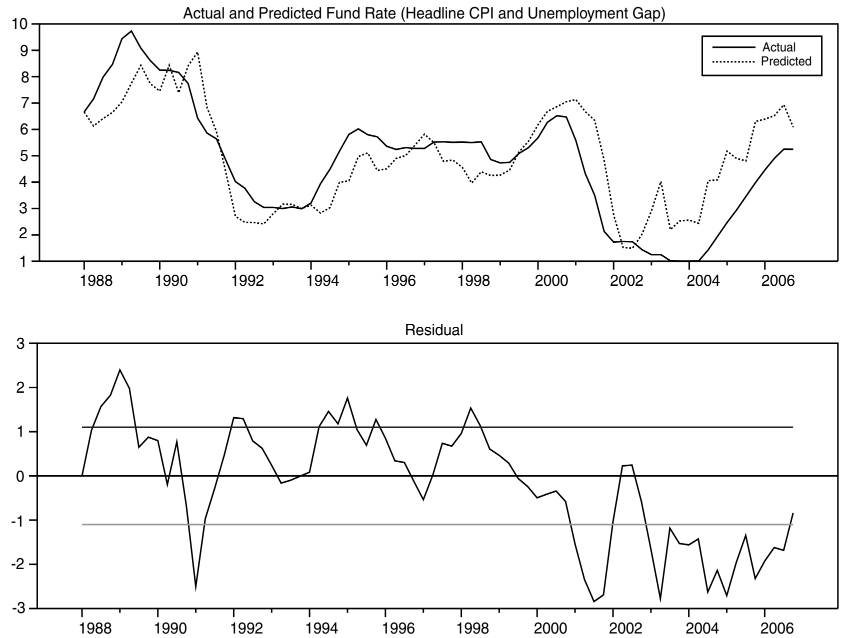
Figure 13 Backward-Looking Taylor Rule



over 2002:1–2006:4, namely, a Taylor rule estimated using the time-varying measure of core inflation tracks actual policy better than a Taylor rule estimated using headline CPI inflation. However, it may be noted that the above result continues to hold if one estimates and compares backward-looking Taylor rules. Namely, a backward-looking Taylor rule estimated using the time-varying measure of core inflation tracks actual policy actions much better than does a Taylor rule with headline CPI inflation (see Figures 13 and 14). However, backward-looking Taylor rules generally do not depict parameter stability, even when they are estimated using the time-varying measure of core inflation.[28]

[28] The Taylor rules considered in this exercise were estimated using smoothed lagged values of inflation and unemployment gap variables, as in the original Taylor rule. We also estimated versions in which we include a lagged value of the federal funds rate, thereby directly allowing interest rate smoothing. This specification gave qualitatively similar results.

Figure 14 Backward-Looking Taylor Rule



Discussion of Results

The empirical results above suggest that monetary policy actions in the Greenspan era can be summarized by a stable Taylor rule according to which the Federal Reserve was forward looking, smoothed interest rates, and focused on a core measure of inflation measured by CPI until 2000 and PCE thereafter. The estimated Taylor rule does not depict any parameter instability, despite the switch in the measure of inflation used in monetary policy deliberations. In contrast, Taylor rules that do not allow for this switch in the measure of inflation, and are instead estimated using CPI inflation (headline or core), depict parameter instability around 2000, indicating that the Greenspan Fed did not react strongly to expected (CPI) inflation.

Within the context of a Taylor-type policy rule, a switch in the measure of inflation is likely to affect the policy rule mainly by altering the constant term of the policy rule if the switch leads to a different inflation target expressed in a new inflation measure. This occurs because the constant term in a Taylor rule has embedded in it the Fed's estimate of its inflation target. However, the constant term in a Taylor rule also has embedded in it the Fed's estimate of the economy's real rate of interest. To see it, rewrite equation (1.1) as

$FR_t^* = rr^* + \pi^* + \alpha_\pi E_t \left(\pi_{t+j}^c - \pi^*\right) + \alpha_u \left(ur_t - ur_t^*\right)$, where rr^* is the real rate and π^* is the inflation target. If we substitute the above equation into equation (1.2), we get equation (1.3), where the constant term is now defined as $\alpha_0 = rr^* + (1 - \alpha_\pi)\,\pi^*$. The constant term thus has embedded in it the Fed's estimates of the real rate of interest as well as its inflation target. However, as is well known, given a reduced-form estimate of the constant term, we can't recover the Fed's estimates of the real rate as well as its inflation target without bringing in additional information.

The switch in the measure of inflation from core CPI to core PCE does not appear to be associated with any significant shift in the estimated Taylor rule used to explain monetary policy actions in the Greenspan years.[29] One possible explanation of why the switch did not lead to any significant shift in the estimated Taylor rule is that while the switch may have lowered the Fed's inflation target expressed in core PCE inflation, it may have also caused the Greenspan Fed to raise its assessment of the economy's real rate of interest, thereby leaving the constant term of the estimated Taylor rule unchanged.[30]

3. CONCLUDING OBSERVATIONS

This article shows that the measure of inflation used in estimating Taylor rules to explain historical monetary policy actions is not innocuous. The FOMC under the chairmanship of Alan Greenspan refined the measure of inflation used in monetary policy deliberations, switching from focusing on CPI to focusing on PCE in the early 1980s. Moreover, Chairman Greenspan encouraged both the FOMC and the financial markets to focus on core rather than headline inflation in implementing policy. As noted in Blinder and Reis (2005), during the Greenspan era an oil shock was considered a "blip" in the inflation process that did not affect long-term inflationary expectations and therefore should be ignored, leading the Fed to focus on core rather than headline inflation in the implementation of monetary policy.

If we estimate a Taylor rule that uses real-time data and we employ the time-varying measure of core inflation, then the estimated policy rule depicts

[29] This result is consistent with the test results of parameter stability discussed above. For each possible break date between 2000:1–2001:4, the Chow test of parameter stability was performed including intercept as well as slope dummies on response coefficients in the policy rule. For all the break dates, the intercept dummy was not statistically different from zero, which is consistent with the absence of a change in the constant term of the policy rule.

[30] Using the metric of comparing means, the sample mean of core PCE inflation rates over 1987:1–2005:4 is 2.5 percent, which is lower than the value (3.1 percent) computed using core CPI inflation rates over the same period. Given the differential trend behavior of these two inflation measures, the Greenspan Fed having an inflation target of, say, 2 percent based on the behavior of core PCE inflation is equivalent to its having an inflation target of 2.6 percent based on the core CPI inflation measure. Hence, the switch from CPI to PCE measure of inflation could have been associated with a downward shift in the constant term of the estimated Taylor rule around 2000.

parameter stability in the Greenspan era and predicts very well the actual path of the federal funds rate over 2001:1–2006:4. In contrast, a Taylor rule that is estimated using headline CPI inflation depicts parameter instability and indicates the actual funds rate was too low relative to the level prescribed, as headline CPI inflation remained above core PCE inflation during most of this short period. Hence, in evaluating monetary policy actions in the Greenspan era, it is important to pay attention to these two real-time features of monetary policy deliberations, namely, the focus on core rather than headline inflation measures and the switch from CPI inflation to PCE inflation.

Following John Taylor's (2007) work, many analysts and some policymakers have begun to contend that, over 2002:1–2005:4, the Federal Reserve may have lowered the federal funds rate too low for too long, suggesting that monetary policy was too loose as seen through the lens of a Taylor rule. The popular explanation of this easier stance on monetary policy during this period is that the Greenspan Fed feared deflation. In fact, the Greenbook forecasts of core PCE inflation indicated substantial deceleration in expected inflation during this subperiod, which did not materialize. However, the result here—that a forward-looking Taylor rule estimated using real-time core PCE inflation data tracks the actual funds rate well—implies that the actual funds rate was determined for fundamental reasons. In real time, the Fed's preferred measure of core PCE inflation fluctuated in a low narrow range.

The core measure of PCE inflation has been extensively revised over the years. In particular, the most recent 2009 vintage data indicates that over 2002–2006, core PCE inflation did not decelerate as much and was substantially higher than what the Federal Reserve knew in real time. When seen through the lens of a Taylor rule, policy deviations using the 2009 vintage data are somewhat larger than those generated using the real-time data. However, it would be misleading to conclude from such evidence that monetary policy was too easy. Several other indicators of inflationary expectations that were available in real time indicate policy was noninflationary over this subperiod.

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