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The Taylor Rule and "Opportunistic" Monetary Policy

We investigate the possibility that the Taylor rule should be formulated as a threshold process such that the Federal Reserve acts more aggressively in some circumstances than in others. It seems reasonable that the Federal Reserve would act more aggressively when inflation is high than when it is low. Similarly, it might be expected that the Federal Reserve responds more to a negative than a positive output gap. Although these specifications receive some empirical support, we find that a modified threshold model that is consistent with "opportunistic" monetary policy makes significant progress towards explaining Federal Reserve behavior.

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DETERMINING THE REACTION OF MONETARY authorities to changes in fundamental economic variables has long been a goal of fed watchers and monetary economists. Much of the recent literature in this area is based on the type of monetary policy rule introduced by Taylor (1993)

$$i_t = \gamma_0 + \pi_t + \alpha_1(\pi_t - \pi^*) + \beta y_t + \gamma_1 i_{t-1} + \gamma_2 i_{t-2} + \varepsilon_t, \qquad (1)$$

where: i_t is the nominal federal funds rate, π_t is the inflation rate over the last four quarters, π^* is the target inflation rate, y_t is output gap measured as percentage deviation of real GDP from its trend, and α_1, β, γ_0, γ_1, and γ_2 are parameters.

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The intuition behind (1) is that the federal funds rate tends to increase when inflation is above its target level and when the output gap is positive. As discussed in Amato and Laubach (1999), Levin, Wieland, and Williams (1999), Rudebusch (2002) and Woodford (1999), the lagged values of the interest rate create some inertia in the system and represent the desire of the Federal Reserve to smooth interest rate changes over time.

Taylor (1993) made it clear that his rule was not intended to be a precise formula. As such, a number of recent papers have argued that a nonlinear rule might explain the actions of the Federal Reserve better than the linear specification given by (1). For example, Cukierman and Muscatelli (2008) and Dolado, Maria-Dolores, and Naveira (2005) suggest that the Federal Reserve prefers inflation to be below the target rather than above the target. In contrast, Cukierman and Gerlach (2003) argue that the loss function is asymmetric in the output gap while Lo and Piger's (2005) "high response" and "low response" regimes correspond to whether or not the economy is in a recession. Surico (2004) allows the Federal Reserve to have asymmetric responses to both inflation and the output gap. Finally, Florio (2006) allows the Federal Reserve to have asymmetric preferences for interest rate smoothing.[1] These different assumptions concerning the type of asymmetry are not innocuous since they lead to very different empirical results. For example, Dolado, Maria-Dolores, and Naveira (2005) find that nonlinearity characterizes U.S. monetary policy after 1983 while Surico (2004) finds nonlinearity only prior to 1979.

In Section 1, we describe the data and estimate a number of Taylor rules in the form of (1). We find that the estimated coefficients exhibit substantial variability such that any linear specification of the Taylor rule is problematic. As a result, in Section 2, we estimate threshold variants of the Taylor rule such that there are two regimes, one with high inflation and the other with low inflation. In the high-inflation regime, the Federal Reserve aggressively fights inflation and discrepancies from full employment. In the low-inflation regime, the Federal Reserve is rather passive in that it tends to maintain the current value of the federal funds rate. Although plausible, the estimated threshold models only partially resolve the problem of parameter instability. Moreover, the estimated thresholds generally split the sample in such a way as to mimic a structural break. As such, we pursue the suggestion of Cukierman and Gerlach (2003) and Lo and Piger (2005) and allow the Federal Reserve to act more aggressively when the economy is in a recession than when it is in an expansion. Nevertheless, we find only weak evidence to support the view that the output gap (or a weighted average of the output gap and the inflation rate) acts as the threshold variable.

In Section 3, we develop a Taylor rule that is consistent with the notion that the Federal Reserve followed "opportunistic" monetary policy. In his 1996 *Remarks to the NABE*, Federal Reserve Governor Laurence Meyer describes opportunistic monetary policy as follows:

1. Another possibility is that the effect of the federal funds rate on the output gap or on the inflation rate may not be linear. If, for example, it is more difficult to eliminate a negative output gap than a positive gap, the Federal Reserve should act more aggressively to counteract a negative output gap.

> "... once inflation becomes modest, ... Federal Reserve policy in the near term focuses on sustaining trend growth at full employment at the prevailing inflation rate. At this point the short-run priorities are twofold: sustaining the expansion and preventing the acceleration of inflation. This is, nevertheless, a strategy for disinflation because it takes advantage of the opportunity of inevitable recessions and potential positive supply shocks to ratchet down inflation over time." (Meyer 1996)

In essence, opportunism implies that the Taylor rule should be nonlinear in that there is an aggressive antiinflation policy only when inflation is high relative to that in the recent past. Surprisingly, we find that the pure opportunistic model does not perform as well as the linear or simple threshold models. Our final model allows the Federal Reserve to react strongly to negative values of the output gap *and* to follow an opportunistic policy regarding inflation. The resultant model has the best in-sample and out-of sample properties for all estimation periods beginning in 1984. In a sense, the rule supports the notion that the Federal Reserve is quite flexible in its intervention strategies. The conclusions and their implications are contained in Section 4.

1. STYLIZED FACTS OF THE TAYLOR RULE VARIABLES

Our data set consists of the monthly values of the federal funds rate and the chain-weighted GDP deflator (p_t) obtained from the data base of the Federal Reserve Bank of St. Louis (http://research.stlouisfed.org/fred2). We chose to follow the variable definitions used in Rudebusch (2002). Specifically, our interest rate (i_t) is the quarterly average of the monthly values of the federal funds rate. The four-quarter inflation rate (π_t) is constructed as

$$\pi_t = 100 * (\ln p_t - \ln p_{t-4}),$$

where: p_t is the chain-weighted GDP deflator.

In order to account for the fact that real GDP is often subject to substantial revisions, we use the real-time values of GDP available at the Philadelphia Federal Reserve Bank's website.[2] Since the data set was originally constructed by Croushore and Stark (2001), we adopt their methodology and filter the real output data with a Hodrick–Prescott (HP) filter. Specifically, beginning with $t = 1963{:}2$, we apply the HP filter to the real-time output series running from 1947:1 through t. The filtered series represents the trend values of real GDP. Call y_t^f the last observation of the filtered series. We construct the output gap for time period $t(y_t)$ as the percentage difference between real-time output at t and the value of y_t^f We then increase t by

2. The real-time data are available at (www.phil.frb.org/econ/forecast/reaindex.html). In an earlier version of the paper, we measured the output gap using the difference between real GDP and the CBO's measure of potential output. This measure of the output gap is far more persistent than the measure we use here.

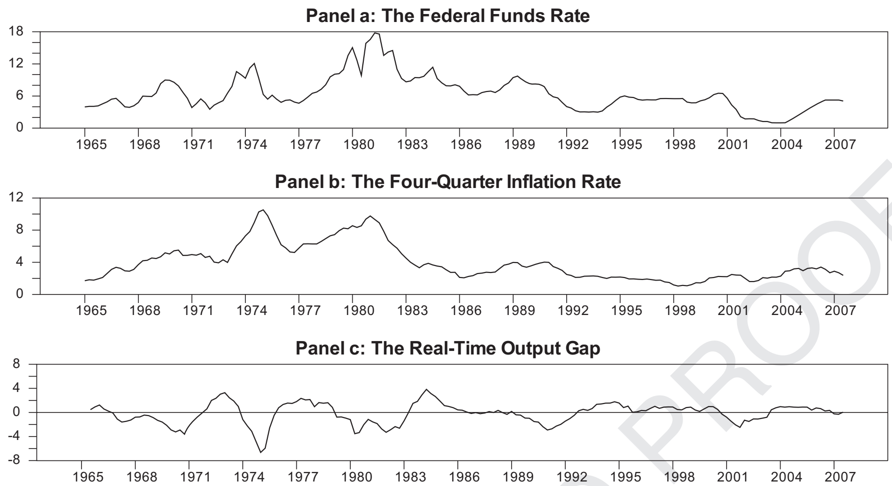

Fig. 1. The Taylor Rule Variables.

one period and repeat the process. As indicated in Croushore and Stark (2001), our aim is not to ascertain the way that real output evolves over the long run. Instead, the goal is to obtain a reasonable measure of the pressure felt by the Federal Reserve to use monetary policy to affect the level of output.

The time paths of i_t, π_t, and y_t for the 1965:3–2007:3 period are shown in Panels *a*, *b*, and *c* of Figure 1.[3] In order to account for the possibility of structural change, we use the data to estimate Taylor rules for the entire sample period as well as for a number of important periods that have been identified in the literature. The early 1970s saw the end of the Bretton Woods system; as such it seems reasonable to use 1973:4 as a potential break date. The change in the Federal Reserve's operating procedures began in 1979:4, and the Volker disinflation ended by 1983:1. Alan Greenspan became Fed Chairman in August 1987 and Ben Bernanke became Chairman in February 2006. We note that these break dates are similar to those used in the literature and are similar to those found by the Bai and Perron (2003) test for multiple structural breaks.[4] For each period containing more than 50 observations, Table 1 reports estimated Taylor rules obtained by setting $\alpha_0 = \gamma_0 - \alpha\pi^*$ and $\alpha = 1 + \alpha_1$ so that (1) becomes:[5]

3. Note that HP filtering the real-time data means that our first observation for the output gap is 1965:3.

4. For example, when we use the full sample allowing for a maximum of six breaks, the Bai and Perron (2003) test using the BIC method of break selection finds 1974:3, 1977:4 and 1980:4 as break dates. Even though the method does not find a break at the 1987:4 or 2005:4, we report results for the Greenspan period. In an earlier version of the paper, we reported the results of the test for breaks in the Taylor rule equation. The full set of results is available from us upon request.

5. The lag length was determined by the general-to-specific methodology. We found that two lagged values of i_t were always sufficient to eliminate any serial correlation. If γ_2 was not statistically significant at the 5% level, we reestimated the Taylor rule using only one lagged value. The last column of Table 1 reports the sum $\gamma_1 + \gamma_2$ along with the *t*-statistic for the null hypothesis that this sum is statistically different from zero.

TABLE 1

The Taylor Rule Over Time

Start	End	α_0	α	β	$\Sigma\gamma_i$	*AIC*
1965:3	1979:3	0.015	−0.016	0.268	1.044	−11.177
		(0.036)	(−0.195)	(4.434)	(13.238)	
	1982:4	−0.314	0.212	0.305	0.917	45.130
		(−0.620)	(2.019)	(3.448)	(14.688)	
	1987:3	−0.214	0.222	0.273	0.894	40.100
		(−0.522)	(2.947)	(3.809)	(19.060)	
	2005:4	−0.144	0.181	0.275	0.919	−18.073
		(−0.800)	(4.059)	(5.886)	(31.197)	
	2007:3	−0.134	0.181	0.276	0.918	−26.165
		(−0.776)	(4.160)	(6.024)	(31.924)	
1973:4	1982:4	−3.975	0.663	0.517	0.947	39.738
		(−2.169)	(2.675)	(3.108)	(11.659)	
	1987:3	−0.788	0.261	0.319	0.920	43.545
		(−1.016)	(2.569)	(2.862)	(14.297)	
	2005:4	−0.166	0.174	0.275	0.921	−3.730
		(−0.827)	(3.573)	(4.930)	(28.794)	
	2007:3	−0.151	0.174	0.276	0.920	−11.312
		(−0.788)	(3.684)	(5.076)	(29.653)	
1979:4	1987:3	1.639	1.040	0.427	0.356	16.425
		(1.974)	(6.058)	(2.970)	(3.028)	
	2005:4	−0.264	0.468	0.348	0.808	−18.892
		(−1.372)	(5.836)	(5.003)	(20.739)	
	2007:3	−0.269	0.464	0.345	0.810	−27.720
		(−1.465)	(6.053)	(5.157)	(21.833)	
1983:1	2005:4	−0.080	0.155	0.147	0.933	−154.904
		(−0.542)	(2.394)	(3.636)	(44.844)	
	2007:3	−0.084	0.158	0.148	0.932	−174.400
		(−0.595)	(2.596)	(3.793)	(47.378)	
1987:4	2005:4	−0.296	0.167	0.234	0.974	−170.242
		(−1.935)	(2.919)	(4.592)	(54.850)	
	2007:3	−0.299	0.167	0.234	0.973	−193.958
		(−2.047)	(3.129)	(4.807)	(57.738)	

Note: Entries in the column $\Sigma\gamma_i$ are the sum of the interest rate smoothing coefficients along with the t-statistic for the null hypothesis that the sum is equal to zero. If γ_2 was in statistically different from zero at the 5% level, the model was reestimated using only one lag of i_t.

$$i_t = \alpha_0 + \alpha\pi_t + \beta y_t + \gamma_1 i_{t-1} + \gamma_2 i_{t-2} + \varepsilon_t. \tag{2}$$

With few exceptions (such as the 1965:3–1979:3 period), the estimated Taylor rules seem reasonable. Consider the estimate for the Greenspan period (1987:4–2005:4)

$$i_t = \underset{(-1.94)}{-0.296} + \underset{(2.92)}{0.167}\pi_t + \underset{(4.59)}{0.234}y_t + \underset{(12.20)}{1.314}i_{t-1} - \underset{(-3.08)}{0.341}i_{t-2} + \varepsilon_t.$$

Notice that the coefficients on inflation and the output gap are both positive and significant at conventional levels. As shown in the last column of Table 1, the sum of the coefficients on the lagged interest rates (i.e., $\gamma_1 + \gamma_2 = 0.974$) is close to unity suggesting a substantial amount of interest rate smoothing. Moreover, the Federal Reserve seems to have followed the so-called Taylor principle in that $\alpha/(1 - \gamma_1 - \gamma_2)$ is greater than unity. As such, in the long run, i_t responds more than proportionally to changes in π_t so that the real interest rate rises (falls) when inflation increases (decreases). Nevertheless, if a linear Taylor rule appropriately describes the behavior of the Federal Reserve, the estimated parameters should be stable over time.[6]

In order to ascertain whether the parameters of the estimated Taylor rules appear to be constant, we used standard recursive estimation methods. For example, for each time period T in the interval 1990:1 to 2007:3, we estimated an equation in the form of (1) using observations 1983:1 through T. Hence, we obtained 71 regression equations each containing an estimate of α_0, α, β, and the sum $\gamma_1 + \gamma_2$. The time paths of the resulting estimated coefficients are displayed in Panels *a* through *d* of Figure 2, respectively. If the parameters are constant over time, we would not expect any particular pattern in the coefficients. Notice that the intercept and coefficient for the output gap fall sharply and then seem to stabilize around 1994. The standard errors for the output gap coefficient are such that it seems reasonable to maintain the hypothesis that the output gap coefficient remained constant over time. The inflation coefficient seems to decline steadily from around 0.859 to 0.158 while the sum $\gamma_1 + \gamma_2$ jumps sharply in the early 1990s and then increases slowly. The point is that the regression parameters are very unstable even for a period that most would deem to be quite tranquil. Although not reported here, parameter instability characterizes all of our estimations of the Taylor rule regardless of the starting date.

2. THRESHOLD MODELS OF THE TAYLOR RULE

The standard derivation of the linear Taylor rule assumes that the Federal Reserve loss function has the form

$$L_t = w(y_t)^2 + (1 - w)(\pi_t - \pi^*), \tag{3}$$

where L_t is a measure of the Federal Reserve's overall loss and w is the weight placed on the output gap in the loss function.

The essential feature of (3) is such that the Federal Reserve is equally concerned with positive and negative discrepancies of the current inflation rate from the target π^*. However, as discussed above, a number of authors have argued that the loss function is likely to be asymmetric around π^* and/or y_t. The so-called "inflation hawks" at the Fed would be more tolerant of an inflation rate that is 1% below target than inflation that is 1% above target. Similarly, a quadratic loss function assumes that

6. In an earlier version of this paper, we presented a number of unit root tests—including the Phillips and Perron (1988) and Elliott, Rothenberg, and Stock (1996) tests–indicating that π_t and i_t appear to be $I(1)$ variables for most of the subsamples used in Table 1. Moreover, we found no meaningful cointegrating relationships between these variables. The details of the tests are available from us upon request. Note that these findings are consistent with those of Siklos and Wohar (2006). One possible explanation of these results is that the tests all assume a linear adjustment process. Another is that the tests have low power to distinguish between highly persistent and unit-root processes.

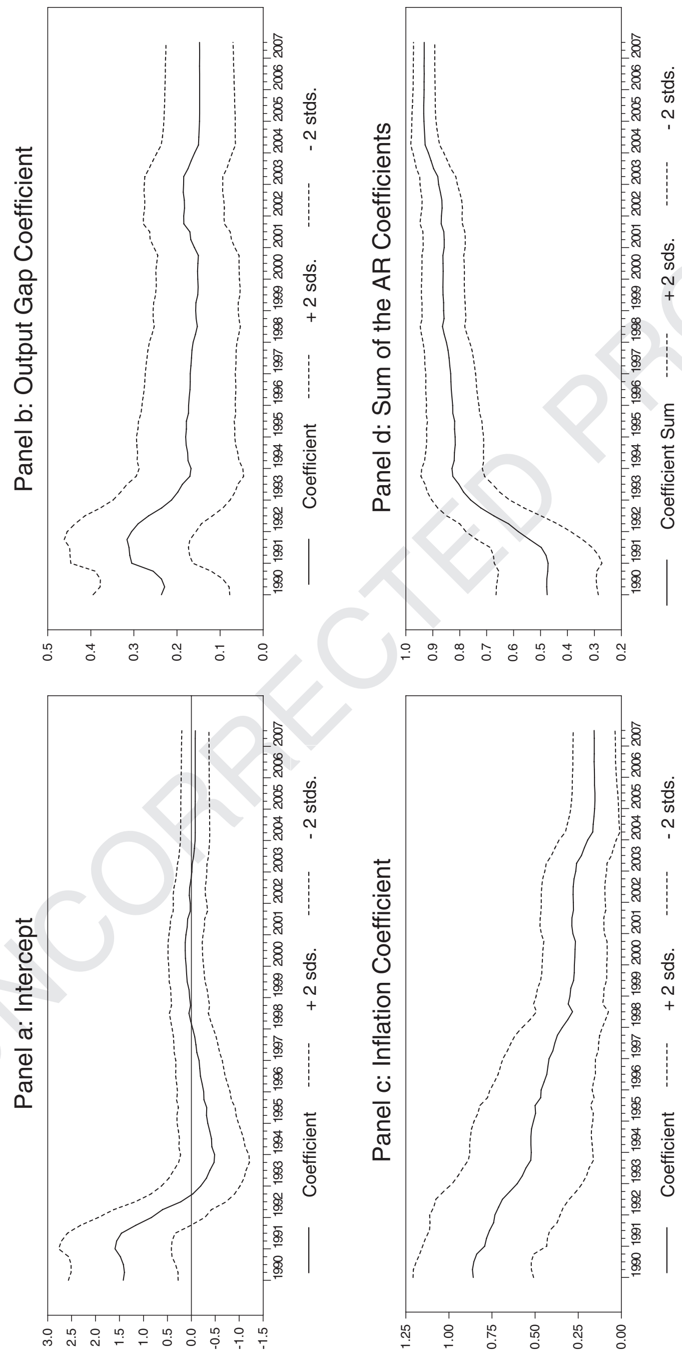

FIG. 2. Recursive Estimation of the Taylor Rule.

the Federal Reserve is unconcerned about the sign of the output gap; 1-unit shortfall of output from potential produces the same loss as a 1-unit increase in output over potential. However, to most observers, the negative values of the output gap in the two Bush presidencies were more problematic than the positive values of the output gap in the Clinton years. These types of nonlinearities would imply that some sort of threshold model is reasonable. Also notice that (3) implies that the loss function is separable in that the losses resulting from inflation and the output gap are independent of each other. Considering a non-separable loss function could help explain why the combination of low output and high inflation is more intolerable than high output and low inflation.

As such, it seems natural to explore the possibility of a threshold model such that the intensity of the Federal Reserve's response depends on the state of the economy. Since the Federal Reserve can be expected to act aggressively when inflation is high, the most natural candidate for the threshold variable is the inflation rate. Since it is also plausible that the Federal Reserve acts aggressively in response to a negative output gap, we investigate the possibility that the output gap is the threshold variable. Toward this end, we performed Hansen's (1997) test to determine whether all values of $\alpha_i = \beta_i$ in the following equation are equal to zero

$$
\begin{aligned}
i_t = {} & (\alpha_0 + \alpha_1 \pi_t + \alpha_2 y_t + \alpha_3 i_{t-1} + \alpha_4 i_{t-2}) I_t \\
& + (1 - I_t)(\beta_0 + \beta_1 \pi_t + \beta_2 y_t + \beta_3 i_{t-1} + \beta_4 i_{t-2}) + \varepsilon_t,
\end{aligned} \tag{4}
$$

where: x_{t-d} is the magnitude of the threshold variable in period $t{-}d$, and the Heavyside indicator $I_t = 1$ if $x_{t-d} > \tau$ and $I_t = 0$ otherwise.[7]

The essential feature of (4) is that there are two linear segments for the Taylor rule. If the value of x_{t-d} exceeds the threshold, the federal funds rate is given by $i_t = \alpha_0 + \alpha_1 \pi_t + \alpha_2 y_t + \alpha_3 i_{t-1} + \alpha_4 i_{t-2} + \varepsilon_t$. Alternatively, if $x_{t-d} \leq \tau$ the federal funds rate is given by $i_t = \beta_0 + \beta_1 \pi_t + \beta_2 y_t + \beta_3 i_{t-1} + \beta_4 i_{t-2} + \varepsilon_t$. If all values of $\alpha_i = \beta_i$ equal the model is linear.

The consistent estimate of τ is obtained using a grid search over all potential thresholds. The customary practice is to eliminate the lowest and highest 15% of the ordered values of x_{t-d} in order to ensure an adequate number of observations on each side of the threshold. However, given the relatively small number of observations in some sample periods, we forced each regime to have at least 25% of the observations. Since the threshold value τ is an unidentified nuisance parameter under the null of linearity, the test for linearity cannot be performed using a standard F-test. Instead, as shown in Hansen (1997), it is necessary to bootstrap the F-statistic. Table 2 reports the estimated value of the threshold parameter (τ), the sample value of the F-statistic for the null hypothesis of no threshold behavior, and the bootstrapped *prob*-value for

7. We let d take on the values of 1 and 2. The consistent estimate of d is obtained from the regression with the best fit. Since our aim at this stage is to indicate the presence of threshold behavior, we report results using only $d = 1$. Moreover, in almost all cases, we found that the estimated delay is unity.

TABLE 2
HANSEN'S TEST FOR A THRESHOLD PROCESS

		Inflation as threshold			Output gap as threshold		
Start	End	τ	F-stat	*prob*-value	τ	F-stat	*prob*-value
1965:3	1979:3	5.049	1.612	0.646	−0.765	2.499	0.233
	1982:4	7.439	6.242	0.002	−0.739	4.761	0.012
	1987:3	6.713	5.083	0.004	−0.739	5.258	0.004
1973:4	1982:4	8.253	8.121	0.001	−2.345	3.036	0.160
	1987:3	8.183	10.553	0.000	−0.739	4.489	0.019
	2005:4	5.759	5.705	0.001	−1.082	7.812	0.000
	2007:3	5.759	6.058	0.001	−1.023	8.082	0.000
1979:4	2005:4	3.647	13.958	0.000	−1.082	9.000	0.000
	2007:3	3.647	14.985	0.000	−0.967	8.995	0.000
1983:1	2005:4	3.260	7.529	0.000	0.345	3.331	0.071
	2007:3	3.242	4.816	0.007	0.883	3.434	0.055
1987:4	2005:4	2.297	3.769	0.068	−0.948	2.279	0.469
	2007:3	2.297	4.160	0.037	−0.948	2.425	0.361

the test. We report results using the inflation rate and the output gap as threshold variables.

Notice that there is strong evidence of threshold behavior in most sample periods. The major exceptions seem to be for the 1965:3–1979:3 period and for the estimations beginning in 1987:4 using y_{t-1} as the threshold variable.[8] As measured by the sample values of the F-statistic, the evidence for asymmetry is usually strongest when π_{t-1} is the threshold variable. However, the estimations beginning in 1973:4 are mixed in that y_{t-1} is most likely to be the threshold variable when the estimation period ends in 2005:4 or 2007:3. Table 3 reports the estimation results for the sample periods beginning with 1979:4, 1983:1 and 1987:4 allowing π_{t-1} to be the threshold variable. Notice that the results for these three sample periods tell the same remarkable story.

First note the estimated range of the threshold values running from $\tau = 3.647$ to $\tau = 2.297$ is quite reasonable as Federal Reserve threshold value for the inflation rate. When inflation crosses the threshold into the high inflation regime, there is a switch in the behavior of the Federal Reserve. When inflation is above the threshold, the estimated Taylor rule seems quite standard. For example, when π_{t-1} exceeded 3.647 in the 1979:4–2007:3 sample period, the estimated Taylor rule is

$$i_t = \underset{(2.631)}{1.578} + \underset{(4.668)}{1.058}\pi_t + \underset{(4.205)}{0.500}y_t + \underset{(2.499)}{0.362}i_{t-1}\,. \tag{5}$$

8. Note that the 1965:3–1979:3 sample and the samples beginning in 1987:4 are relatively short. It is possible that Hansen's (1997) test does not have sufficient power to detect threshold behavior over these periods. Of course, it is also possible that the threshold test is actually detecting structural change over the long sample periods.

TABLE 3
The Estimated Threshold Models

Start	End	τ	α_1	β_1	α_2	β_2	$\alpha_3 + \alpha_4$	$\beta_3 + \beta_4$	*AIC*
1979:4	2005:4	3.647	1.066	0.141	0.523	0.153	0.371	0.965	−62.760
			(4.555)	(2.860)	(4.208)	(4.116)	(2.788)	(67.658)	
	2007:3	3.647	1.058	0.138	0.500	0.154	0.362	0.964	−75.461
			(4.668)	(3.064)	(4.205)	(4.242)	(2.499)	(68.147)	
1983:1	2005:4	3.260	1.251	0.152	0.342	0.194	0.487	0.967	−173.131
			(3.096)	(2.259)	(4.063)	(3.430)	(2.372)	(52.753)	
	2007:3	3.242	1.039	0.149	0.211	0.196	0.756	0.964	−183.601
			(2.817)	(2.370)	(4.610)	(3.574)	(7.741)	(53.210)	
1987:4	2005:4	2.297	0.569	−0.120	0.414	0.184	0.960	0.934	−176.082
			(4.478)	(−0.982)	(5.091)	(3.484)	(30.853)	(38.169)	
	2007:3	2.297	0.528	−0.120	0.406	0.184	0.964	0.934	−201.208
			(5.184)	(−0.982)	(4.907)	(3.484)	(33.159)	(38.169)	

Note: π_{t-1} as the threshold variable.

In the low inflation regime, the estimated Taylor rule is

$$i_t = \underset{(-1.464)}{-0.177} + \underset{(3.064)}{0.138}\pi_t + \underset{(4.242)}{0.154}y_t + \underset{(22.428)}{1.444}i_{t-1} - \underset{(-8.445)}{0.480}i_{t-2}\,. \tag{6}$$

The important point to note is that the coefficients on π_t and y_t are much greater in the high-inflation regime than in the low-inflation regime. Moreover, the sum of the interest rate smoothing coefficients is far greater when inflation is low than when inflation is high. In essence, the Federal Reserve is far more responsive to contemporaneous movements in π_t and y_t whenever inflation exceeds the threshold value.[9] These estimates stand in stark contrast to usual linear estimates of the Taylor rule shown in Table 1. As measured by the *AIC*, the fits of the various threshold models are superior to those of the associated linear model. Also notice that the linear variant of the rule seems to "average" the responses of the Federal Reserve across the high and low inflation regimes.

It is interesting to compare the recursive estimates of the linear Taylor rule to the recursive estimates of the threshold model. For each time period T in the interval 1993:1 to 2007:3, we estimated an equation in the form of (4) using observations 1983:1 through T.[10] Panel *a* of Figure 3 shows the values of π_t along with the recursive estimates of the threshold. The first point of the line labeled "Threshold" shows the estimated threshold value for the sample period ending in 1993:1, and so on. Panel *b* shows the coefficients for the output gap for the high- and low-inflation regimes

9. There is a distinction between the short-run and long-run responsiveness of the Federal Reserve. The long-run responses of i_t to inflation and the output gap are $\alpha/(1 - \gamma_1 - \gamma_2)$ and $\beta/(1 - \gamma_1 - \gamma_2)$, respectively. As long as economy does not switch between regimes, the estimated long-run responses are highest in the low-inflation regime.

10. We begin at 1983:1 (as opposed to 1990:1) to ensure there are enough observations to estimate a reasonable model for each regime.

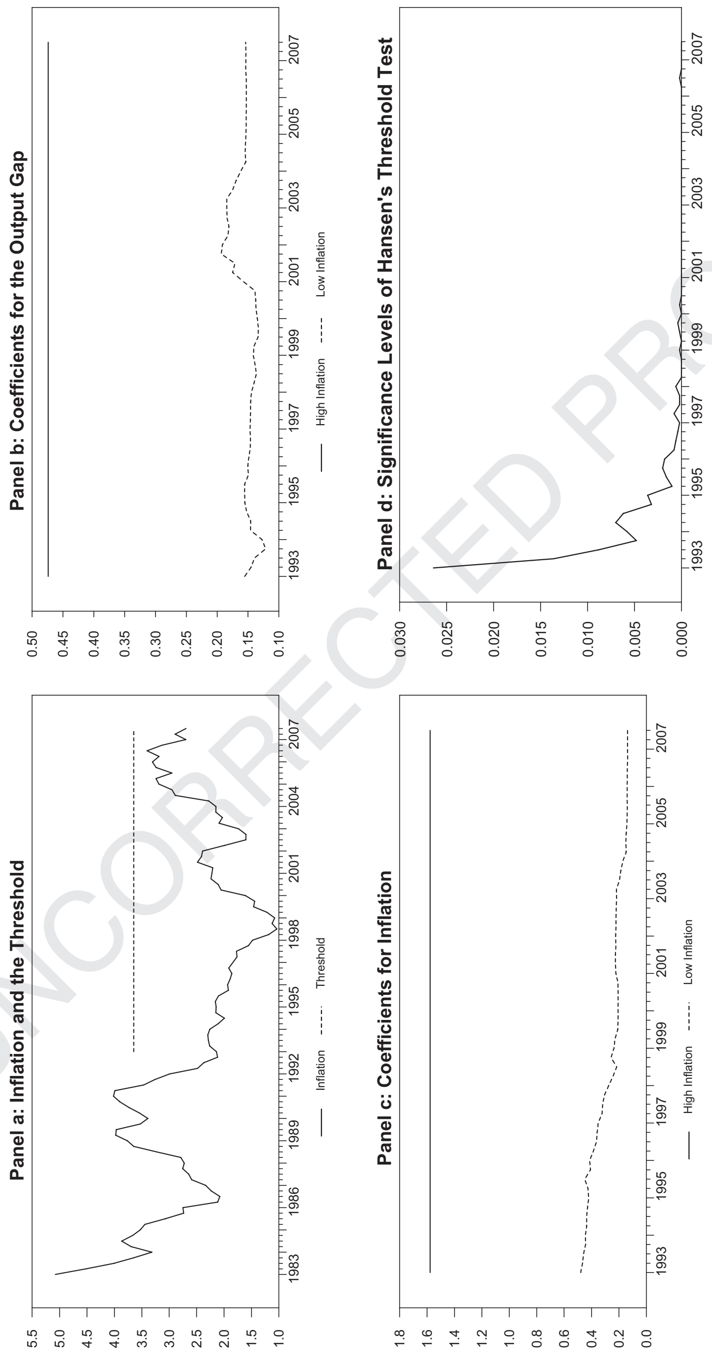

FIG. 3. Recursive Estimation of the Threshold Model.

(i.e., α_2 and β_2, respectively). Panel c shows the inflation coefficients α_1 and β_1. The significance levels of Hansen's test for a threshold process are shown in Panel d. Notice that it is always possible to reject the null of no threshold process at the 1% significance level for any sample beyond 1993:3 When we compare the coefficients in Panels b and c to their counterparts in Figure 2, it is clear that the parameters of the threshold process are very stable.

Although plausible, the estimated threshold models do have a number of problems. As reported in Tables 2 and 3, the estimated threshold values decline as the starting point of the sample approaches 1987:4. The coefficient placed on inflation in the high-action regime (i.e., the value of α_1) and the sample values of Hansen's F-statistic generally decline as well. Moreover, there seems to be an excessive amount of interest rate smoothing in the high inflation regime. This is especially true for the Greenspan period even though his reputation as an "Inflation Hawk" suggests that the opposite should be true. Finally, notice that estimated thresholds often do little more than to split the sample. For example, as shown in Panel a of Figure 3, inflation is always below the threshold after 1991:2 resulting in the dubious implication that the Federal Reserve was relatively passive for the last 17 years.[11]

3. THE OPPORTUNISTIC MODEL

A more promising direction than simply using a fixed threshold is to introduce an "opportunistic" policy such that the target rate of inflation changes over time. Instead of having the fixed inflation target π^*, "opportunism" suggests that there is an intermediate target that can be gradually decreased over time. Consider the Federal Reserve Bank of San Francisco's (1996) description of opportunistic disinflation:

> "An opportunistic monetary strategy also assumes an ultimate target of price stability and distinguishes an interim inflation target from the ultimate one. However, except when inflation is high, the opportunistic policymaker's interim inflation target is simply the current rate of inflation. Thus, the opportunistic strategy eschews deliberate action to reduce inflation, but instead waits for unforeseen but favorable price surprises to reduce inflation." (Federal Reserve Bank of San Francisco 1996).

Bomfim and Rudebusch (2000) posit an opportunistic Taylor rule of the form

$$i_t = \alpha_0 + \pi_t + \alpha(\pi_t - \pi_t^*) + \beta y_t, \tag{7}$$

where π_t^* is the intermediate, or *interim*, target value of the inflation rate and the subscript t is intended to show that the target can change. Similarly, Orphanides and

11. We also allowed the threshold variable to be a weighted average of π_{t-d} and y_{t-d} such that: $I_t = 1$ if $(1 - w)\pi_{t-d} + wy_{t-d} \geq \tau$ and $I_t = 0$ otherwise. The value of w was estimated using a grid search. We found that the weights were so close to unity that the estimations were almost identical to the threshold models constraining $w = 0$.

Wilcox (2002) and Aksoy et al. (2006) begin with the following nonquadratic loss function to model opportunistic policy

$$L_t = (1-\delta)\left(\pi_t - \pi_t^*\right)^2 + \delta|y_t|. \tag{8}$$

We begin by estimating a threshold model in the form of (4) but allow the threshold variable to be an interim target such that

$$I_t = 1 \text{ if } \pi_{t-1} > \pi_{t-1}^* \quad \text{and} \quad I_t = 0 \quad \text{otherwise.}$$

where: π_{t-1}^* is the interim target for period $t-1$.

As indicated by Bomfim and Rudebusch (2000), the interim target should depend on the long-run target value of inflation as well as "inherited" or past inflation. As such, it seems reasonable to represent the intermediate target by a simple average of the inflation rate prevailing 1 and 2 years ago.[12] Given that the Federal Reserve is also concerned about interest rate smoothing, we estimated a model in the form of (4) such that the indicator function is

$$I_t = 1 \text{ if } \pi_{t-1} > (\pi_{t-5} + \pi_{t-9})/2 \quad \text{and} \quad I_t = 0 \quad \text{otherwise.} \tag{9}$$

The essential feature of (9) is that past inflation serves as the value of "inherited" inflation in such a way that the threshold drifts downward as inflation generally declines. In essence, as inflation declines, the intermediate goal is obtained and the Federal Reserve can be in the relatively inactive state. A regime change occurs if the current rate of inflation exceeds the average rate of the last two years. Unlike the theoretical models of the opportunistic Taylor rule, we do not impose a long-run target inflation rate so that (9) allows the interim target to ratchet upward if there is sustained inflation. An additional statistical advantage of (9) is that the threshold model has been converted to the momentum threshold model introduced in Enders and Granger (1998). Since the threshold variable $\pi_{t-1} - (\pi_{t-5} + \pi_{t-9})/2$ is clearly stationary, conditioning the regimes on a stationary variable has better properties than conditioning the regime change on a nonstationary, or highly persistent, variable.

Table 4 reports the results for a number of sample periods. As in the simple threshold models, when inflation is below (above) the threshold, the feedback response of the Federal Reserve is relatively small (large). Although the estimated models seem to correct some of the deficiencies of the previous models, they do not fit the data as well as the weighted threshold model or most of the threshold models using π_{t-1} as the threshold variable.

12. We considered other plausible formulations for the interim target including $\pi_{t-1} - \pi_{t-5}$, $\pi_{t-1} - \pi_{t-9}$, and $\pi_{t-1} - (1/8)\Sigma\pi_{t-i}$ where $i = 2, \ldots, 9$. Although the results were similar to those reported below, the specification in equation (9) resulted in the best overall fit. We also set the indicator function according to whether $\pi_{t-1} - (\pi_{t-5} + \pi_{t-9})/2 - t > 0$ where τ is the consistent estimate resulting from a grid search. Details are available from us upon request.

TABLE 4
THE OPPORTUNISTIC MODEL

Start	End	α_1	β_1	α_2	β_2	$\alpha_3+\alpha_4$	$\beta_3+\beta_4$	*AIC*
1979:4	2005:4	0.584	0.132	0.714	0.181	0.839	0.904	−19.562
		(2.324)	(1.242)	(4.585)	(1.675)	(8.508)	(22.721)	
	2007:3	0.577	0.136	0.700	0.180	0.844	0.902	−28.634
		(2.313)	(1.323)	(4.520)	(1.682)	(8.807)	(22.118)	
1983:1	2005:4	0.331	0.096	0.459	0.124	1.007	0.931	−159.789
		(3.642)	(1.186)	(6.056)	(2.588)	(37.575)	(27.795)	
	2007:3	0.330	0.100	0.457	0.123	1.008	0.931	−180.138
		(3.757)	(1.294)	(6.076)	(2.589)	(37.930)	(27.550)	
1987:4	2005:4	0.331	−0.034	0.459	0.116	1.007	0.961	−176.539
		(3.642)	(−0.356)	(6.056)	(2.403)	(37.575)	(47.627)	
	2007:3	0.330	−0.011	0.457	0.115	1.008	0.963	−200.992
		(3.757)	(−0.127)	(6.076)	(2.346)	(37.930)	(49.733)	

TABLE 5
THE FULL OPPORTUNISTIC MODEL

Start	End	α_1	β_1	α_2	β_2	$\alpha_3+\alpha_4$	$\beta_3+\beta_4$	*AIC*
1979:4	2005:4	1.095	0.147	1.161	0.170	0.461	0.910	−62.308
		(5.009)	(1.753)	(6.475)	(1.726)	(4.113)	(25.567)	
	2007:3	1.095	0.158	1.161	0.170	0.461	0.907	−74.759
		(5.009)	(2.008)	(6.475)	(1.754)	(4.113)	(24.308)	
1983:1	2005:4	1.076	0.123	0.659	0.102	0.736	0.937	−163.543
		(7.228)	(2.457)	(7.375)	(2.237)	(15.785)	(32.249)	
	2007:3	1.076	0.128	0.659	0.103	0.736	0.936	−184.261
		(7.228)	(2.867)	(7.375)	(2.268)	(15.785)	(31.540)	
1987:4	2005:4	1.121	0.095	0.666	0.135	0.738	0.974	−194.416
		(6.566)	(1.448)	(7.352)	(2.816)	(15.980)	(55.721)	
	2007:3	1.121	0.095	0.666	0.136	0.738	0.973	−220.678
		(6.566)	(1.622)	(7.352)	(2.869)	(15.980)	(58.202)	

3.1 The Full "Opportunistic Model"

Notice that the explanations of opportunistic policy involve an interim target rate of inflation *and* the current state of the output gap. Although an opportunistic policy will not push down inflation once it is modest, it also focuses on sustaining trend growth. As such, it seems sensible to allow the Federal Reserve to be policy active when the inflation is high relative to the interim threshold (i.e., when $\pi_{t-1} > (\pi_{t-5} + \pi_{t-9})/2$ *and* when the output gap is negative. Consider the following specification for the threshold variable

$$I_t = 1 \text{ if } \pi_{t-1} > (\pi_{t-5} + \pi_{t-9})/2 \quad \text{and if } y_{t-1} < 0; \quad I_t = 0 \text{ otherwise.} \quad (10)$$

The results are shown in Table 5. As in all of the threshold models, the Federal Reserve is more aggressive when the system is above the threshold than when it is

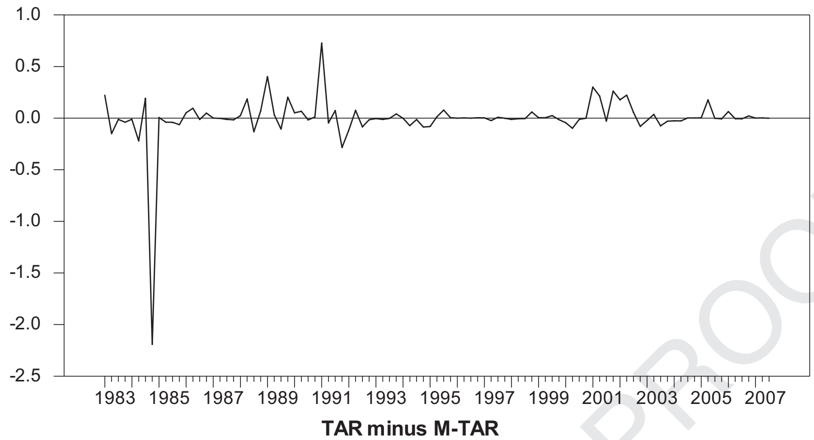

FIG. 4. Difference of the Squared Residuals.

below the threshold. Notice that the asymmetry is most pronounced in the opportunistic model. As measured by the *AIC*, the fit of the full opportunistic model is superior to that of the simple threshold model for the 1983:1–2007:3, 1987:4–2005:4, and 1987:4–2007:3 sample periods but not for the other sample periods.

To get a better sense of the differences between the fixed threshold model and the model given by (11), let $\{\hat{\varepsilon}_{1t}^2\}$ represent the sequence of squared residuals from the threshold model and let $\{\hat{\varepsilon}_{2t}^2\}$ represent the sequence of squared residuals from the opportunistic model. Figure 4 shows the time path of $\hat{\varepsilon}_{1t}^2 - \hat{\varepsilon}_{2t}^2$ resulting from estimating both models over the 1983:1–2007:3 period. Note the very negative value occurring in 1984:4 suggesting that the opportunistic model "missed" the decline in the Federal Funds rate by more than the simple threshold model. However, for the rest of the sample, the squared residuals of the threshold model are usually larger than those of the opportunistic model. The suggestion is that opportunistic disinflation did not really begin until a fairly aggressive rate cut in late 1984.

3.2 Out-of-Sample Forecasting

In this section, we perform an out-of-sample forecasting exercise in order to corroborate our in-sample findings. Note that we cannot use the standard methodology since the alternative Taylor rule specifications contain contemporary values of the inflation rate and the output gap as explanatory variables. As such, it is not possible to obtain a forecast for the federal funds rate in $t + 1$ without forecasting the inflation rate and the output gap for $t + 1$ as well. This creates a problem since any differences in the forecasting performance of the various functional forms might be due to the method used to forecast the so-called explanatory variables. To circumvent this problem, we use the so called "backward-looking" variants of the Taylor rule. Hence, for the linear, threshold, opportunistic and full opportunistic specifications, we replace y_t with y_{t-1}

TABLE 6

Properties of the Out of Sample Forecast Errors

Start	End	N		Linear	TAR	Oppor.	Full oppor.
					Recursive estimation		
1979:4	2005:4	54	Mean	−0.396	***−0.075***	−0.489	−0.190
			Variance	0.580	***0.108***	0.943	0.443
	2007:3	61	Mean	−0.365	***−0.073***	−0.447	−0.166
			Variance	0.520	***0.096***	0.848	0.397
1983:1	2005:4	41	Mean	−0.049	***−0.008***	−0.129	−0.008
			Variance	0.107	***0.096***	0.174	0.112
	2007:3	48	Mean	−0.047	−0.049	−0.120	***−0.012***
			Variance	***0.093***	0.121	0.150	0.097
1987:4	2005:4	22	Mean	−0.119	−0.263	−0.266	***−0.116***
			Variance	0.110	0.317	0.244	***0.105***
	2007:3	29	Mean	−0.104	−0.215	−0.213	***−0.098***
			Variance	0.085	0.250	0.195	***0.083***
					Full-period estimation		
1979:4	2005:4			0.925	**0.534**	0.921	0.670
	2007:3			0.868	**0.501**	0.864	0.628
1983:1	2005:4			0.184	**0.158**	0.171	0.160
	2007:3			0.171	0.154	0.160	**0.149**
1987:4	2005:4			0.097	0.090	0.093	**0.072**
	2007:3			0.090	0.083	0.086	**0.066**

Notes: Each estimated model has at least 50 observations. As such, the models are estimated beginning with the starting date plus 49 additional observations. N refers to the number of out of sample forecasts. Entries in bold represent the smallest value in a row. **Q1**

and π_t with π_{t-1}. For example, for the linear variant of the Taylor rule, we can replace (2) with

$$i_t = \alpha_0 + \alpha\pi_{t-1} + \beta y_{t-1} + \gamma_1 i_{t-1} + \gamma_2 i_{t-2} + \varepsilon_t. \tag{11}$$

Once the coefficients $\alpha_0, \alpha, \beta, \gamma_1$, and γ_2 have been estimated, it is straightforward to update (11) by one period and use the contemporaneous values of π_t, y_t, i_t and i_{t-1} to forecast i_{t+1}. Note that we use expanding windows to obtain the various out-of-sample forecasts. Specifically, for a sample period with T observations, we estimate each model using observations 1 through 50. The estimated model is used to forecast the value of federal funds rate for period 51. The difference between the forecasted and actual value of the rate is the one-step ahead forecast error. Next, the process can be repeated using observations through 51 in order to obtain the forecast error for period 52. The process is repeated until $N = T - 50$ forecasts are obtained.

As shown in Table 6, the out-of-sample forecasts provide corroborating evidence in support of the threshold and full opportunistic forms of the Taylor rule. For the 1979:4–2005:4, 1979:4–2007:3 and 1983:1–2005:4 periods, the forecast errors from the threshold model (using the inflation rate as the threshold variable) have a mean closest to zero and the smallest variance. The results for the 1983:1–2007:3 period are mixed in that the linear model has the smallest variance while the full opportunistic model has least bias. For the 1987:4–2005:4 and 1987:4–2007:3 periods, the forecast errors from the full opportunistic model have a mean closest to zero and the smallest variance.

It is well known that forecasting models containing coefficients that are small relative to their standard errors tend to have very large forecasting errors. This is especially troublesome for the nonlinear Taylor rules since each contains an estimated threshold value and 10 coefficients. In the early stages of the recursive estimation, these 11 values are estimated using as few as 50 observations. An alternative methodology is to use the coefficients from models estimated using observations 1 through T. For example, if we estimate a backward-looking linear Taylor rule over the 1979:4–2007:3 period, we obtain $i_t = -0.046 + 0.394\pi_{t-1} + 0.247y_{t-1} + 0.854i_{t-1} - 0.048i_{t-2}$. Now, for $t = 1980{:}1$, the one-step ahead forecast is $-0.046 + 0.394\pi_t + 0.247y_t + 0.854i_t - 0.048i_{t-1}$ and the forecast error is the regression residual for 1980:1. The properties of these regression residuals are shown on the lower portion of Table 6 labeled "Full-Period Estimation." Only the variances are shown since the mean of the regression residuals are necessarily zero.

For the periods beginning with 1979:4, the forecast errors from the simple threshold model have the smallest variance. For the periods beginning with 1987:4, the forecast errors from the full opportunistic model have the smallest variance. The threshold model results in the smallest forecast error variance for the 1983:1–2005:4 period while the errors from the full opportunistic model have the smallest variance for the 1983:1–2007:3 period.

4. CONCLUSION

We estimate standard linear Taylor rules for a number of sample periods and subject them to a number of diagnostic checks. Since the estimated models contain a substantial amount of parameter instability, a nonlinear specification might be more reasonable. In fact, if Federal Reserve preferences are such that high inflation is more costly than low inflation or a negative output gap is more costly than a positive gap, the Taylor rule should be nonlinear. In particular, periods of high inflation *and/or* a positive output gap should induce a very strong interest rate response from the Federal Reserve. We estimate several threshold models alternatively using the inflation rate, output gap and a weighted average of the two as the threshold variables. Although the results seem plausible, the estimates have a number of statistical problems and do not capture the tendency for the estimated thresholds to fall as the starting date of the estimation increases.

We show that there is ample statistical evidence supporting the view that the Taylor rule is a threshold process that is consistent with an opportunistic monetary policy. Our version of the opportunistic model allows the Federal Reserve to be policy active when the inflation is high relative to the interim threshold *and* when the output gap is negative. The estimated models seem plausible and explain the key deficiencies present in the linear Taylor rules. First, with an opportunistic policy rule, the inflation rate and the output gap will be persistent since the Federal Reserve acts aggressively only in certain circumstances. Secondly, parameter instability (and the lack of a linear cointegrating relationship) would be expected if the Federal Reserve behaved differently in some periods than in others. Since the linear Taylor rules are an "average" of the two different policy regimes, the estimated coefficients of the rule will change as whenever the regime changes. Finally, the opportunistic model captures the tendency of the estimated threshold values to decline over time.

In his original paper, Taylor (1993) makes it clear that a simple rule in the form of (1) is too simplistic to completely characterize Federal Reserve behavior. In the abstract, he states "An objective of the paper is to preserve the concept of such a policy rule in a policy environment where it is practically impossible to follow mechanically any particular algebraic formula that describes the policy rule." Similarly, Svensson (2003) raised serious doubts about a simple Taylor rule because it is "incomplete and too vague to be operational" since "there are no rules for when deviations from the instrument rule are appropriate." Our findings support the notion that there is no simple rule that is consistent with the data. Instead, we find that the Federal Reserve seems to obey the dictum *"If it ain't broke, don't fix it."* When inflation exceeds its interim target and the output gap is negative, the Federal Reserve acts very aggressively. The responses are far greater than those predicted from a pure linear model. In more normal times, the Federal Reserve acts relatively passively and tends to maintain the current value of the federal funds rate.

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Queries

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