# Taylor's Rule and the Fed: 1970–1997

John P. Judd
and Glenn D. Rudebusch

Vice President and Associate Director of Research, and Research Officer, respectively, Federal Reserve Bank of San Francisco. We thank Kenneth Kasa, Bharat Trehan, and Carl Walsh for useful comments and Alison Wallace for excellent research assistance; they are not responsible for any errors or omissions.

*This paper estimates a simple model of the Federal Reserve's "reaction function"—that is, the relationship between economic developments and the Fed's response to them. We focus on how this estimated reaction function has changed over time. Such changes are not surprising given compositional changes in the Federal Open Market Committee, and we consider three subsamples delineated by the terms of recent Fed Chairmen. We find that the estimated reaction functions for each period vary in ways that seem broadly consistent with the success or failure during the period at controlling inflation. These results suggest that a Taylor-rule framework is a useful way to summarize key elements of monetary policy.*

Macroeconomists have long been interested in modeling the Federal Reserve's "reaction function"—that is, modeling how the Fed alters monetary policy in response to economic developments. The Fed's reaction function plays an important role in a wide variety of macroeconomic analyses. It can provide a basis for forecasting changes in the Fed's policy instrument—namely, short-term interest rates. Also, within the context of a macro model, the reaction function is an important element in evaluating Fed policy and the effects of other policy actions (e.g., fiscal policy) or economic shocks (e.g., the 1970s oil embargo). Finally, when rational expectations are assumed in macro models, knowing the correct reaction function is an important element in estimating the entire model. For example, with forward-looking expectations, estimates of a parameter such as the one linking real spending to the policy instrument will likely depend crucially on expected monetary policy and the nature of the monetary policy regime.

Numerous reaction functions have been estimated. Khoury (1990), for example, surveys 42 such empirical Fed reaction functions from various studies. Moreover, the large numbers of monetary policy vector autoregressions (VARs) (e.g., Bernanke and Blinder 1992) that have been estimated recently also include an equation that can be interpreted as a Fed reaction function (see Rudebusch 1998).

However, despite this work, researchers have not been particularly successful in providing a definitive representation of Fed behavior. Khoury finds little consistency in the significance of various regressors in the reaction functions she surveys. She states (p. 28): "One who [examines] just one of these reaction functions may feel convinced that one has learned how the Fed responds to economic conditions, but that seeming knowledge disappears as one reads a large number of these studies." Overall, it appears that there have not been any great successes in modeling Fed behavior with a single, stable reaction function. As an illustration, McNees (1992) compares his latest estimate of a Fed reaction function to his previous estimate (1986) and states (p. 11): "The number of modifications to the original specification required to make it track the past six years serve[s] as a clear illustration that policy reaction functions can be fragile."

There are a number of plausible explanations for such instability. For example, a central bank's reactions may be too complex to be adequately captured by a simple linear regression. Another factor may be changes in the composition of the Federal Open Market Committee (FOMC). Such compositional changes may bring to the fore policymakers with different preferences and different conceptions of the appropriate operation and likely transmission of monetary policy. While many people and events influence policy, arguably one of the more important and *identifiable* compositional changes is in the Fed Chairmanship. Changes associated with different Chairmen may be exogenous, but there also may be an endogenous element that represents an adaption to "lessons" learned from prior experiences. Indeed, Chairmen may be chosen who are seen as likely to avoid the mistakes of the past.[1] For example, part of the backing for Paul Volcker as Chairman in the high-inflation environment of 1979 may have come from the expectation that he would be tough on inflation.[2]

Accordingly, in this paper we estimate reaction functions for three separate empirical subsamples delineated by the identity of the Fed Chairman: specifically, we consider the terms of Arthur Burns (1970.Q1–1978.Q1), Paul Volcker (1979.Q3–1987.Q2), and Alan Greenspan (1987.Q3–present). We omit any discussion of policy under Chairman Miller (1978.Q2–1979.Q2) because of his short tenure. This delineation gives us three subsamples of moderate and approximately equal length that are selected in an *a priori* fashion.

The organizing principle for our investigation is the Taylor rule, which we use as a rough gauge for characterizing and evaluating the broad differences in the relative weights given to monetary policy goal variables between periods. The rule specifies that the real federal funds rate reacts to two key goal variables—deviations of contemporaneous inflation from an inflation target and deviations of real output from its long-run potential level. These variables would appear to be consistent with the Fed's legislated mandate.[3] Moreover, Taylor (1993) argued that this rule represents "good" policy, in the sense that it relates a plausible Fed instrument to reasonable goal variables, and it stabilizes both inflation and output reasonably well in a variety of macroeconomic models. More recent model simulation studies (e.g., Rudebusch and Svensson 1998 and Levin, Wieland, and Williams 1997) have reinforced the latter conclusion.

Moreover, these recent studies suggest that although Taylor-type rules are very simple, they may be capable of capturing the essential elements of more realistic regimes in which the central bank "looks at everything." Simple Taylor-type reaction functions were found to perform almost as well as optimal, forecast-based reaction functions that incorporate all the information available in the models examined. In addition, the simple specification was found to perform almost as well as reaction functions that explicitly include a variety of additional variables. These results appear to be fairly robust across a variety of macroeconomic models. Thus, the general form of the Taylor rule may be a good device for capturing the key elements of policy in a variety of policy regimes.

The rule as originally specified by Taylor serves as a useful starting point for our investigation below. After briefly examining this rule, we focus on econometrically estimating a dynamic version of the rule for the three periods defined above. We find that, overall, the estimated dynamic Taylor-type reaction functions do provide a way to capture important elements of the policy regimes in place during these periods. The key elements of the estimated reaction functions for each period also vary in ways that seem broadly consistent with the success or failure during the periods at controlling inflation. This conclusion is reinforced at the end of the paper by explicit evaluations of the reaction functions in the three periods in the context of a small macro model.

We do not regard the results of this investigation as providing a complete representation of Fed behavior, in part because we have controlled for only one source of sample instability. However, we hope our results serve as a springboard for a discussion of some of the salient features—and changes—in Federal Reserve behavior over time. Also, as noted above, it is important to develop a better understanding of how the Fed's reaction function has changed over time for macroeconometric research.

1. However, attempts to avoid the mistakes of the past sometimes may lead to new mistakes. De Long (1997, p. 250) argues that ". . . at the deepest level, the truest cause of the inflation in the 1970s was the shadow cast by the great depression . . . ."

2. De Long (1997, p. 274) argues, "A mandate to fight inflation by inducing a significant recession was in place by 1979, as a result of a combination of fears about the cost of inflation, worry about what the 'transformation of every business venture into a speculation on monetary policy' was doing to the underlying prosperity of the American economy, and fear that the structure of expectations was about to become unanchored and that permanent double-digit inflation was about to become a possibility."

3. The 1977 amendment to the Federal Reserve Act requires the Fed to "promote effectively the goals of maximum employment, stable prices, and moderate long-term interest rates." The Humphrey-Hawkins Act of 1978 affirms the responsibility of the federal government in general to promote "full employment and production, . . . and reasonable price stability," among other things.

## I. TAYLOR'S ORIGINAL RULE

Taylor (1993) suggests a very specific and simple rule for monetary policy. His rule sets the level of the nominal federal funds rate equal to the rate of inflation (in effect, making it an equation for the ex post *real* funds rate) plus an "equilibrium" real funds rate (a "natural" rate that is seen as consistent with full employment) plus an equally weighted average of two gaps: (1) the four-quarter moving average of actual inflation in the GDP deflator less a target rate, and (2) the percent deviation of real GDP from an estimate of its potential level:

$$i_t = \pi_t + r^* + 0.5(\pi_t - \pi^*) + 0.5(y_t) \qquad (1)$$

where $i$ = federal funds rate,
$r^*$ = equilibrium real federal funds rate,
$\pi$ = average inflation rate over the contemporaneous and prior three quarters (GDP deflator),
$\pi^*$ = target inflation rate
$y$ = output gap (100·(real GDP – potential GDP) ÷ potential GDP).[4]

Taylor did not econometrically estimate this equation. He assumed that the weights the Fed gave to deviations of inflation and output were both equal to 0.5; thus, for example, if inflation were 1 percentage point above its target, the Fed would set the real funds rate 50 basis points above its equilibrium value. Furthermore, Taylor assumed that the equilibrium real interest rate and the inflation target were both equal to 2 percent. We shall examine these assumptions below; however, it is instructive to consider the interest rate recommendations from the original Taylor rule.[5]

Figure 1 illustrates the original Taylor rule during 1970–1998. The top panel shows the recommendations of the rule on a quarterly basis. The bottom two panels show the variables that enter the rule—the GDP gap and inflation. As explained earlier, higher levels of both variables lead to a higher level of the recommended funds rate. In 1979, for example, the rule recommended a high funds rate mainly because inflation was quite high, and to a lesser extent, because real GDP exceeded its potential level by a small amount.

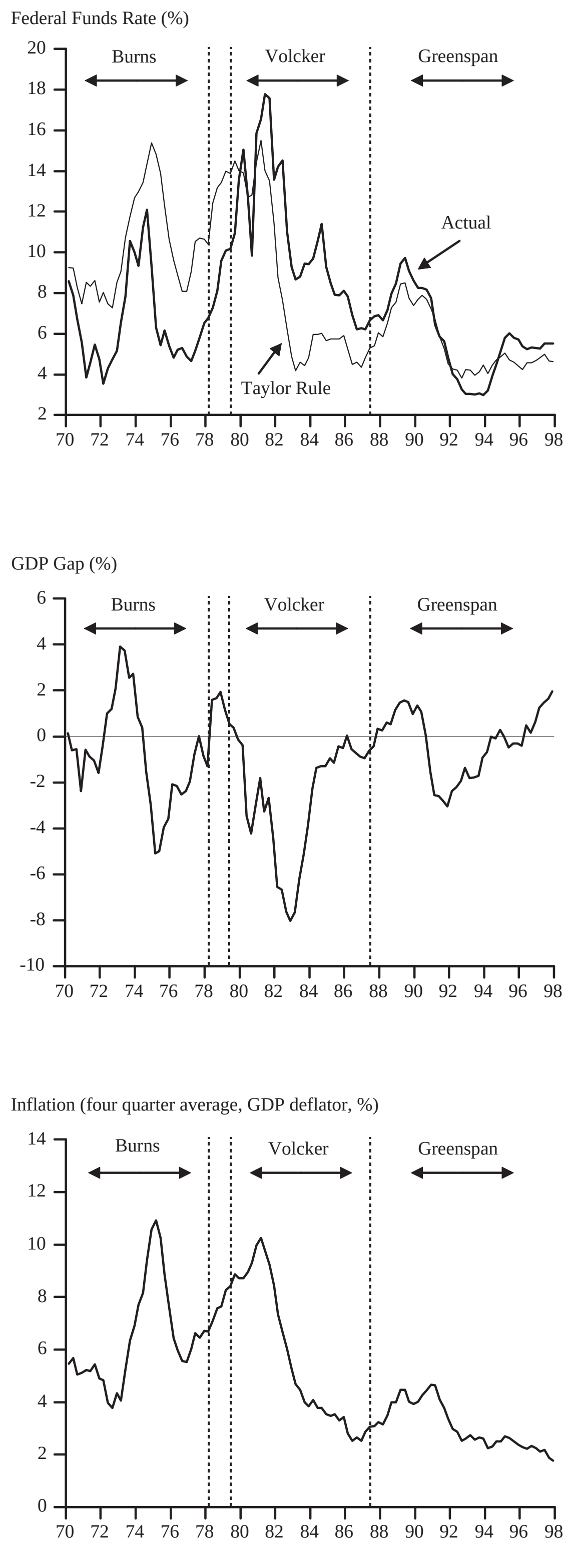
As shown in Figure 1, the original Taylor rule fits reasonably well to the actual funds rate during the Greenspan period. It captures the major swings in the funds rate over the period, but with less amplitude. The $R^2$ for the period is 87 percent for quarterly levels of the nominal funds rate,

4. Taylor (1993) used a log linear trend of real GDP over 1984.Q1 to 1992.Q3 as a measure of potential GDP. As discussed below, we have used a more flexible structural estimate.

5. For a complementary analysis, see Taylor (1997).

FIGURE 1

THE TAYLOR RULE AND ITS COMPONENTS



and 52 percent for quarterly changes. The arguments in the rule—inflation and the GDP gap—roughly correspond with goals legislated for U.S. monetary policy—stable prices and full employment. In this spirit, Governor Meyer (1998) stresses that stabilizing real GDP around its trend in the short run and controlling inflation in the longer term are important concerns of the Fed. Although U.S. policymakers look at many economic and financial indicators, the two gaps specified in the rule may be highly stylized measures of important short- and long-run concerns. Also, the GDP gap can be interpreted not only as a measure of business cycle conditions, but also as an indicator of future inflation in the context of a Phillips curve model. Measures of the productive capacity of the U.S. economy, whether measured by potential GDP, industrial capacity, or the "natural" rate of unemployment, appear to figure prominently in Fed forecasts of future inflation (Greenspan 1995).[6] Overall, by focusing on policy responses to the Fed's basic goal variables, the Taylor rule implicitly captures policy responses to the many economic factors that affect the evolution of those goal variables.[7]

Judd and Trehan (1995) argue that the Taylor rule also provides some perspective on policies during the Burns and Volcker periods. With regard to the Burns period, although the movement of the actual funds rate was highly correlated with the rule's prescriptions, the funds rate itself was consistently lower than the rule's recommended rate (Figure 1). This result is consistent with the overall increase in inflation during this period, and it confirms that the rule, with its explicit 2 percent inflation target, might have held inflation to a much lower level than policy actually did. During the Volcker period, when the Fed significantly reduced inflation, the funds rate was consistently higher than what the rule recommended, suggesting that the Fed was more aggressive in reducing inflation than the rule would have been.

## II. ISSUES IN ESTIMATING TAYLOR'S RULE

The original Taylor rule appears to provide a rough description of policy during the Greenspan period, as well as a useful benchmark for discussing the policy regimes in place during the Burns and Volcker periods. While the original rule provides a reasonable starting point, this section examines alternatives to Taylor's simple specification by econometrically estimating the reaction function weights, rather than simply choosing parameters as Taylor did. Estimating Taylor-type equations may provide a better description of Fed policy. We consider several issues in estimating a reaction function based on the Taylor rule, including the specification of dynamics, the equilibrium real rate, the inflation target, and the output gap.[8]

### *Estimating the Taylor Rule with Dynamics*

It is fairly straightforward to estimate a Taylor rule as in equation (1). Simply replace the rule-based recommended nominal funds rate with the historical series, add a residual error term to capture deviations from the rule, and estimate the weights as coefficients. One complication to this procedure is that central banks often appear to adjust interest rates in a gradual fashion—taking small, distinct steps toward a desired setting (see, e.g., Rudebusch 1995). We allow for such interest rate smoothing by estimating the Taylor rule in the context of an error correction model. This approach allows for the possibility that the funds rate adjusts *gradually* to achieve the rate recommended by the rule.[9]

In our specification, we replace equation (1) with

$$(2) \qquad i_t^* = \pi_t + r^* + \lambda_1 (\pi_t - \pi^*) + \lambda_2 y_t + \lambda_3 y_{t-1}$$

where $i_t^*$ is explicitly denoted as the recommended rate that will be achieved through gradual adjustment. Also, equation (2) includes an additional lagged gap term along with the contemporaneous gap. This is a general specification that allows for the possibility that the Fed responds to a variety of variables proposed as reasonable monetary policy targets, including inflation alone ($\lambda_2 = \lambda_3 = 0$, as in

6. Given the lags in the monetary transmission mechanism, an explicitly forward-looking version of the Taylor rule—with inflation and output *forecasts* as arguments—also might be appropriate. Clarida, Gali, and Gertler (1997a, 1997b) estimate a rule using inflation forecasts and obtain results similar to our own, and Rudebusch and Svensson (1998) examine the theoretical properties of such a rule.

7. The Taylor rule has gained the attention of some Fed policymakers (Blinder 1996, *Business Week* 1996, Meyer 1998, and Yellen 1996), who have used it as a helpful, broad characterization of U.S. monetary policy. In addition, it has gained some acceptance outside the Fed as a way to think about how the Fed might react to economic and inflationary developments (Prudential Economics 1996, and Salomon Brothers 1995a, 1995b). Of course, there are always questions about the reliability of any current implications of the rule because of uncertainty about the level of potential GDP. Some analysts argue that increased productivity, due to computer and other technological developments, means that potential output is being mis-measured. See Trehan (1997) for a discussion of the debate about productivity.

8. We use current data throughout this paper. It would be preferable to use the original data that policymakers actually were looking at when decisions about the funds rate were being made. Unfortunately, we do not have access to these data for our full 1970–1997 sample period. See Orphanides (1997) for an analysis of the effects of original versus final data in estimating a Taylor rule for the 1987–1992 period.

9. Mehra (1994) employs a similar dynamic specification.

Meltzer 1987), nominal GDP growth ($\lambda_1 = \lambda_2 = -\lambda_3$, as in McCallum 1988), inflation and real GDP growth with different weights ($\lambda_1 \neq \lambda_2 = -\lambda_3$), as well as inflation and the GDP gap in level form (as in Taylor 1993).

The dynamics of adjustment of the actual level of the funds rate to $i_t^*$ are given by

$$\Delta i_t = \gamma(i^*_t - i_{t-1}) + \rho\Delta i_{t-1} . \qquad (3)$$

That is, the change in the funds rate at time $t$ partially corrects the "error" between last period's setting and the current recommended level (the first term), as well as maintaining some of the "momentum" from last period's funds rate change (the second term).[10]

By substituting equation (2) into (3), we obtain the equation to be estimated:

$$\Delta i_t = \gamma\alpha - \gamma i_{t-1} + \gamma(1 + \lambda_1)\pi_t + \gamma\lambda_2 y_t + \gamma\lambda_3 y_{t-1} + \rho\Delta i_{t-1} , \qquad (4)$$

where $\alpha = r^* - \lambda_1\pi^*$. This equation provides estimates of the weights on inflation and output in the rule and on the speed of adjustment to the rule.

### *Determining $r^*$ and $\pi^*$*

As is clear from equation (4), our estimation cannot pin down *both* the equilibrium real funds rate ($r^*$) and the inflation target ($\pi^*$) simultaneously. These two terms are combined in the constant term ($\alpha$) and cannot be identified separately. The economics of this lack of identification are clear in the original Taylor rule of equation (1): The contemporaneous arithmetic effect on the recommended policy rate is the same for a 1 percentage point increase in $r^*$ and for a 2 percentage point decrease in $\pi^*$. If both of these magnitudes are unknown, then neither can be individually identified from the estimate of the single parameter $\alpha$.

Of course, if we assume a particular value for the equilibrium funds rate, then, through the estimates of $\alpha$ and $\lambda_1$, we can obtain an estimate of the inflation target. Conversely, an assumption about the inflation target can yield an estimate of the equilibrium rate. Table 1 sheds some light on plausible estimates of these quantities. One simple benchmark for the equilibrium real funds rate is the average real rate that prevailed historically over periods with a common start and end inflation rate.[11] As shown in the first column of Table 1, over a long sample from the early 1960s to the present, inflation edged up, on net, only slightly, while the real funds rate averaged 2.39 percent, which appears to be in the range of reasonable estimates.[12] During the Greenspan period (column 2), the real rate averaged 2.82, which is a bit higher. However, this higher level is consistent with the fact that inflation fell more than 1 percentage point during the Greenspan sample while it rose slightly during the long sample. Certainly, Taylor's (1993) suggestion that 2 percent was a reasonable guess for the value of the equilibrium rate during the Greenspan period seems plausible. It is more difficult to pin down the equilibrium real rate in the Volcker period. During this period, the real

10. We think that this "error correction" framework is a useful one for the consideration of dynamics. However, although the funds rate, the output gap, and the inflation rate are highly persistent, we make no claims that they are nonstationary (consistent with Rudebusch 1993).

11. This is analogous to using the average unemployment rate over periods with no net change in inflation to estimate a constant "natural" rate of unemployment (or NAIRU).

12. The real rates in Table 1 are calculated on an ex post basis as in equation (1), but similar results were obtained using ex ante rates constructed with the one-year-ahead inflation forecasts from the Philadelphia Fed's inflation expectations survey.

TABLE 1

INTEREST RATES AND INFLATION

| | LONG SAMPLE (61.Q1–97.Q4) | GREENSPAN (87.Q3–97.Q4) | VOLCKER (79.Q3–87.Q2) | BURNS (70.Q1–78.Q1) |
|---|---|---|---|---|
| Average real interest rate (%) | 2.39 | 2.82 | 5.35 | 0.02 |
| Percentage point change in inflation | 0.38 | –1.32 | –5.81 | 1.23 |
| Average inflation (%) | 4.38 | 3.03 | 5.35 | 6.47 |
| End-of-sample inflation (%) | 1.77 | 1.77 | 3.07 | 6.69 |

NOTE: The change in inflation (in percentage points) is calculated as the difference in four-quarter inflation from the first quarter to the last quarter of the sample. End-of-sample inflation is average inflation over the final four quarters of the sample. Inflation is measured as the four-quarter change in the GDP deflator, and the interest rate is the federal funds rate.

rate averaged over 5 percent, but there was also a large decline in inflation, so this average rate is likely much higher than the equilibrium real rate.[13] Conversely, real rates averaged about zero during the Burns period, but during this time inflation and inflationary pressures were rising, so the equilibrium rate was most likely higher than the average.

It is less clear how to obtain implicit inflation targets from the historical data. Table 1 provides the average levels of inflation over the various samples. However, given the persistence of inflation, the assumption that the target inflation rate of policymakers has been achieved on average in various samples seems less plausible than the assumption regarding the real funds rate (i.e., that cyclical fluctuations have averaged out over time). Policymakers, notably in the early part of the Volcker period, could have "inherited" persistent inflation rates much different from their own target rate, which could then skew their sample averages. More interesting perhaps is the end-of-sample inflation rate, which gives a reading on what policymakers were able to achieve by the end of their tenure. Note that this rate for Greenspan is close to the 2 percent target assumed in Taylor (1993).

As this discussion should make clear, there is much uncertainty in choosing values for $r^*$ and $\pi^*$.[14] Therefore, we will show results below under a variety of assumptions about these magnitudes.

### *Estimating Potential Real GDP*

One final issue to consider is the specification of the real output gap, which is defined as the percentage difference between real GDP and potential GDP. Potential output is unobserved and must be estimated. An atheoretical method to do this is to fit a trend to the data—again, on the assumption that over time cyclical fluctuations average out. For example, Taylor (1993) simply used a linear trend of log real GDP over a short sample period (1984–1992) as a proxy for potential output. One also could use a segmented linear trend (following Perron 1989) or a quadratic trend (as in Clarida, Gertler, Gali 1997a, 1997b) or other nonstructural methods (see Cogley 1997).

We believe a structural approach to estimating the output gap is more appropriate conceptually than an atheoretic approach, since the presence of output in the policy rule not only may reflect an interest in stabilizing real fluctuations but also may provide policymakers some information on future inflation. The structural approach is also the one typically used by policymakers at the Fed and elsewhere. In this paper, we use a structural definition of potential GDP that was developed at the Congressional Budget Office (1995). It is denoted $Y^*$, and the associated gap is shown in Figure 1.[15] This measure of potential output is not a simple fitted GDP trend, but is estimated in terms of a relationship with future inflation similar to the way a time-varying NAIRU is estimated within the context of a Phillips curve. We examine the robustness of our results to alternative measures of the gap in the Appendix.

## III. ESTIMATES OF REACTION FUNCTIONS

Our main hypothesis is that taking account of changes in Fed Chairmen helps to account for changes in the Fed's reaction function. Accordingly, we conduct Chow tests on equation (4) for two breaks during the 1970.Q1–1997.Q4 period corresponding to the terms of Chairmen Burns, Volcker, and Greenspan (the Miller term, 1978.Q2–1979.Q2, was excluded). While a finding of significant breaks in the data would not be strong evidence in favor of our hypothesis, it would at least be a reasonable initial step that should be taken before proceeding to estimate separate reaction functions for those periods.

The test gives the null hypothesis of no structural change a p-value of 0.00 (i.e., it rejects stability at the 0.00 percent level of significance). In addition, we looked at the Burns/Volcker period and tested for a break between their terms, and similarly at the Volcker/Greenspan period and tested for a break between their terms. These tests rejected stability at significance levels of 0.00 and 0.07, respectively.

In the remainder of this section, we present three exhibits that detail the estimates of separate reaction functions for each of the three Chairmen. We estimate the basic equation (equation (4)) using OLS and then re-estimate the equation after eliminating insignificant terms.[16]

13. Still, it is possible that the equilibrium rate was elevated during the Volcker period given the large federal budget deficits. For a model-based definition of a time-varying equilibrium rate, see Bomfim (1997).

14. There is also, of course, the issue of time variation in $\pi^*$ and $r^*$ (as noted in footnote 13). Even during a given Chairman's term, there may well be changes in the target inflation rate. Indeed, this is the essence of the opportunistic approach to monetary policy described by Bomfim and Rudebusch (1998).

15. This series is conceptually similar and highly correlated with the $Q^*$ series in Braun 1990; Hallman, Porter, and Small 1991; and Orphanides (1997).

16. Given the lags in the transmission process of monetary policy, there is little danger of reverse causation from $i_t$ to $\pi_t$ and $y_t$.

*Exhibit 1: The Greenspan Period, 1987.Q3–1997.Q4*

The lagged gap is insignificant in A, the basic regression, so it is eliminated in B. Regression B explains 71 percent of the quarterly variation in the change in the funds rate (with an adjusted $R^2 = 0.67$), and has a standard error of 27 basis points. Not surprisingly, this regression has a closer fit with the data than Taylor's original specification.[17]

Several interesting issues arise from regression B. First, the estimates suggest gradual, rather than instantaneous, adjustment of the funds rate to the rule. The funds rate typically adjusts enough to eliminate 28 percent of the difference between the lagged actual and rule-recommended funds rate each quarter. Second, the estimated weight on the GDP gap of 0.99 is higher than Taylor assumed (0.50). In this regard, some researchers have found that a larger weight on the output gap than Taylor assumed produces a lower output variance for a given inflation variance in model simulations (e.g., Rudebusch and Svensson 1998 and Williams 1997).

Finally, the data provide a fairly narrow range of estimates of the equilibrium real funds rate and the inflation target. The various estimates of the equilibrium funds rate and the inflation target that are consistent with the estimated constant term can be seen in the Figure in Exhibit 1. The average long-sample and Greenspan-sample real funds rates and the end-of-sample inflation rate are consistent with a fairly tight range of tradeoffs on the line. The estimates of both the inflation target and the real equilibrium funds rate all lie in a range from 1.8 to 2.8 percent—not far from Taylor's assumption of 2 percent.

EXHIBIT 1

REGRESSION RESULTS FOR GREENSPAN PERIOD, 1987.Q3–1997.Q4

| | $\alpha$ | $\gamma$ | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\rho$ | $\bar{R}^2$ | *SEE* | *Q* |
|---|---|---|---|---|---|---|---|---|---|
| A | 1.21 | 0.27 | 0.57 | 1.10 | –0.12 | 0.43 | 0.67 | 0.27 | 20.32 |
| | (1.79) | (4.87) | (2.72) | (2.83) | (–0.31) | (3.94) | | | (0.03) |
| B | 1.31 | 0.28 | 0.54 | 0.99 | | 0.42 | 0.67 | 0.27 | 20.78 |
| | (2.26) | (5.27) | (2.96) | (7.46) | | (4.00) | | | (0.02) |

GREENSPAN REGRESSION INFORMATION

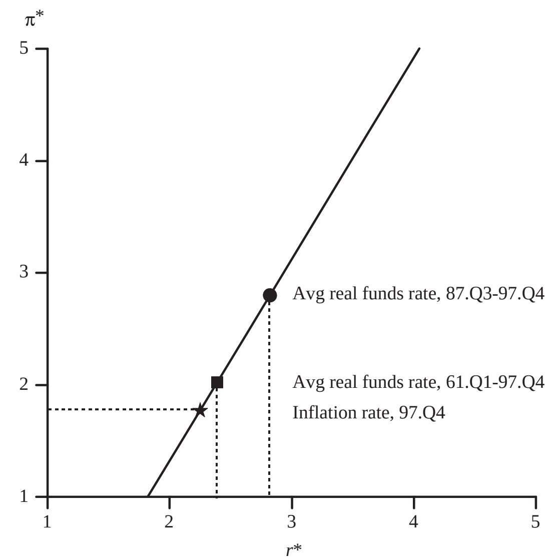



*Exhibit 2: The Volcker Period, 1979.Q3–1987.Q2*

As with the prior regression, estimation of the basic equation (A) finds evidence of partial adjustment of the funds rate to the rule. However, the dynamic pattern is somewhat different in that the lagged dependent variable is not significant; thus, in regression B, we drop this term. Regression A also suggests that the Volcker period involved a response to the change in, rather than the level of, the GDP gap. Indeed, this restriction cannot be rejected at any conventional significance level. In regression B, the change in the GDP gap enters. The coefficient on the inflation gap in B is very close to the 0.5 assumed by Taylor, although the estimated coefficient is only very marginally statistically significant. Overall, our results suggest that policy was concerned with the rate of inflation relative to a target and with the growth rate of real GDP relative to the growth rate of potential GDP.

However, the equation is estimated with much less precision for the Volcker period than for the Greenspan period. The coefficients on $\lambda_1$, $\lambda_2$, and $\lambda_3$ are individually significant only at the 6 to 8 percent level (although they are jointly significant at the 1 percent level), and the standard error is 1.31 percentage points compared to 0.27 percentage point in the Greenspan period. In part, this could

17. The *Q*-statistic suggests the possibility of autocorrelation in the regression. Much of this may be due to our use of time-aggregated data. When we respecified the regression using end-of-quarter funds rate data, the *Q*-statistic did not show signs of autocorrelation, the lagged change in the funds rate became statistically insignificant, and the other coefficients were close to the results in the original specification. This result adds to our confidence in the specification of the right-hand-side variables in regression B, which we retained in the interest of obtaining an equation that can be used in a quarterly macroeconomic model with quarterly average measurement of the funds rate.

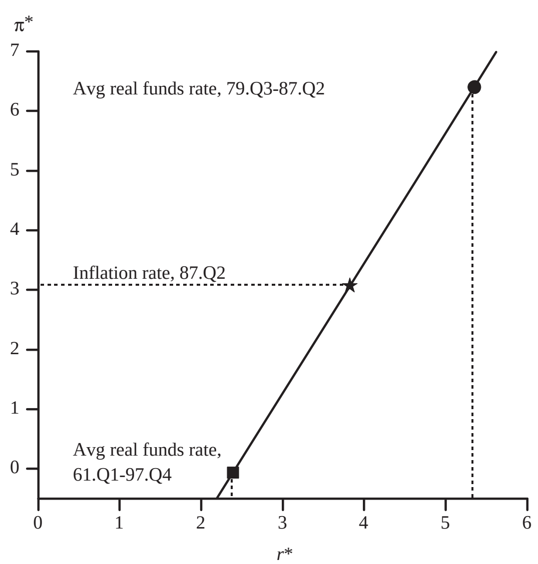
## EXHIBIT 2

### REGRESSION RESULTS FOR VOLCKER PERIOD, 1979.Q3–1987.Q2

| | $\alpha$ | $\gamma$ | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\rho$ | $\bar{R}^2$ | *SEE* | *Q* |
|---|---|---|---|---|---|---|---|---|---|
| A | 2.04 | 0.36 | 0.69 | 2.40 | –2.04 | –0.08 | 0.47 | 1.33 | 10.75 |
| | (0.87) | (2.25) | (1.32) | (1.35) | (–1.42) | (–0.44) | | | (0.22) |
| B | 2.42 | 0.44 | 0.46 | 1.53* | –1.53* | — | 0.48 | 1.31 | 9.43 |
| | (1.56) | (3.64) | (1.79) | (1.92) | (–1.92) | | | | (0.31) |

* restriction: $\lambda_2 + \lambda_3 = 0$

### VOLCKER REGRESSION INFORMATION




be because the policy problem in 1979 was so clear: double-digit inflation then was so far above any reasonable inflation target that policy did not need to be as concerned with the rather refined judgments about funds rate settings provided by a Taylor-style reaction function. Instead, policy could make gross judgments about keeping the real funds rate at a "high" level until inflation began to come down. Alternatively, the imprecision could reflect noisy movements in the funds rate under a nonborrowed reserves operating procedure.

As shown in the Figure, we obtain a wider range of estimates for the implicit inflation target during the Volcker period than during the Greenspan period. This occurs because the average real funds rate during Volcker's tenure (5.35 percent) differs substantially from the average over the entire sample (2.39 percent). The corresponding estimates of the inflation target range from 6.4 percent to –0.1 percent. These estimates bracket the end-of-Volcker-sample inflation rate of 3.07 percent, which corresponds to an $r^*$ of 3.8 percent. The initial tightening of monetary policy could be justified by any of these inflation targets, since inflation was almost 9 percent at the beginning of the Volcker period. Thereafter, it is not possible to tell if the high real funds rates (relative to the Greenspan period) reflects a very low inflation target or a belief that the equilibrium real interest rate was unusually high, possibly because of a perceived need to offset the effects of highly expansionary fiscal policy.

### *Exhibit 3: The Burns Period, 1970.Q1–1978.Q1*

A key feature of this Exhibit is the insignificance of the coefficient on the inflation gap in the general regression A. Note that this does not mean that inflation considerations are entirely absent from the regression for the Burns period. As is clear in equation (2), even when $\lambda_1 = 0$, the nominal funds rate is affected by movements in inflation; however, these movements are simply the one-for-one changes that are necessary to hold the level of the real funds rate unchanged in the face of changes in inflation. Thus, the regressions suggest that the *real* funds rate was *not* adjusted on the basis of changes in inflation.

The lack of a response of the real funds rate to deviations between inflation and an inflation target will be a critical failing for a monetary policy rule. Without the "anchor" of an inflation target to moor the economy, nominal quantities, like inflation and aggregate demand, will be allowed to drift. Indeed, the lack of an implicit inflation target appears to be consistent with the increase in inflation during the Burns period (Figure 1). Of course, other factors may have played a role as well. In particular, there were two large oil shocks in the Burns period. These events no doubt contributed to the inflationary problems of the period, although a consistent policy response to these inflation shocks most likely would have reduced their effects. We address this issue in more detail in the next section.

When the insignificant inflation and contemporaneous gap terms are dropped, we obtain regression B, which shows partial adjustment of the funds rate to a rule that includes only the lagged GDP gap.[18] Since the inflation gap is not in the regression, the constant term ($\alpha$) provides an estimate of the equilibrium real funds rate ($r^*$) implicit in Fed

18. This regression shows signs of autocorrelation (the *Q*-statistic has a p-value of 0.6 percent). As with the Greenspan regression, when the

EXHIBIT 3

REGRESSION RESULTS FOR BURNS PERIOD, 1970.Q1–1978.Q1

| | $\alpha$ | $\gamma$ | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\rho$ | $\bar{R}^2$ | *SEE* | *Q* |
|---|---|---|---|---|---|---|---|---|---|
| A | 1.68 | 0.56 | –0.15 | 0.16 | 0.72 | 0.25 | 0.53 | 0.84 | 15.92 |
| | (1.43) | (4.34) | (–0.80) | (0.45) | (2.59) | (1.67) | | | (0.04) |
| | $\alpha = r^*$ | | | | | | | | |
| B | 0.71 | 0.58 | — | — | 0.89 | 0.26 | 0.52 | 0.84 | 14.81 |
| | (2.68) | (4.78) | | | (5.85) | (1.76) | | | (0.06) |

policy during the period. (This can be seen in equation (4) by setting $\lambda_1 = 0$, which makes $\alpha = r^*$.) One interpretation of this estimate (i.e., that $r^* = 0.7$ percent) is that policy was predicated on the belief that the equilibrium real funds rate was well below postwar experience in the U.S.

A perhaps more plausible interpretation is that the level of the output gap prevailing at the time was consistently mis-estimated during the Burns period. If, for example, the *average* level of the output gap were estimated to be around $1\frac{1}{2}$ percentage points lower than our current estimate for that period, then the estimates in regression B would be consistent with an *average* equilibrium funds rate of around 2 percent. The existence of such large mistakes in the contemporaneous estimates of the output gap have been given an important role during the period by many analysts (e.g., Blinder 1979, p. 35). Such a consistent string of mistakes would not be too surprising. During the Burns period, productivity and potential output both exhibited a surprising (and still largely unexplained) slowdown in growth, and demographic factors, especially the entrance of the baby boom generation into the labor force, conspired to create an increase in the natural rate of unemployment that also was unexpected. Indeed, during the Burns period, there was a widespread view that an unemployment rate of 4 to 5 percent was a suitable benchmark rate for policy. In contrast, recent (time-varying) estimates of the natural rate that prevailed during the Burns period are in the 6 percent range (e.g., Gordon 1997). Such a difference could account for the consistently easy policy during the Burns period. (With an Okun's Law coefficient of 2, the unemployment gap error translates into an underestimation of the output gap on the order of 2 to 4 percent, which would put the funds rate too low.)

funds rate is defined in terms of the level of the last week in the quarter, rather than as a quarterly average, the coefficients in the equation change very little, but the *Q*-statistic becomes insignificant.

## IV. MODEL-BASED EVALUATION OF ALTERNATIVE POLICY RULES

It has become common to evaluate the effectiveness of policy rules or reaction functions like the ones estimated above in terms of the volatility of inflation and output that might result if the rule were used by policymakers. Estimates of this volatility can be obtained from simulations of macro models that include the rule to be evaluated (or by similar analytical methods). See, for example, Rudebusch and Svensson (1998) and Levin, Wieland, and Williams (1997) for recent examples. While exercises of this type can provide useful information for evaluating alternative rules, they are not likely to provide conclusive answers. The results depend upon the particular model employed in the analysis, and because there is no single consensus model in macroeconomics, results from any one model will be subject to debate. (Also, in many cases, the relative rankings of alternative rules are not clear because a tradeoff exists between a rule that has a lower inflation variance and another rule that has a lower real GDP variance.)

As an initial step in evaluating the reaction functions estimated in this paper, we have used a simple model from Rudebusch and Svensson (1998). It includes an aggregate supply equation (or "Phillips curve") that relates inflation to the output gap:

$$(5)\quad \tilde{\pi}_{t+1} = 0.68\tilde{\pi}_t - 0.09\tilde{\pi}_{t-1} + 0.29\tilde{\pi}_{t-2} + 0.12\tilde{\pi}_{t-3} + 0.15\, y_t + \varepsilon_{t+1},$$

(where $\tilde{\pi}_t$ is the quarterly, not four-quarter, inflation rate) and an aggregate demand equation (or "IS curve") that relates output to a short-term interest rate:

$$(6)\quad y_{t+1} = 1.17y_t - 0.27y_{t-1} - 0.09(\bar{i}_t - \pi_t) + \eta_{t+1}$$

(where $\bar{i}_t$ is the average funds rate over the current and prior three quarters). This simple model produces transparent results, captures the spirit of many practical policy-oriented macroeconomic models, and fits the data quite well.[19] In addition to these equations, the estimated reaction functions for the three periods were included one at a time (as well as the original Taylor rule), and the unconditional standard deviations of inflation and the output gap were calculated.

The results are presented in Table 2. In the Rudebusch-Svensson model, the estimated reaction function for the

19. The equations were estimated from 1961.Q1 to 1996.Q4. See Rudebusch and Svensson (1998) for details. The estimates in (5) and (6) differ very slightly from those in that paper because of the longer sample and data revisions.

TABLE 2

Model-Based Volatility Results

| Monetary Policy Reaction Function | Standard Deviation $\pi_t$ | $y_t$ |
|---|---|---|
| Taylor rule | 3.86 | 2.23 |
| Greenspan period | 3.87 | 2.18 |
| Volcker period | 4.80 | 2.73 |
| Burns period | Does not converge | |

Greenspan period has an advantage over the function for the Volcker period: the former function produces a lower standard deviation for the real output gap and about the same standard deviation for (four-quarter) inflation. However, we would not want to emphasize this comparison too much because the differences are not large and may be reversed in a different model. The function for the Greenspan period produces about the same volatility of both inflation and real GDP as the original Taylor rule.

The results for the Burns period seem more telling, since the model did not converge when that reaction function was included. This dynamic instability reflects the fact that inflation is not anchored in the Burns period. This result is likely to show up in a variety of models when the reaction function for the Burns period is used. Indeed, Clarida, Gali, and Gertler (1997a) use a calibrated forward-looking model to show that their estimated pre-1979 reaction function is unstable.

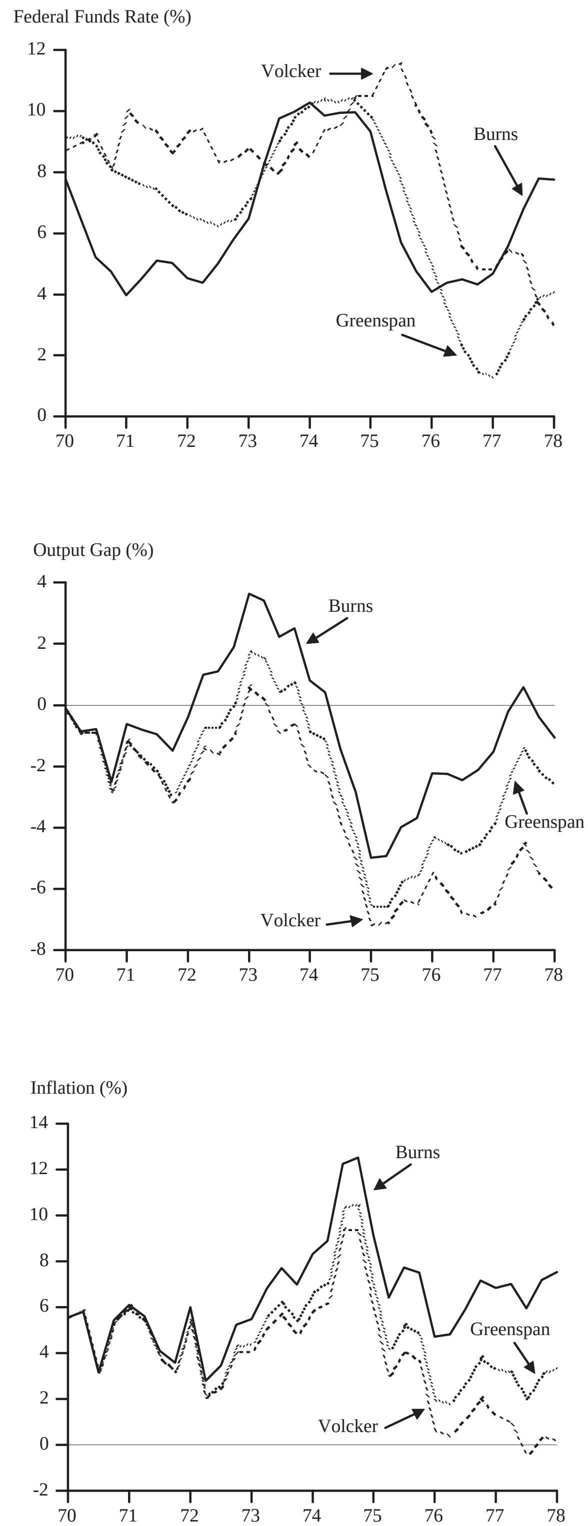
The contrast between the three estimated reaction functions is demonstrated in Figure 2 with counterfactual simulations of the Burns period. These are simulations of equations (5) and (6) along with, in turn, the Burns, Volcker, and Greenspan reaction functions. The actual historical shocks to equations (5) and (6) in the Burns period are used, so in all three cases inflation is pushed up by unfavorable shocks. Still, the difference between the Burns reaction function and the other two is striking, for only with the Burns reaction function does inflation remain at a high level.

## V. Conclusions

The estimates in this paper indicate that a Taylor-type reaction function seems to capture some important elements of monetary policy during Alan Greenspan's tenure to date as Federal Reserve Chairman. This regression implies that movements in the funds rate over that period have been

FIGURE 2

Counterfactual Simulations: 1970.Q1–1978.Q1



broadly consistent with a policy regime aimed at low inflation in the long run and a stable level of output around trend in the short run. However, the results differ somewhat from Taylor's original specification of the rule in two main ways. The funds rate appears to have reacted about twice as strongly to the GDP gap as Taylor assumed, and it appears to have moved gradually, rather than instantaneously, into rough accord with the estimated Taylor rule.

The estimates for the Volcker period are less precise than those for the Greenspan period. Nonetheless, they suggest that the Fed adjusted the funds rate gradually in response to concerns with achieving an inflation target well below the rate inherited by the FOMC in the late 1970s. This result is consistent with the substantial progress achieved in reducing inflation during the period. Policy also appears to have given weight to cyclical considerations, but this concern came in the form of reactions to the growth rate rather than to the level of real GDP.

In the Burns period, we find a weak policy response to inflation. Instead, policy seems to have been geared mainly toward gradual responses to the state of the business cycle. Moreover, some evidence suggests that policy either was oriented around an unusually low estimate of the equilibrium real funds rate or around an estimate of potential output that appears to have been too high in retrospect. These results seem consistent with the key feature of Burns's tenure as Chairman of the Fed—rising inflation—and they appear to show up as dynamic instability in our model simulations.

Overall, the dynamic Taylor-type reaction functions estimated during the Burns, Volcker, and Greenspan periods, appear to have differed in important ways from one another. As noted above, this investigation has not provided a complete representation of changes in Fed behavior, in part because we have controlled for only one source of sample instability. This may account for the sensitivity of some of the results to alternative specifications as shown in the Appendix. However, we hope our results represent a step in the direction of uncovering the key elements—and changes—in Federal Reserve behavior over time.

The finding that the monetary policy regime may have changed in significant ways over time has implications for at least two strands of literature in macroeconomics. First, the finding raises questions about attempts to estimate monetary policy shocks using identified VARs estimated over long sample periods. If the implicit reaction functions in these VARs do not properly capture the changes in the way policy was formulated, then the estimated shocks will not properly measure the "surprises" in policy. Thus, our results reinforce the conclusions of Rudebusch (1998) that such VARs may be misspecified. Second, in macroeconomic models with rational expectations, parameters throughout the models depend upon the monetary policy regime in place. If the policy regime has changed frequently in the postwar period, it may be difficult to obtain good estimates of these rational expectations models, in part because we may not have long enough sample periods under a consistent policy regime.

## APPENDIX: ALTERNATIVE SPECIFICATIONS

We examine the robustness of the results presented in the text by looking at regressions using alternative measures of inflation and the GDP gap. The results are presented in Table A1. With regard to inflation, the estimated regressions show little sensitivity to these alternative measures.

With regard to the GDP gap, we estimate reaction functions using three estimates of potential GDP, namely, $Y^*$, which is described in the text, a segmented linear trend with one break in 1973.Q1, and a quadratic trend. Figure A1 shows the alternative estimates of potential output and the corresponding GDP gaps. The GDP gap measured in terms of $Y^*$ has cross-correlations of 0.99 and 0.80 with the quadratic and linear trend gaps, respectively. A recent example of a divergence among these series occurred in the 1990s, when the segmented linear trend showed output consistently below potential, while the other two measures showed a rising gap that became positive toward the end of the sample. Differences like these can have noticeable effects on Fed policy concerns. The regression results for the reaction function using the linear trend differ from those using the other gap measures in Table A1. In fact, in the Greenspan period, the introduction of the linear trend actually changes the sign of the response to the inflation gap. The alternative measures of the gap have little effect on the results for the Burns or the Volcker periods.

# TABLE A1

## REACTION FUNCTIONS—ALTERNATIVE SPECIFICATIONS
INFLATION

| | $\alpha$ | $\gamma$ | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\rho$ | $r^*$ | $\bar{R}^2$ | *SEE* | *Q* |
|---|---|---|---|---|---|---|---|---|---|---|
| GREENSPAN | | | | | | | | | | |
| GDP Deflator | 1.31 | 0.28 | 0.54 | 0.99 | – | 0.42 | – | 0.67 | 0.27 | 20.78 |
| | (2.26) | (5.27) | (2.96) | (7.46) | – | (4.00) | – | – | – | (0.02) |
| PCE Price Index | 2.39 | 0.23 | 0.07 | 1.02 | – | 0.44 | – | 0.62 | 0.29 | 12.12 |
| | (3.56) | (4.30) | (0.37) | (5.66) | – | (3.89) | – | – | – | (0.28) |
| Core CPI | 1.00 | 0.25 | 0.37 | 1.15 | – | 0.49 | – | 0.64 | 0.28 | 16.24 |
| | (1.28) | (4.56) | (1.79) | (7.20) | – | (4.47) | – | – | – | (0.09) |
| VOLCKER | | | | | | | | | | |
| GDP Deflator | 2.42 | 0.44 | 0.46 | 1.53 | –1.53 | – | – | 0.48 | 1.31 | 9.43 |
| | (1.56) | (3.64) | (1.79) | (1.92) | (–1.92) | – | – | – | – | (0.31) |
| PCE Price Index | 1.46 | 0.29 | 0.54 | 2.58 | –2.58 | – | – | 0.40 | 1.41 | 9.06 |
| | (0.52) | (2.59) | (1.21) | (1.65) | (–1.65) | – | – | – | – | (0.34) |
| Core CPI | 1.32 | 0.35 | 0.35 | 2.57 | –2.57 | – | – | 0.43 | 1.37 | 8.70 |
| | (0.57) | (3.03) | (1.11) | (2.07) | (–2.07) | – | – | – | – | (0.37) |
| BURNS | $\alpha = r^*$ | | | | | | | | | |
| GDP Deflator | 0.71 | 0.58 | – | – | 0.89 | 0.26 | 0.71 | 0.52 | 0.84 | 14.81 |
| | (2.68) | (4.78) | – | – | (5.85) | (1.76) | (2.68) | – | – | (0.06) |
| PCE Price Index | 0.95 | 0.51 | – | – | 0.86 | 0.17 | 0.95 | 0.48 | 0.87 | 16.97 |
| | (2.98) | (4.33) | – | – | (4.67) | (1.14) | (2.98) | – | – | (0.03) |
| Core CPI | 1.30 | 0.56 | – | – | 1.14 | 0.34 | 1.30 | 0.40 | 0.94 | 10.72 |
| | (4.17) | (3.46) | – | – | (6.12) | (1.99) | (4.17) | – | – | (0.22) |

## REACTION FUNCTIONS—ALTERNATIVE SPECIFICATIONS
POTENTIAL GDP

| | $\alpha$ | $\gamma$ | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\rho$ | $r^*$ | $\bar{R}^2$ | *SEE* | *Q* |
|---|---|---|---|---|---|---|---|---|---|---|
| GREENSPAN | | | | | | | | | | |
| $Y^*$ | 1.31 | 0.28 | 0.54 | 0.99 | – | 0.42 | – | 0.67 | 0.27 | 20.78 |
| | (2.26) | (5.27) | (2.96) | (7.46) | – | (4.00) | – | – | – | (0.02) |
| Segmented Linear Trend | 5.35 | 0.18 | –0.99 | 0.90 | – | 0.54 | – | 0.58 | 0.31 | 10.71 |
| | (3.52) | (3.56) | (–1.93) | (3.99) | – | (4.88) | – | – | – | (0.38) |
| Quadratic Trend | 1.09 | 0.28 | 0.37 | 0.82 | – | 0.52 | – | 0.64 | 0.28 | 19.10 |
| | (1.80) | (4.77) | (1.90) | (7.05) | – | (4.94) | – | – | – | (0.04) |

(continued)

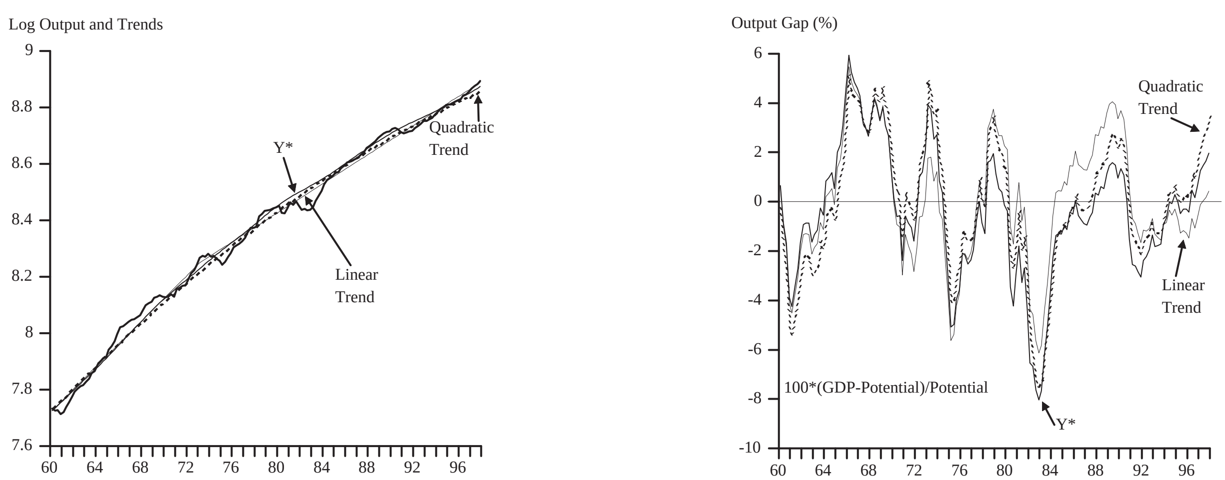
## TABLE A1 (Continued)

### REACTION FUNCTIONS—ALTERNATIVE SPECIFICATIONS
POTENTIAL GDP

| | α | γ | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | ρ | $r*$ | $\bar{R}^2$ | *SEE* | *Q* |
|---|---|---|---|---|---|---|---|---|---|---|
| VOLCKER | | | | | | | | | | |
| *Y** | 2.42 | 0.44 | 0.46 | 1.53 | –1.53 | – | – | 0.48 | 1.31 | 9.43 |
| | (1.56) | (3.64) | (1.79) | (1.92) | (–1.92) | – | – | – | – | (0.31) |
| Segmented Linear Trend | 2.29 | 0.43 | 0.48 | 1.57 | –1.57 | – | – | 0.48 | 1.31 | 9.28 |
| | (1.39) | (3.46) | (1.75) | (1.84) | (–1.84) | – | – | – | – | (0.32) |
| Quadratic Trend | 2.23 | 0.43 | 0.50 | 1.60 | –1.60 | – | – | 0.48 | 1.31 | 9.23 |
| | (1.33) | (3.46) | (1.78) | (1.84) | (–1.84) | – | – | – | – | (0.32) |
| BURNS | α = $r*$ | | | | | | | | | |
| *Y** | 0.71 | 0.58 | – | – | 0.89 | 0.26 | 0.71 | 0.52 | 0.84 | 14.81 |
| | (2.68) | (4.78) | – | – | (5.85) | (1.76) | (2.68) | – | – | (0.06) |
| Segmented Linear Trend | 1.54 | 0.52 | – | – | 1.07 | 0.25 | 1.54 | 0.46 | 0.89 | 13.88 |
| | (3.76) | (4.15) | – | – | (4.83) | (1.59) | (3.76) | – | – | (0.09) |
| Quadratic Trend | –0.15 | 0.59 | – | – | 0.88 | 0.26 | –0.15 | 0.52 | 0.84 | 14.57 |
| | (–0.58) | (4.78) | – | – | (5.90) | (1.78) | (–0.58) | – | – | (0.07) |

## FIGURE A1

### ALTERNATIVE ESTIMATES



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