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## The Greenbook and U.S. Monetary Policy

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**IMF Working Paper**

Fiscal Affairs Department

**The Greenbook and U.S. Monetary Policy**

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**Abstract**

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Although very attractive both theoretically and empirically, Taylor rules imply mechanical responses by the policy variable (interest rate) to fundamental ones (inflation and output gap). This study looks for empirical evidence of a more sophisticated monetary policy, one which takes into account expected future developments. An important piece of information added is the “Greenbook” forecast series, calculated by the Federal Reserve staff and which allow evaluation of expected inflation shocks. These shocks are significant in the estimated Taylor rule, confirming that policymaking is forward looking. This paper also demonstrates that a simple Taylor rule may be a misspecification if policymakers have in mind a time-varying inflation target.

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## I. INTRODUCTION

It seems intuitive that policymaking should be preemptive, anticipating future developments. There has been much theoretical discussion recently in the economic literature describing monetary policy as forward looking. However, at the same time, not much empirical evidence of forward-looking policy exists.

Because they use lagged fundamentals, most studies assume that monetary policy rules respond to developments that have already taken place. This assumption is based on the idea that a very high degree of inertia in variables such as inflation and output makes lags powerful predictors of leads. Such policy is, however, overly mechanical, giving rise to the impression that even a cook can run the Federal Reserve.

In this paper I argue that policymaking is indeed forward looking. Such a statement, however, leaves room for various interpretations.

Most of the research in this direction assumes that monetary policy is forward looking in the sense that it aims at the public's expectations, which in turn affect contemporaneous fundamentals. Yet such a policy may still be mechanical. Lansing and Trehan (2001), for instance, develop a model where fundamentals are driven both by inertia and expectations, but where the optimal rule is nevertheless lag based, thus assuming a mechanical backward response.

Monetary policy can also be considered forward looking in the sense that it responds to shocks, about which policymakers have some information. These shocks can vary in nature. They may reflect unusually bad or good harvests, or changes in the world price of oil or gold, for example. Finally they may reflect public expectations, even if these expectations are not driven by fundamentals.

Thus, these two types of forward-looking models are not inherently different, but they are not necessarily the same either. In an environment with rational expectations but without private information, these two approaches would depict the same picture. However, if policymakers have access to information which is not readily available to the general public, then responding to public expectations may not prove to be efficient. Romer and Romer (2000) provide evidence of such asymmetry in information available to both public and the Federal Reserve.

This study provides statistical evidence of a policy that is forward looking in the sense that it responds to shocks, whether they are expected by the public or not. Calculations of these shocks are based on the "Greenbook" forecasts<sup>2</sup> of inflation and output, and thus represent the Federal Reserve's expectations. They are statistically significant in the estimated policy rule, confirming that policymakers take into account future developments, and that policy is more preemptive than a simple response to inertial components would suggest.

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<sup>2</sup> Greenbook forecasts are produced before each meeting of the Federal Open Market Committee by the Research staff at the Board of Governors. See page 10.

The advantage of using the Greenbook forecasts is twofold. First, it allows testing for the rule's "direction." Second, the use of forecasts allows one to calculate more precisely the real-time estimates of lagged potential output which policymakers had at hand.

Most authors use ex post estimates of output gap, obtained by detrending the revised data for output. Tchaidze (2001) uses a more realistic specification of output gap, which is based on preliminary estimates of actual output, using only its lagged observations for estimating the economy's potential level. This paper constitutes one more step toward an even more realistic analysis by including the Greenbook forecasts into an information set, based on which output gap estimates are calculated.

The paper contains six sections: Section II estimates backward-looking rules using different estimates of the lagged output gap, starting with a commonly used specification based on both lags and leads of output, and proceeding to more realistic specifications based first on lags only, and then on lags and forecasts that reflect additional information policymakers have; Section III uses a simple model to derive a forward-looking rule, one which responds to inertial components of inflation and output gap as well as to expected shocks, and then discusses empirical results. Among other results, it argues that the inflation response coefficient is higher than the usually suggested values, at about 2.5; Section IV provides some historical evidence justifying the behavior of the Federal Reserve in a way suggested by the model; Section V attempts to explain why a similar exercise applied to Paul Volcker's tenure term does not produce results consistent with his inflation-hawk reputation; and Section VI concludes.

## II. REESTIMATING LAG-BASED RULES

This section estimates a backward-looking Taylor rule which responds only to movements in lagged fundamentals. The backward-looking specification of a Taylor rule looks as follows:

$$i_t = C + C_1\pi_{t-1} + C_2y_{t-1},$$

where  $i$  is an overnight interest rate set by the Federal Reserve (also known as the federal funds rate);  $\pi$  is inflation, measured as an annual growth of the GNP/GDP deflator;<sup>3</sup> and  $y$  is the output gap, measured as a difference between log-output and its trend. The rule is based on lagged fundamentals, as they are the most up-to-date pieces of information available to policymakers. All the data are quarterly. The sample<sup>4</sup> runs from 1987:Q3 to 1994:Q4.

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<sup>3</sup> Until 1993, GNP rather than GDP was used as a main indicator of national output. This switch is not expected to have any major impact on the results.

<sup>4</sup> I start my sample in 1987:Q3 as it is the first quarter of Alan Greenspan's chairmanship of the Federal Reserve Board. I end my sample in 1994 because Greenbook forecasts for later observations were not available to me (see further).

Next I compare different estimates of the output gap to achieve the most realistic picture of an environment in which policymakers make decisions, and then I estimate the rule.

### A. Three Sets of Output Gap Estimates

I use three different sets of estimates of fundamentals. The first may be considered ex post; the two others, real-time. The main difference among them is the way output gap estimates are constructed.

The very first specification of the rule uses 1999 vintage data for inflation and output levels. Most of these data (particularly the earlier components) have been substantially revised since their initial releases. For this particular specification I use estimates of output gap, which I call “lags and leads.” I detrend the whole path for log-output (1947:Q1—1999:Q2) using a Hodrick-Prescott filter.

Of course for most of the univariate detrending techniques (linear, quadratic, HP) as well as for multivariate ones, calculating a trend at any point in time  $t$  very much depends not only on lagged but also on lead observations. Had the economy evolved differently after  $t$ , trend estimates would have been different.

Imagine that after a long period of growth, output declines over one or two consecutive periods. At this point, we cannot draw a straightforward conclusion—whether the decline is a temporary correction, which will be followed by further growth, or is the signal of the business cycle's turning point. Only after observing output over several more periods can we tell exactly what is happening, as this then allows for a more precise estimate of the trend at a point of interest  $t$ . Orphanides and van Norden (1999) cite lack of information about an economy's future developments as a main cause of errors in real-time estimates of the gap.

Thus, the second specification of output gap is “lags only.” For every point in time  $t$ , I detrend lagged observations of the output levels, from 1947:Q1 till  $t-1$ . Thus, the estimates are obtained using the so-called one-sided Hodrick-Prescott filter. Also, the inflation and output data that I use are unrevised, as reported in the Philadelphia Federal Reserve's real-time web dataset (for details see Croushore and Stark, 1999). Excluding leads of the data and ignoring revisions have a drastic effect on output gap estimates. An error term (defined as the difference between ex post lags-and-leads, and real-time lags-only estimates of output gap) ranges from -1.54 to 3.33, with a mean of 0.53, and a standard deviation of 1.45 (see Table 1). Tchaidze (2001) argues that most of these errors should be attributed to the exclusion of leads rather than to revisions.

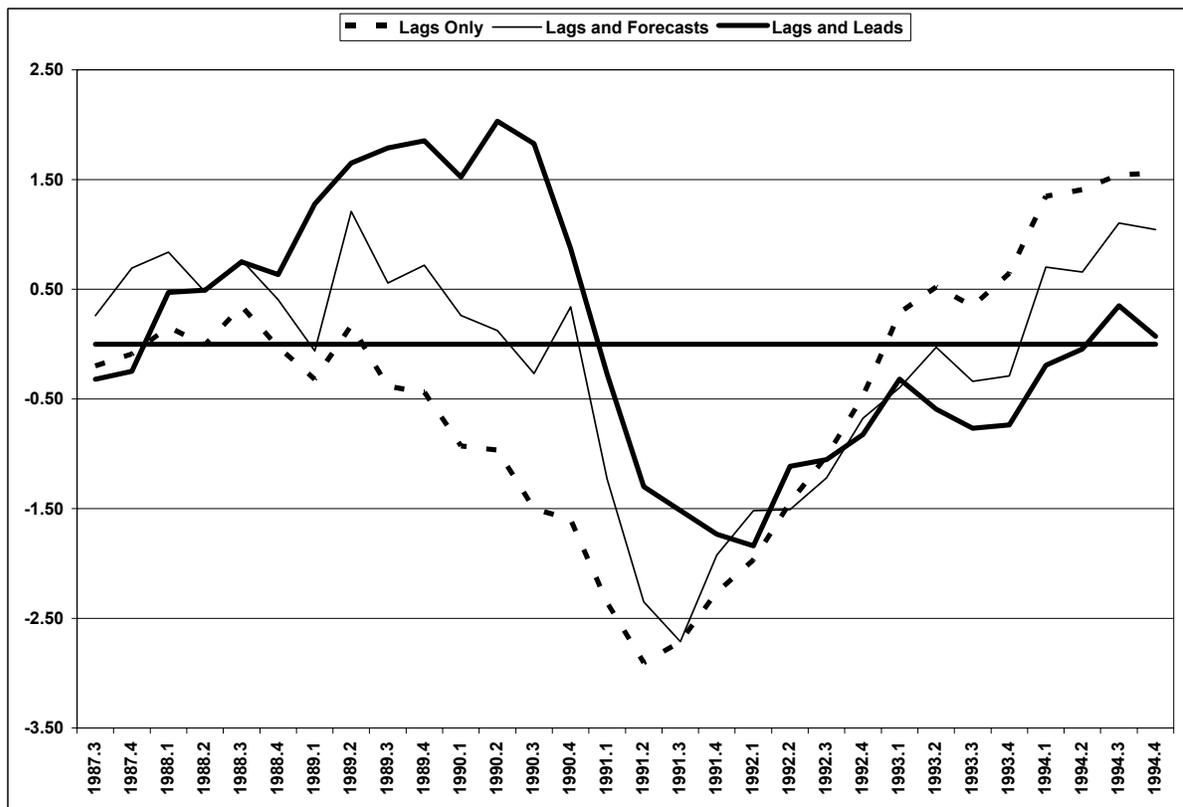
Table 1. Errors in Real-Time Estimates of Output Gap

	Lags and Leads—Lags Only	Lags and Leads—Lags and Forecasts
<b>Mean</b>	0.53	0.24
<b>St.Deviation</b>	1.45	0.87
<b>Max</b>	3.33	2.09
<b>Min</b>	-1.54	-0.97

Although the data released in various statistical bulletins do not suggest much about further developments in the economy, policymakers undoubtedly know more. Even though they do not observe the leads of output and cannot make correct estimations of the trend based on observed values, they may be observing other signals which indicate approximate values of the trend and the direction which it is going to follow. Although over longer horizons these estimates become less and less precise, policymakers gain additional leverage, as they can influence future developments through the setting of policy variables.

To account for these factors, I construct the third set of estimates called “lags and forecasts.” At every point in time  $t$ , I detrend the time series, which consists of observed lagged values (from 1947:Q1 until  $t-1$ ) and the forecasts for the contemporaneous as well as the four following quarters (from  $t$  until  $t+4$ ). Detrending such series allows me to construct estimates which would be closer to those that policymakers used.

Figure 1. Output Gap Estimates



To construct forecasts of output, I use forecasts of output growth as reported in the “Current Economic and Financial Conditions” issues, also known as the “Greenbook.” The Greenbook is a collection of various data that are prepared by the economists at the Federal Reserve Board, which are presented to the Board of the Governors before their regular meetings (the board usually meets eight times a year).

For security reasons, the Greenbook data become publicly available only with a five-year lag. Note that data are not really forecasts in the sense that they do not reflect the policy being implemented, but rather assumptions of the economists about future policy and shocks. Obviously, had a different set of assumptions been made, in each case the forecast would have been different. However, since at the very short horizons, policy has a minimal effect (if any at all), I can assume that only the forecasts for  $t+3$  and  $t+4$  are not invariant with respect to the assumptions about the future policy.

As Table 1 indicates, the inclusion of forecasts significantly improves real-time gap estimates. Both the mean and standard deviations of the error term are about half of what they were before. Maximum and minimum values are much smaller in absolute terms as well. Figure 1 also shows that most of the time the lags-and-forecasts estimates lie between the lags-and-leads and the lags-only estimates, indicating an obvious improvement in estimation results.

### B. Estimating the Rule

Since the lags-and-forecasts output gap estimates are much closer to the ex post lags-and-leads estimates than the estimates which are based on lags only, it should not be surprising that the difference between ex post and real-time estimates of the Taylor rule diminishes as well once the lags-and-forecasts gap estimates are used rather than those based on lags only (see Table 2). Not only is the difference between the values of response coefficient estimates smaller, the difference in fit practically disappears.<sup>5</sup>

Table 2. Rules with Various Output Gap Specifications<sup>6</sup>

	<b>INFL LAG</b>	<b>GAP LAG</b>	<b>CNST</b>	<b>Adj R<sup>2</sup></b>	<b>SSR</b>
<b>Lags and Leads</b>	1.58 (0.31)	1.25 (0.13)	0.32 (1.05)	0.86	19.88
<b>Lags and Forecasts</b>	2.33 (0.23)	1.02 (0.14)	-1.39 (0.94)	0.82	24.58
<b>Lags Only</b>	2.90 (0.27)	0.83 (0.17)	-2.97 (1.11)	0.73	38.01

<sup>5</sup> The differences among estimates are also caused by the revisions. As mentioned earlier, the lags-and-leads specification uses revised data, while the other two use unrevised data. Tchaidze (2001) shows that accounting for revisions for this particular subsample is an important factor.

<sup>6</sup> All the estimations in this paper are performed with an OLS/Newey-West (Newey and West, 1987) procedure, thus accounting standard errors for possible heteroscedasticity and autocorrelation.

The results still suggest a very strong inflation response of 2.3, which is higher than the values usually suggested (1.4–2.0; see Rudebusch, 2001) and a strong output gap response of 1.0 leaning to the right end of the usually suggested range (0.5–1.0; see Rudebusch, 2001). Even though fits for the lags-and-leads and lags-and-forecasts regressions are almost identical, there is a difference in the values of the estimated coefficients. The values for the lags-and-leads specification are very similar to the suggested values<sup>7</sup> of 1.5, 1 and 1. The values for the lags-and-forecasts specifications are different.

Testing whether coefficients in the lags-and-forecasts specification are equal to those suggested by the lags-and-leads specification provides the following results: we cannot reject a hypothesis that an output gap coefficient for the lags-and-forecasts specification is equal to 1.25, the value suggested by the lags-and-leads specification, but we reject the hypothesis  $C_\pi = 1.58$  at a 0.05 level of significance. Likewise we reject a hypothesis  $C = 0.32$ ,  $C_\pi = 1.58$  and  $C_y = 1.25$  at the 0.05 significance level as well.

Thus, even though for all of the parameters, confidence intervals in the lags-and-leads and lags-and-forecasts regressions have a nonempty intersection, the tests indicate that there is a substantial difference between the two, and in particular, that the inflation coefficient is much higher than 1.5.

### III. FORWARD-LOOKING RULES

This section estimates a forward-looking specification of the rule, one which responds to movements in expected rather than lagged variables. The next subsection uses a simple model of a closed economy to provide a theoretical basis for such a rule, while the following subsection discusses results of the estimation.

#### A. Theoretical Model

To describe the economy, I use a model which has become a somewhat standard tool for such purposes (Romer, 2000). The annual model was proposed by Ball (1999) and Svensson (1997). Orphanides (1998b) develops a similar semiannual model, and Rudebusch and Svensson (1999) derive an analogous model formulated in quarterly terms.

The model consists of the two following equations:

$$(\pi_{t+1} - \pi^*) = (\pi_t - \pi^*) + \alpha y_t + \varepsilon_{t+1} \quad \text{and} \quad (1)$$

$$y_{t+1} = \lambda y_t - \beta(r_t - r^*) + \eta_{t+1}, \quad (2)$$

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<sup>7</sup> The rule suggested by Taylor (1993) originally had an inflation coefficient of 1.5, an output gap coefficient of 0.5, and a constant term of 1. Several studies have suggested, however, a stronger response to output gap (Ball, 1999; Williams, 1999).

where a period is one year,  $r_t$  is a real interest rate set by policymakers,  $\pi_{t-1}$  and  $y_{t-1}$  refer to the newest information available to them before making a decision, and  $\pi^*$  and  $r^*$  refer to the respective long-run levels of inflation and real interest rate.

Equation (1) is an accelerationist Phillip's curve. Equation (2) is an IS curve, assuming an inertial output gap, which is affected by a real interest rate  $r_t$ . Finally,  $\varepsilon_{t+1}$  and  $\eta_{t+1}$  are zero-mean, normally distributed random variables, reflecting supply and demand shocks.

Note that the model is completely backward looking, and thus implicitly assumes adaptive expectations. It is a common observation that alternative frameworks, assuming rational expectations, do not fit observed data as well, unless there are some agents that are backward looking to some degree (for example, Ball, 2000; Fuhrer, 1997; Roberts, 1997 and 1998).

The model assumes that policymakers can affect inflation only within two periods, as monetary policy has an effect on output gap with a one-period lag, and output gap affects inflation with a one-period lag as well. This means that when policymakers are designing monetary policy by setting an instrument variable  $r_t$ , they treat expected inflation  $E_t\pi_{t+1}$  as given. Furthermore, as equation (2) shows, setting the interest rate is tantamount to setting the expected output gap—for any given  $E_t y_{t+1}$  we can find  $r_t$ , such that the expected output gap for the next period will be equal to  $E_t y_{t+1}$ .

I assume that policymakers are minimizing a weighted sum of inflation and output gap variances. As Romer (2000) shows, such an objective implies a linear response function of the following form:

$$E_t y_{t+1} = -qE_t(\pi_{t+1} - \pi^*), \quad (3)$$

where  $q$  is a parameter, determined by the weights that policymakers assign to inflation and output gap variances. Higher  $q$  is associated with a higher weight being placed on inflation variance, while lower  $q$  is associated with a higher weight being put on output gap variance.

Equation (3) shows that whenever policymakers expect inflation to be above its long-run level, they contract the economy in order to prevent it from overheating. At the same time, whenever inflation is expected to be below its long-run level, they loosen up and push the output above its potential level.

Although previous authors have assumed that shocks  $\varepsilon$  and  $\eta$  are completely unforecastable, I assume that policymakers do have some information about them. In particular, although unconditional expectations  $E\varepsilon_{t+1}$  and  $E\eta_{t+1}$  are zero, policymakers' expectations  $E_t\varepsilon_{t+1}$  and  $E_t\eta_{t+1}$  as of time  $t$  are not necessarily so.

Substituting equations (1) and (2) into (3), we can solve for the interest rate in terms of lagged output gap and inflation, as well as expected output gap and inflation shocks:

$$r_t = r^* + C_\pi(\pi_t - \pi^*) + C_y y_t + C_\pi E_t \varepsilon_{t+1} + \beta^{-1} E_t \eta_{t+1},$$

where  $C_\pi = q/\beta$  and  $C_y = (\lambda + q\alpha)/\beta$ . This formulation suggests that the more anti-inflationary the preferences of policymakers, the more aggressive the corresponding policy in response to deviations in both inflation and output gap lags.

Reformulating the rule in terms of a nominal rather than a real interest rate results in the following:

$$i_t = (r^* - C_\pi \pi^*) + (1 + C_\pi)\pi_t + C_y y_t + C_\pi E_t \varepsilon_{t+1} + \beta^{-1} E_t \eta_{t+1}. \quad (4)$$

Note that the policymakers respond to “inertial” variables  $\pi_t$  and  $y_t$  as well as expected shocks  $E_t \varepsilon_{t+1}$  and  $E_t \eta_{t+1}$ .

Unfortunately, not all of these variables, particularly those reflecting expectations, are readily available when it comes to empirical estimations. The Greenbook does provide data on output growth and inflation forecasts, and at first glance, these might seem sufficient to solve the problem. However, the issue is more delicate.

Since inflation is predetermined for one period ahead and does not depend on the interest rate, I can use equation (1) by substituting the Greenbook forecasts in place of expected inflation  $E_t \pi_{t+1}$  and treat residuals as the expected inflation shock  $E_t \varepsilon_{t+1}$ :

$$E_t \pi_{t+1} = \pi_t + \alpha y_t + E_t \varepsilon_{t+1}.$$

At the same time, as equation (2) demonstrates, expected output shock  $E_t \eta_{t+1}$  cannot be recovered, as it depends on the assumed values of the interest rate, which are not observed.

As already mentioned, the Greenbook forecasts are calculated before the Federal Reserve Board makes a decision, and thus are not based on the true value of the policy instrument. They do not reflect implemented policy in the same manner as do forecasts produced by the Bank of England or the Bank of Canada.

The path for the interest rate assumed in these forecasts is suggested by the director of the Research Department (Michael Prell for the period covered). Very often, alternative forecasts are produced as well, and these are sometimes (though not always) included in the Greenbook. Over the course of a forecast exercise, the suggested path may well be revised if the staff (or their models) suggest that the path is unlikely actually to be realized in the economy.

Finally, apart from models, economists also use their own judgment when calculating forecasts, suggesting that these forecasts are highly subjective and do not necessarily reflect the Board's opinions.

As mentioned earlier, the main interest in this study is whether the rule is forward looking—that is, takes into account expected shocks—or purely mechanical—that is, simply uses lags of the fundamentals. If these shocks are not directly included among the regressors, such a

rule can be mistaken for a mechanical, backward-looking rule. However, when estimated as such, one implication would be a lower fit and a larger sum of squared residuals.

Thus, estimating a lag-based rule, both with and without inclusion of the expected inflation shock and comparing sums of squared residuals, should indeed demonstrate whether a cook can run the Federal Reserve or not.

In addition to that, the model implies that the coefficients for lagged inflation and expected inflation shock should satisfy a restriction imposed by equation (4)—the difference between them should be equal to 1. Testing this hypothesis would provide another way of testing whether policymaking is forward looking or not.

## B. Empirical Results

This subsection presents empirical results. Since the data that I use is quarterly, the notations are slightly different from those in the previous subsection. In particular, the newest pieces of information that are observed by policymakers are lagged quarterly inflation  $\pi_{t-1}^q$ , and lagged output gap  $y_{t-1}^q$ , measured as in Section II, on the basis of the lags-and-forecasts specification. The inflation forecast for one year ahead corresponds to the third quarter horizon forecast  $E_t \pi_{t+3}^q$ .

I start by calculating expected inflation shock variable  $E_t \varepsilon_{t+3}^q$ . I estimate the forecast Phillip's curve, analogous to equation (1), but using  $E_t \pi_{t+3}^q$  as a dependent variable, and assume that a residual term reflects expectations of the shock, which are not related to developments in lagged fundamentals.

The estimated forecast Phillip's curve is as follows:

$$E_t \pi_{t+3}^q = 1.04 \pi_{t-1}^q + 0.34 y_{t-1}^q \quad R^2=0.72. \quad (5)$$

(0.04)                      (0.08)

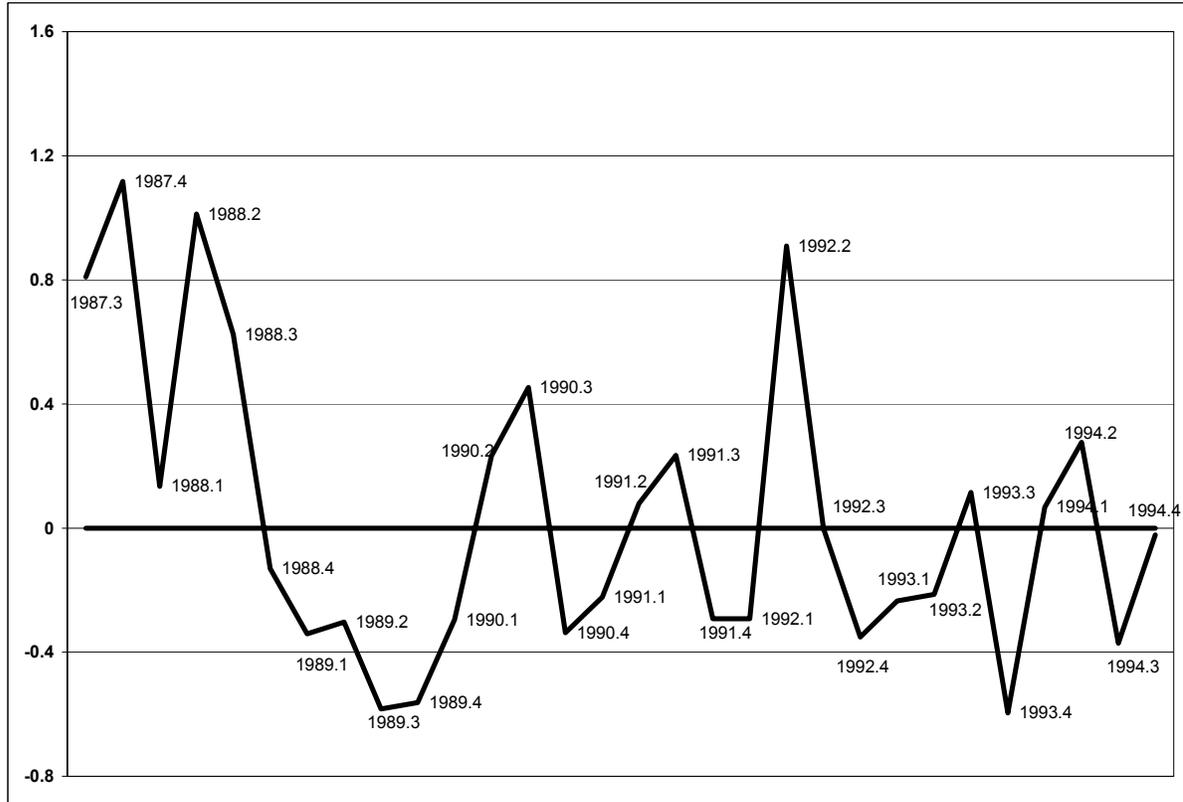
Note that the coefficient on lagged inflation is very close to 1, and that the coefficient on lagged output gap is 0.34, corresponding to a sacrifice ratio of 3 (output gap of -3 percent, in absence of shocks, causes a 1 percent decrease in inflation), which is close to the estimates reported by Mankiw (1997) and Sachs (1985), 2.8 and 2.9, respectively.

Next, I define  $E_t \varepsilon_{t+3}^q$  as the difference between actual forecasts and fitted values based on equation (5):

$$E_t \varepsilon_{t+3}^q = E_t \pi_{t+3}^q - 1.04 \pi_{t-1}^q - 0.34 y_{t-1}^q.$$

Figure 2 demonstrates the magnitude of these shocks. Most of the time, they are small, with a standard deviation of 0.48. There are, however, several points where the expected shock reaches levels of 1 percent and higher, particularly in the second half of 1987, in 1988.2, and in 1992.2. Those moments will be discussed later on, in Section IV.

Figure 2. Expected  $t+3$  Inflation Shock as of  $t$



Estimating backward- and forward-looking specifications of the rule produces the following results:<sup>8</sup>

$$i_t = -2.03 + 2.52 \pi_{t-1}^q + 1.04 y_{t-1}^q + 1.25 E_t \varepsilon_{t+3}^q \quad \text{Adj } R^2 = 0.89; \text{ SSR} = 14.94$$

(0.70)    (0.32)    (0.28)    (0.29)

$$i_t = -1.39 + 2.33 \pi_{t-1}^q + 1.02 y_{t-1}^q \quad \text{Adj } R^2 = 0.82; \text{ SSR} = 24.58.$$

(0.94)    (0.23)    (0.14)

Inclusion of the expected inflation shock does improve the results, increasing the fit and lowering the sum of squared residuals. The difference between the coefficients on lagged inflation and expected inflation shock is close to 1, as the model predicts.

The presence of the expected inflation shock in the estimated rule serves as evidence that the Federal Reserve's policy is forward looking, a factor ignored by the traditional Taylor rule. It suggests that instead of responding to events only after they have occurred, the Federal

<sup>8</sup> Standard errors in the forward-looking specification are calculated according to the methodology described in Pagan (1984) in order to account for a generated regressor  $E_t \varepsilon_{t+3}^q$ .

Reserve does take into account expected developments—the respective monetary policy is, in fact, designed to preempt rather than just react.

Note that the inflation coefficient is still estimated to be higher than the usually suggested values. In fact, Orphanides (1998a) reports an almost identical coefficient of 2.51 when substituting inflation and output gap forecasts for the third quarter horizon into the rule.

Estimates of the response parameters can also be used to estimate implied values for the real interest rate and inflation targets. Tchaidze (2001) calculates these according to the following formulas:

$$\hat{\pi}^* = \frac{r^* - \hat{C}}{\hat{C}_\pi} \quad \text{and} \quad \hat{r}^* = \hat{C} + \hat{C}_\pi \hat{\pi}^*,$$

where  $\hat{C}$  and  $\hat{C}_\pi$  are estimates of the constant and the inflation response corresponding to the Taylor rule.

An assumption about one of the targets allows us to calculate the value for the other. Taylor (1993) suggests a 2 percent target for both variables. Judd and Rudebusch (1998) argue that under certain circumstances average values may signal policymakers' intentions.

Assuming  $\hat{r}^*$  at a 2.00 level suggests  $\hat{\pi}^*$  equal to 3.22, while assuming  $\hat{\pi}^*$  equal to the sample's average<sup>9</sup> of 2.48 suggests  $\hat{r}^*$  equal to 3.61.

Likewise, assuming  $\hat{\pi}^*$  to be equal to 2.00 produces  $\hat{r}^*$  of 0.47, which is unrealistically low. At the same time, assuming  $\hat{r}^*$  to be equal to the sample's average of 3.48 results in  $\hat{\pi}^*$  equal to 2.32.

These calculations suggest that, although assumption of a real interest rate target of 2.0-2.3 percent may seem sensible, an appropriate value for the inflation would be much higher, at around 3.2–3.5 percent. That transforms into a 5.2–5.8 percent target for the nominal interest rate, while an average over the sample is 5.97 percent.

#### IV. HISTORICAL EVIDENCE

In this section I present some evidence from various historical records. These are consistent with my estimates of expected shocks and confirm the behavior of the Federal Reserve suggested by the results of the previous section.

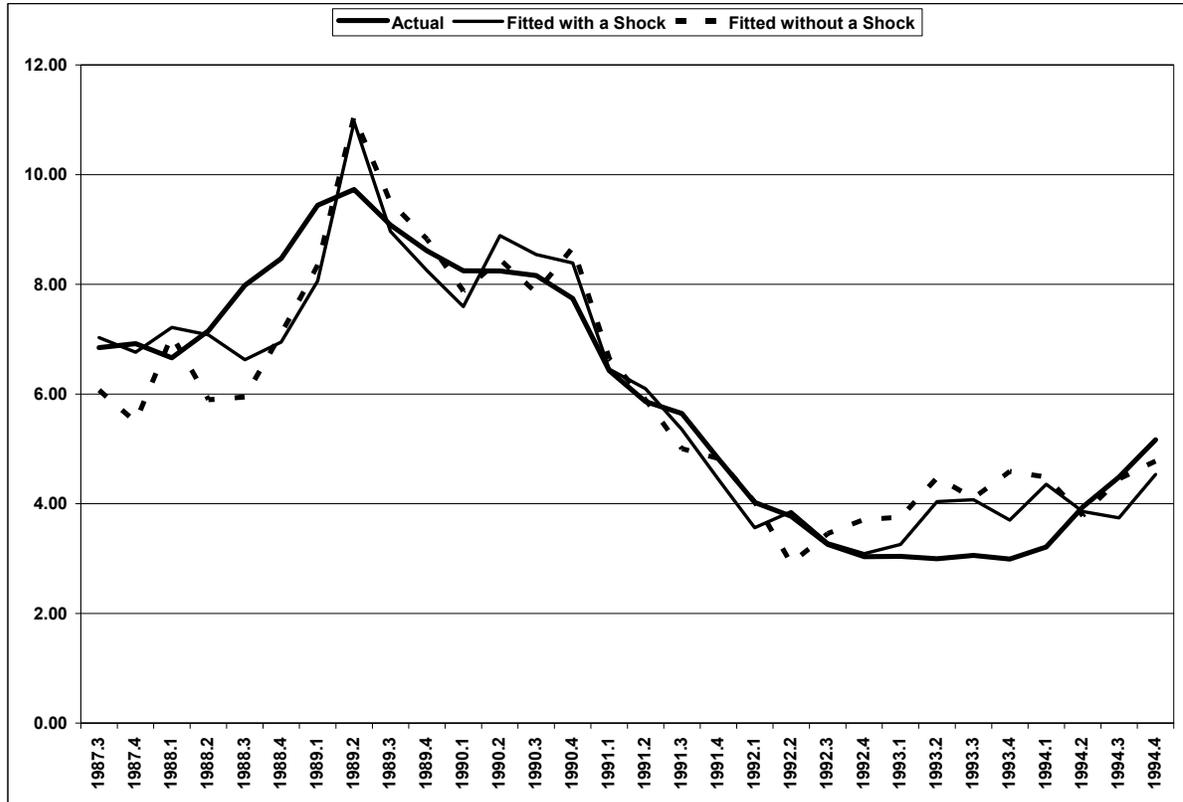
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<sup>9</sup> Average inflation and real interest rate are calculated using revised data.

### A. Expected Inflation Shocks

Figure 3 shows the actual path for the federal funds rate as well as the fitted values based on the regressions with and without inflation shock included among the regressors. Most of the time, the difference between the two fitted series is not large, although inclusion of the shock seems to bring the series suggested by the rule closer to the actual path.

Figure 3. Federal Funds Rate: Actual and Fitted Values



There are, however, several points where there is a substantial difference (about 1 percent and even more) between the backward-looking rule and the actual path of the interest rate, whereas the difference between the forward-looking rule and the actual path is much lower. These divergences are caused by the high values of expected inflation shock (see Figure 2).

In particular, notice the difference between the two rules in 1987:Q3 and 1987:Q4, when the values suggested by the backward rule are 6.07 percent and 5.49 percent respectively; corresponding values for the forward-looking rule are 7.03 percent and 6.76 percent, and the actual values are 6.84 percent and 6.92 percent. Such a difference arises from a sharp increase in inflationary expectations. The 1988 *Economic Report of the President* (see Council of Economic Advisers) cites a “potential for greater inflation, associated in part with weakness of the dollar” and in part with the flaring up inflation expectations as the basis for such tightening (*ERP*, 1988, p. 38). The *ERP* explicitly points out that such policy was desirable in order to avoid inevitable inflationary expectations: “With output growth

apparently well-maintained and inflation expectations building at times, the Federal Reserve acted to forestall a resurgence of deep-rooted inflation and to retain hard-won gains towards price stability” (*ERP*, 1988, pp. 39).

Less than a year later, in 1988:Q2 and 1988:Q3, there was another peak in expected inflation shock, which causes another divergence between the two rules. This peak reflects upward pressure created by the excessive liquidity pumped into the economy following the October 1987 stock market crash. Later on, the Federal Reserve had to reverse its policy and tighten as it became “evident that the stock market crash would not seriously affect spending growth” (*ERP*, 1989, p. 280).

Finally, the last peak in inflation expectations of 1992:Q2 seems to reflect a producer price inflation rebound, unusually low throughout 1991 as a result of declining oil prices from their peak during the Middle East conflict in 1990:Q3 (*ERP*, 1993, p. 47).

### **B. Expected Output Gap Shocks: The Last Piece of a Puzzle?**

As Figure 3 shows, the inclusion of the expected inflation shock does not explain all of the movements of the federal funds rate. In particular, from 1988:Q3 through 1989:Q1, the actual monetary policy was much tighter than the rule suggests (the differences are 1.36 percent, 1.52 percent and 1.38 percent), while in 1989:Q2 and from 1993:Q2 through 1994:Q1, the rule prescribes an interest rate about 1 percent higher than actual.

As equation (4) suggests, the difference may be explained by expected output gap shocks. As discussed earlier, these could not be retrieved from the Greenbook forecasts, and thus are omitted from empirical estimations. However, equation (4) suggests that residuals from the estimation of the forward-looking specification of the rule (as in Section III) are proportional to the expected output gap shock, as they are given by  $\beta^{-1}E_t\eta_{t+3}^q$ , where  $\beta$  is a parameter of the IS curve (2) that reflects the sensitivity of output gap with respect to changes in real interest rate. Ball (1999) uses  $\beta = 1$  in his calibrations.

I define

$$\beta^{-1}E_t\eta_{t+3}^q = i_t - (-2.03 + 2.52\pi_{t-1}^q + 1.04y_{t-1}^q + 1.25E_t\varepsilon_{t+3}^q)$$

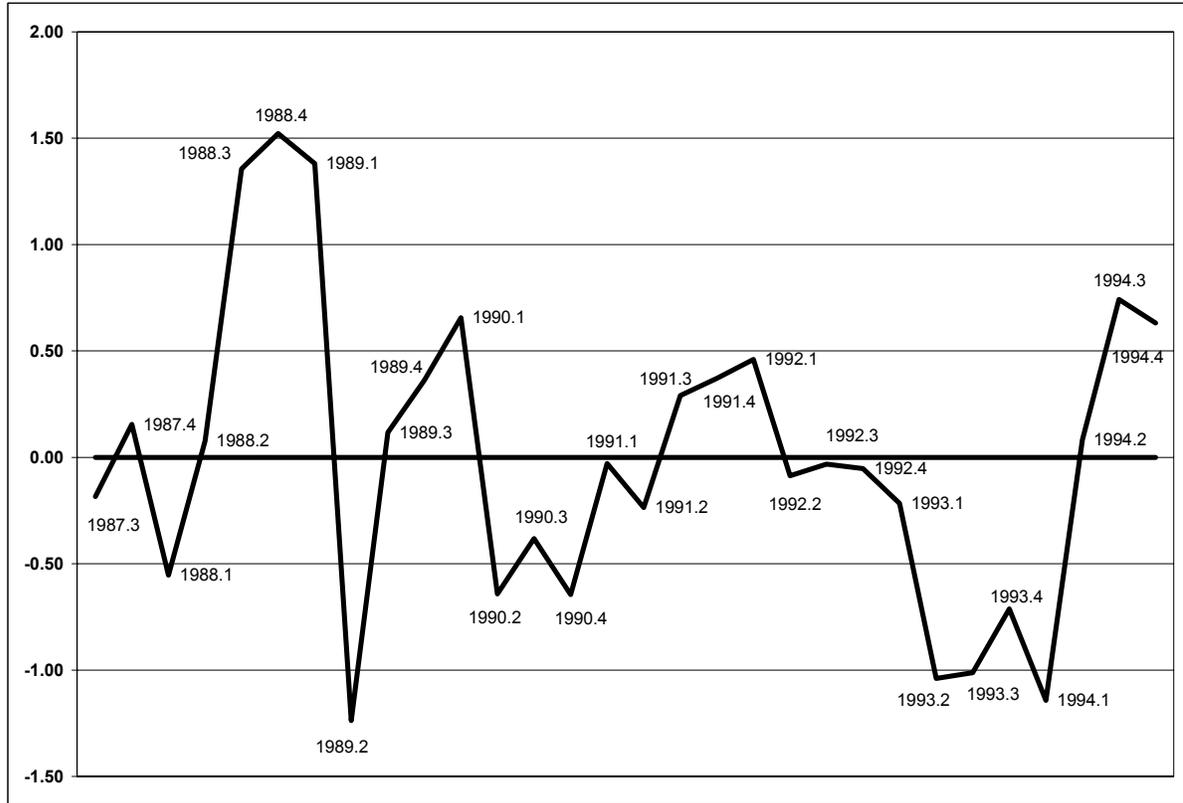
and plot this variable on Figure 4.

A much tighter policy than that suggested by the rule from 1988:Q3 through 1989:Q1 is translated into an excess demand, which is confirmed by the *Economic Report of the President* (1989, p. 275), which cites unusually rapid growth in producers' investments in durable equipment and in the dollar's real depreciation, which made U.S.–produced goods more competitive on the international markets.

Likewise, Figure 4 suggests expected declines in output in 1989:Q2 and from 1993:Q2 through 1994:Q1, for which the rule prescribes an interest rate about 1 percent higher than actual. I could not find, however, explicit confirmations of such beliefs, which means that

other factors (such as, for example, exogenous shifts in policymakers' preferences) may have been at play.

Figure 4. Expected  $t+3$  Output Gap “Shock” as of  $t$



### V. HOW “TOUGH” WAS PAUL VOLCKER?<sup>10</sup>

Section III estimates the Taylor rule for the 1987–1994 period and finds an inflation response of 2.5 and output gap response of 1.0. At the same time, subjecting the period of Paul Volcker's chairmanship (1979:Q3–1987:Q2) to a similar exercise produces values indicative of a rather passive monetary policy. This section aims to rehabilitate Volcker by suggesting the misspecification of a Taylor rule, which assumes a constant inflation target, as a possible explanation.

As discussed in the first part of Section III, the Taylor rule assumes that policymakers, having in mind some targets for real interest rate and inflation ( $r^*$  and  $\pi^*$  correspondingly), adjust nominal interest rate  $i_t$  every time the output gap  $y_{t-1}$  is nonzero or inflation  $\pi_{t-1}$  is above or below  $\pi^*$ :

<sup>10</sup> Solely for the purpose of brevity, I “identify” the monetary policy of the Federal Reserve with the chairman of its Board. The proper title for this section would have been “How tough was the Federal Reserve during the chairmanship of Paul Volcker?”

$$\begin{aligned} i_t &= r^* + \pi_{t-1} + C_\pi (\pi_{t-1} - \pi^*) + C_y y_{t-1} + \varepsilon_t \quad \text{and} \\ i_t &= (r^* - C_\pi \pi^*) + (1 + C_\pi) \pi_{t-1} + C_y y_{t-1} + \varepsilon_t, \end{aligned} \quad (6)$$

where  $C_\pi$  and  $C_y$  reflect the relative weights policymakers assign to inflation and output gap variances, and  $\varepsilon_t$  reflects all other considerations policymakers have in mind, such as expected shocks to output gap and inflation. The rule is based on lagged fundamentals, as contemporaneous fundamentals have not yet been realized and lagged observations are the most up-to-date pieces of information available to policymakers.

Such a specification suggests that an intercept obtained from regressing nominal interest rate  $i_t$  on lagged inflation  $\pi_{t-1}$  and output gap  $y_{t-1}$  reflects the real interest rate and inflation targets, both of which are assumed to be constant.

It is exactly here where we find the possibility of a misspecification. When Paul Volcker assumed office, inflation was slightly lower than 9 percent. It reached 10 percent in early 1981 and then fell to 2.3 percent in 1986, after which it slightly rose again. Assuming a constant inflation target means assuming very high inflation gaps  $\pi_{t-1} - \pi^*$ . As (6) suggests, this would produce a small inflation response coefficient  $C_\pi$ . Indeed, estimating such a rule produces the following outcome (HAC standard errors in parentheses):

$$i_t = 4.23 + 1.13 \pi_{t-1} + 0.15 y_{t-1} \quad R^2 = 0.77. \quad (7)$$

(0.72)    (0.11)    (0.19)

The inflation response is roughly equal to 1, while the output gap response is roughly 0, which means that real interest rate is hardly responding to movements in fundamentals at all, being set equal to 4.23. Such interpretation of the monetary policy, however, does not match Volcker's reputation as an inflation hawk.

It seems, however, more plausible to assume a time-varying, decreasing inflation target  $\pi^*$ . This would produce smaller inflation gaps, and thus probably a higher inflation response.

One possible way to address this issue would be to assume a decreasing function in place of  $\pi^*$  and reestimate the rule. That implies a certain degree of arbitrariness, however, and cannot possibly be accurate. Hence, I use an alternative. In particular, I assume that Paul Volcker was as “tough” as Alan Greenspan<sup>11</sup> (that is, his inflation and output gap response coefficients were 2.5 and 1.0 as well), and calculate a time-varying intercept, which is needed to justify the observed path of the interest rate.

Formally, note that equation (6) can be rewritten as

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<sup>11</sup> See previous footnote.

$$\frac{i_t - (1 + C_\pi)\pi_{t-1} - C_y y_{t-1}}{-C_\pi} = \pi_{t-1}^* + \frac{r^* + \varepsilon_t}{-C_\pi}. \quad (8)$$

Next, I define  $V_t$  as

$$V_t = \frac{i_t - 2.5\pi_{t-1} - 1.0y_{t-1}}{-1.5}.$$

If Volcker was following exactly the same rule as Greenspan, but had in mind a time-varying inflation target, then according to (8),  $V_t$  is equal to  $\pi_{t-1}^* - (r^* + \varepsilon_t)/1.5$  and oscillates around a negatively sloped trend. Oscillations that cannot be identified precisely for reasons explained earlier are caused by  $\varepsilon_t$ . I assume however, that on average they are zero, and thus  $V_t$  has a trend which is different from  $\pi_{t-1}^*$  only by a constant, equal to  $-r^*/1.5$ .

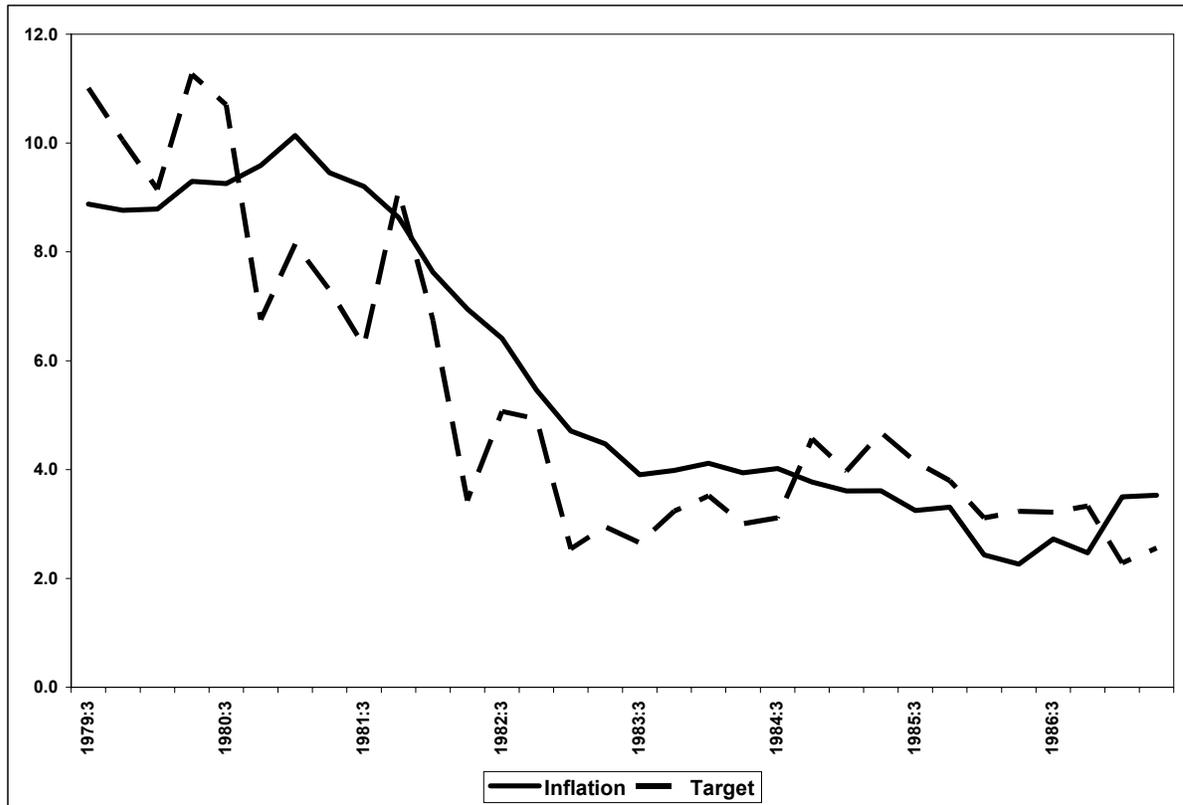
Assuming that Volcker achieved his goal by the end of his term would allow us to calculate  $r^*$ . To do this, we need to find  $r^*$  such that  $\pi_t^*$  and  $\pi_t$  move around the same trend at the end of the sample. Deviations of  $\pi_t^*$  from such a trend would be due to the presence of  $\varepsilon_t$ , while deviations of  $\pi_t$  would be due to unexpected shocks that have hit the economy.

Figure 5 plots  $\pi_t^*$  calculated from  $V_t$  with  $r^*$  assumed to be equal to 4.32, the value which equalizes average  $\pi_t$  and  $\pi_t^*$  for the 1983:Q3–1987:Q2 period. We can see that indeed  $\pi_t^*$  has a decreasing trend as well as  $\pi_t$ . More than that, there is a clear break in both variables around mid-1983, when they start to move around a flatter trend.

The inflation gap, defined as  $\pi_t - \pi_t^*$ , ranges from -2.09 to 3.56, with a mean of 0.44 and standard deviation of 1.47. However, after 1983:Q3 it does not become larger than 1.25 percent in absolute value (the mean is 0.06; standard deviation, 0.89). Had it been possible to calculate  $\varepsilon_t$  precisely, the inflation gap might have been even smaller.

Although this exercise should not be interpreted as proving that Volcker was following the same policy rule as Greenspan, it does suggest that an aggressive monetary policy with high response coefficients similar to one found for the Greenspan-era Federal Reserve but with a time-varying inflation target, can potentially be mistaken for a “passive” policy with a constant inflation target.

Figure 5. Actual Inflation and Implied Inflation Target During Volcker's Tenure



## VI. CONCLUSION

This study incorporates information contained in the Greenbook forecasts into evaluating the Greenspan-era Taylor rule. This is done in two ways.

First, forecasts help to improve the estimates of policymakers' real-time beliefs about the state of the economy. Second, they allow the retrieval of the Federal Reserve's expectations concerning future inflationary developments.

These expectations are significantly present in the Taylor rule, which indicates that monetary policymaking is not as myopic as might be inferred from a class of simple backward-looking policy rules. Apart from responding to inertial components of fundamentals, such as inflation and output gap, the Federal Reserve takes into account future inflation shocks in a way consistent with the optimal behavior suggested by a simple two-equation model.

Together, these three variables explain about 90 percent of the movements in the Federal Funds Rate. The remaining 10 percent may represent expected output gap shocks, which could not be recovered from the Greenbook forecasts.

This paper confirms the hawkishness of the Greenspan-era Federal Reserve. This is reflected in the inflation response coefficient of 2.5, which is much higher than the usually suggested values.

Finally, it also demonstrates that a simple Taylor rule may be a misspecification if policymakers have in mind a time-varying inflation target. Such a misspecification might explain the seeming passivity of monetary policy during Paul Volcker's chairmanship term as suggested by a simple Taylor rule.

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