Inflation Persistence and the Taylor Principle

Christian J. Murray
University of Houston

Alex Nikolsko-Rzhevskyy
University of Memphis

David H. Papell
University of Houston

June 25, 2009

Abstract

Although the persistence of inflation is a central concern of macroeconomics, there is no consensus regarding whether inflation is stationary or has a unit root. In the context of a "textbook" macroeconomic model, inflation is stationary if the Taylor principle is satisfied. We estimate Markov switching models for inflation and real-time forward-looking Taylor rules. Inflation appears to have a unit root for most of 1967 – 1981, but is stationary before and afterwards. The response to inflation is also regime dependent, with the pre and post-Volcker samples containing monetary regimes where the Fed did and did not follow the Taylor principle.

Correspondence:

Department of Economics, University of Houston, Houston, TX 77204-5019
Chris Murray, Tel: (713) 743-3835, Fax: (713) 743-3798, e-mail: cmurray@mail.uh.edu
Alex Nikolsko-Rzhevskyy, Tel: (832) 858-2187, e-mail: alex.rzhevskyy@gmail.com
David Papell, Tel: (713) 743-3807, Fax: (713) 743-3798, e-mail: dpapell@uh.edu

We thank seminar participants at the University of Alabama, University of Cincinnati, University of Washington, the Federal Reserve Bank of Dallas, the Federal Reserve Bank of St. Louis, Texas Econometrics Camp XI, and the 14th Annual Symposium of the SNDE. We are grateful to Dean Croushore, Athanasios Orphanides and Glenn Rudebusch for providing their data.

1. Introduction

The persistence of inflation is a central concern of macroeconomics. In the New Keynesian macroeconomic model, with Taylor (1979) being among the earliest and best known examples, there is no tradeoff between the *level* of unemployment and the *level* of inflation, but there is a tradeoff between the *variability* of unemployment and the *persistence* of inflation.

The standard way to measure persistence in economic time series is through the autoregressive/unit root model. If the unit root null hypothesis can be rejected in favor of the alternative hypothesis of level stationarity, shocks will eventually dissipate and the series will revert to its equilibrium level. Conversely, if the unit root null cannot be rejected, shocks are permanent and the series never returns to its original value.

What do we know about unit roots and inflation? The answer is, not much. There have been a number of studies that test for unit roots in inflation, and the results are all over the map. In some of the studies, the unit root null is rejected in favor of the alternative of stationarity. In others, the unit root null cannot be rejected. In still others, the null can be rejected for some time periods, but not for others. Furthermore, there does not appear to be a clear pattern involving either time periods or techniques that accounts for the variety of results.

What could account for these inconclusive results? One possibility, of course, is that inflation is close enough to having a unit root that existent statistical techniques cannot conclusively answer the question. In that case, the answer itself becomes uninteresting. Whether inflation is stationary with an autoregressive coefficient of 0.999 or a unit root with a coefficient of 1.0 does not make any difference for the study of persistence over any economically relevant time horizon.

The purpose of this paper is to investigate a different, and potentially more interesting, hypothesis. Suppose that inflation is stationary during some time periods and follows a unit root during others. In particular, we will investigate the hypothesis that inflation switches regimes between stationary and unit root states. This would certainly be consistent with inconclusive results from the application of unit root tests.

The hypothesis of regime switching between stationary and unit root states seems problematic for most macroeconomic variables. The choice between stationarity and unit root behavior for real GDP is related to the predictions of various macroeconomic models, and it is difficult to see why the economy would follow one model during some regimes and a different model during others. While it is sometimes postulated that real exchange rates follow some variant of a threshold autoregressive process and exhibit unit root behavior for small deviations from parity and stationary behavior for large deviations from parity, this is based on arbitrage arguments do not seem applicable to inflation. Unit roots in financial variables such as nominal interest rates and nominal exchange rates are often justified based on information acquisition in markets, and it is difficult to see how these would be subject to regime switches across time.

The main idea that underlies this paper is that inflation is a policy variable for which regime switching between stationary and unit root states emerges as a natural outcome of a standard macroeconomic model. In the context of a "textbook" model with an IS curve, a Phillips curve, and a Taylor rule, inflation will be stationary if and only if the central bank follows the Taylor principle and raises the nominal interest rate more than point-for-point when inflation exceeds the target inflation rate, so that the real interest rate rises. We investigate whether periods for which inflation is stationary (contains a unit root) correspond to periods for which the Taylor principle is satisfied (not satisfied).[1]

This idea is closely related to research on the Taylor principle and indeterminacy of inflation. Clarida, Gali, and Gertler (2000) and Woodford (2008) show how, in the context of a New Keynesian dynamic stochastic general equilibrium (DSGE) model, a rise in expected inflation will lead to a decline in the real interest rate, stimulate aggregate demand, and become self-fulfilling if (approximately) the coefficient on the inflation gap in the Taylor rule is below unity. We focus on a unit root in inflation because, while the unit root hypothesis is testable, indeterminacy can only be inferred.

The first hypothesis of the paper is that inflation can be characterized by regime switching between stationary and unit root states. We estimate a Markov switching model for quarterly U.S. inflation from 1954:3 to 2007:1. We find that there are two distinct inflationary regimes, one in which inflation has a unit root, and one in which inflationary shocks are transitory. The estimated dates for the unit root state are most of the 1967:3 – 1981:1 period, during which U.S. inflation experienced its highest levels. Beginning in 1981:2, when disinflation began, we estimate that the inflation rate is mean reverting.

The second hypothesis is that the regime switches in inflation can be explained by changes in the parameters of the Taylor rule. While there is an extensive literature on whether or not the Taylor principle holds during different periods, the choice of sub-samples is typically made exogenously, usually to correspond with the tenure of various Federal Reserve Chairmen. Taylor (1999) estimates rules over the 1960:1 – 1979:4 (pre-Volcker) and 1987:1 – 1997:3 (Greenspan) periods, and finds that the coefficient on inflation is greater than unity, so that the Taylor principle holds, only in the latter period. Clarida, Gali, and Gertler (2000) divide their sample into the 1960:1 – 1979:2 (pre-Volcker) and 1979:3 – 1996:4 (Volcker-Greenspan) periods, and also find that the Taylor principle holds only in the latter period. Their results are robust to various measures of the output gap and to excluding the first three years of the Volcker regime.[2]

---

[1] In the context of a forward looking New Keynesian Phillips Curve, Cogley and Sbordone (2008) hypothesize that inflation persistence stems from changes in trend inflation, which they attribute to changes in monetary policy.

[2] Favero and Monacelli (2005), estimate two-state Markov switching models for the pre-Volcker (1961:3 – 1979:2) and Volcker-Greenspan (1982:2 – 2002:4) periods. While they find evidence of two monetary regimes in each

While the initial research on Taylor rule estimation used revised data, following the work of Orphanides (2001) it has become standard practice to use real-time data that was available to policymakers at the time that interest-rate-setting decisions were made. Orphanides (2004), using real-time data, estimates Taylor rules for the 1965:4 – 1979:2 (pre-Volcker) and 1979:3 – 1995:4 (Volcker-Greenspan) periods. In contrast to earlier research with revised data, he finds that there was no significant difference in the interest rate response to inflation between the pre-Volcker and Volcker-Greenspan periods, with the Taylor principle being satisfied during both periods. In addition, he finds that the interest rate responded to the output gap during the Pre-Volcker, but not the Volcker-Greenspan, periods.

Changes in the degree of monetary policy activism have also been studied by Cogley and Sargent (2001, 2005), Primiceri (2005), and Sims and Zha (2006) using Bayesian structural vector autoregressive models with time-varying coefficients. While Cogley and Sargent (2001) find that monetary policy was activist in the early 1960s, became neutral in the early 1970s, stayed passive for the remainder of the 1970s, and was activist from the early 1980s onward, Sims and Zha find that time variation in the variances of the disturbances is more important than time variation in the coefficients of the monetary policy rule. However, when Cogley and Sargent (2005) allow for heteroskedasticity, they still find important changes in monetary policy. Levin and Piger (2008), using Bayesian model selection in modeling the persistence of inflation, find that models with changes only in residual variance are dominated by models with changes in conditional mean parameters. Primiceri (2005) finds evidence of higher volatility of monetary policy shocks before 1983 and that systematic monetary policy has become more responsive to inflation and unemployment during the last 20 years relative to the 1960s and 1970s. The Taylor principle, however, is not violated in either period. Lubik and Schorfheide (2004) use a Bayesian approach to estimate a New Keynesian DSGE model. They find that, while monetary policy reacted very aggressively towards inflation during the Volcker-Greenspan period, it was much less active during the pre-Volcker period. They cannot reject the possibility of equilibrium indeterminacy for the earlier period.

We estimate a Markov switching model for a forward looking Taylor rule, utilizing various real-time inflation forecasts and measures of the output gap. We find evidence of two separate regimes, where the Fed follows the Taylor principle in one state, but not the other. The estimated dates for the Taylor principle state are 1965:4 – 1972:4, 1975:2 – 1979:3, and 1985:4 – 2007:1. The dates for which monetary policy is stabilizing, so that the Taylor rule obeys the Taylor principle, correspond fairly closely with the dates for which inflation is characterized by a stationary state. Conversely, the dates for which monetary policy is not stabilizing correspond fairly closely with the dates for which inflation is characterized by a

---

period, the Taylor principle is satisfied in neither state for the pre-Volcker period and in one of the states for the Volcker-Greenspan period.

unit root state. In addition, the coefficient on the output gap is only significant in the stable Taylor rule state.

The period between 1981 and 1985, however, is an exception to the correspondence, as inflation is characterized by a stationary state but the Taylor principle is not satisfied. During this period of rapidly falling inflation, the Federal Reserve operating procedures involved targeting non-borrowed reserves rather than the Federal Funds Rate.[3] When inflation fell, the Federal Funds rate did not fall by enough to satisfy the Taylor principle so that, as shown by Taylor (1999), the Federal Funds rate was too high compared with the baseline of a Taylor (1993) rule. In contrast to the "textbook" example where the Taylor principle does not hold because policy is too accommodative, the Taylor principle did not hold during this period because policy was too restrictive.

Another seemingly anomalous result is that, with the exception of 1973 and 1974, the Taylor principle held during almost all of the Great Inflation. Levin and Taylor (2009), using data on *ex ante* real interest rates, characterize monetary policy from 1965 to 1980 as a series of stop-start episodes of rising inflation, belated policy tightening, and contracting economic activity which causes a reversal of the policy tightening before inflation returns to its initial rate. Estimating a Taylor rule with shifts in the intercept in 1970:2 and 1976:1 to allow for increases in the Fed's implicit inflation objective, they find that the Taylor principle held during the 1965:1 – 1980:3 period.

A major theme of this paper is that, by using Markov switching methods, we are able to choose policy regimes endogenously rather than impose regimes exogenously based on different Federal Reserve chairmanships. A direct comparison of our results is with Orphanides (2004) who, using real-time data, finds that the Taylor principle held in both the Pre-Volcker and the Volcker-Greenspan periods. When the break date is endogenized, each of Orphanides' regimes contains periods where the Fed both followed and did not follow the Taylor principle. Another comparison is with Boivin (2006), who uses real-time data to estimate a forward-looking Taylor rule with time-varying coefficients.[4] He finds that the Fed's response to forecasted inflation was strong until 1974, fell in the second half of the 1970s (perhaps not satisfying the Taylor principle), and strengthened between 1980 and 1982. The response to real economic activity weakened throughout the 1970s and, from the mid-1980s on, responded strongly to inflation and weakly to real activity. While our regimes do not correspond exactly with his time-varying coefficients, our results on the monetary policy response to inflation are much more congruent with Boivin (2006) than with Orphanides (2004), who finds that the Taylor principle has held consistently since 1965. Our results on the monetary policy response to real economic activity, in contrast, accord with neither Orphanides (2004) nor Boivin (2006).

---

[3] See Goodfriend (2007) for further discussion.

[4] Kim and Nelson (2006) and Kim, Kishor, and Nelson (2007) also estimate time-varying parameters models with revised and real time data, respectively.

2. The Uncertain Unit Root in Inflation

There is a large literature that investigates unit roots in inflation. The Appendix summarizes the evolution of ideas about the stationarity of inflation in the empirical literature during the last three decades. While Nelson and Schwert (1977) and Barsky (1987) find evidence supporting the presence of a unit root in inflation, Rose (1988) rejects the unit root hypothesis and Neusser (1991) presents evidence, consistent with the stationarity of inflation, that the ex-post real interest rate is stationary. Baillie et al. (1996) find strong evidence of long memory with mean reverting behavior while Culver and Papell (1997) reject the unit root using panel, but not univariate, methods. More recently, Bai and Ng (2001) and Henry and Shields (2003) cannot reject the unit root null for the U.S. inflation rate.

A number of studies (endogenously or exogenously) divide the series into sub-samples and examine their properties. For example, McCulloch and Stec (2000) argue that a unit root process governs the U.S. inflation series from the mid 1970's to the mid 1980's; before and after that time period, the U.S. inflation series is nearly stationary. Barsky (1987) divides the time span into two periods and shows that inflation was stationary until 1960 and became integrated thereafter. Brunner and Hess (1993) arrive at the same conclusion by also having 1960 as a threshold year. Ireland (1999) and Stock and Watson (1999) report some rejections of the unit root null, but only at the 10% level for some sub-samples. Evans and Wachtel (1993) estimate a Markov Switching model of inflation, with one state non-stationary by construction. They find that inflation is I(1) during 1965 – 1985 and I(0) otherwise.

Levin and Piger (2003) estimate a univariate autoregressive model of inflation dynamics applying both classical and Bayesian econometric methods, while allowing for a structural break at an unknown date. They find strong evidence for a break in the intercept of the AR equation around 1991.2. Allowing for a break in intercept, the inflation measures generally exhibit relatively low inflation persistence, rejecting the unit root for all measures of inflation.

Pivetta and Reis (2007) look at a quarterly series of inflation since 1965 and conclude that persistence is constant and relatively high. Using various classical and Bayesian methods with several different measures of persistence, they are unable to reject the unit root. Benati (2008) comes to the same conclusion looking at GDP and PCE inflations after 1951. The author estimates an AR (p) model via the Hansen (1999) 'grid bootstrap' median-unbiased estimator of the sum of the autoregressive coefficients.

While the empirical literature on inflation is large, it is not conclusive. The overall impression is that the question of whether U.S. inflation contains a unit root or is stationary has not been answered, and is unlikely to be answered by the application of more unit root tests.

3. The Taylor Rule and Inflation

In this section, we construct a "textbook" macroeconomic model consisting of an IS curve, a Taylor rule, and a Phillips curve and show that inflation has a unit root if and only if the Taylor rule follows the Taylor principle.[5] Following Taylor (1993), the monetary policy rule postulated to be followed by the Fed is

$$r_t^* = \pi_t + \delta(\pi_t - \pi^*) + \omega\hat{y}_t + R^* \tag{1}$$

where r_t^* is the short-term nominal interest rate target (Federal Funds Rate), π_t is the inflation rate, π^* is the target level of inflation (usually considered equal to 2%), $\hat{y}_t$ is the percentage deviation of output from its long run trend (the output gap), and R^* is the equilibrium level of the real interest rate (also usually considered equal to 2%).

According to the Taylor rule, the Fed raises the nominal interest rate if inflation rises above its target and/or if output is above potential output, and lowers the nominal interest rate if inflation falls below its target and/or if output is below potential output. The target level of output deviation from long run trend $\hat{y}_t$ is 0 because, according to the natural rate hypothesis, output cannot be permanently raised above potential. The target level for inflation is positive because it is generally believed that deflation is much worse for an economy than low inflation. According to what has become known as the "Goldilocks Economy" (not too hot, not too cold, but just right), if inflation equals its target of 2% and the output gap is zero, the nominal interest rate would be 4%, the inflation rate would be 2%, and the real interest rate would be 2%.

The parameters π^* and R^* can be combined into one constant term, which leads to the following equation,

$$r_t^* = \mu + (1+\delta)\pi_t + \omega\hat{y}_t \tag{2}$$

The condition $(1+\delta) > 1$, known as the Taylor principle, states that, when inflation rises above target, the Fed raises the nominal interest rate by more than point-for-point, so that the real interest rate rises. This has been emphasized by Taylor as the crucial condition for economic stability. Two aspects of the Taylor principle are worth noting. First, according to Taylor's (1993) original formulation, $\delta = \omega = 0.5$, so that the Taylor principle was automatically satisfied by the Taylor rule. Second, as emphasized by Greenspan (2004), the Taylor principle is essential to the conduct of monetary policy independently of the specific form of the Taylor rule. Suppose that ω was equal to zero, so that the Fed only responded to inflation and not to the output gap. The condition for the Taylor principle would be unchanged.

[5] To our knowledge, the first textbook to present this "textbook" model was Hall and Taylor (1997).

The textbook macro model is completed by adding an IS curve,

$$\hat{y}_t = -\sigma(R_t - R^*), \tag{3}$$

where the output gap depends negatively on the difference between the real interest rate and the equilibrium real interest rate, and a "textbook" Phillips curve,

$$\pi_t = \pi_{t-1} + \lambda \hat{y}_t + \varepsilon_t \tag{4}$$

where inflation is above last period's inflation if the output gap is positive and below last period's inflation if the output gap is negative.[6]

Consider the following thought experiment. Start with inflation equal to its target level and the output gap equal to zero. Now suppose there is a positive shock to inflation. If the Taylor principle is satisfied, the Fed would raise the nominal interest rate in Equation (2) more than point-for-point, increasing the real interest rate. The increase in the real interest rate will lead to a negative output gap by the IS curve (3) and, in turn, to a decrease in inflation by the Phillips curve (4). The process will continue until inflation returned to its original, target, level. Since there is no long-run effect of the shock, inflation is stationary if the Taylor principle is satisfied.

Now consider the same shock to inflation if the Taylor principle is not satisfied. Suppose that $\delta = 0$. In this case, the Fed would raise the nominal interest rate in (2) exactly point-for-point, leaving the real interest rate unchanged. With an unchanged real interest rate, the output gap in (3) would stay at 0 and inflation in (4) would not be brought down. Since the effect of the shock never dissipates, inflation has a unit root if the Taylor principle is not satisfied.

The exact correspondence between stationary inflation and the Taylor principle does not necessarily generalize beyond the textbook version of the model. In the New Keynesian models of Clarida, Gali, and Gertler (2000) and Woodford (2008), among others, which consist of an aggregate supply relation, an intertemporal IS relation, and a Taylor rule, the condition for a determinate solution becomes more complicated if there is a systematic response of the interest rate to output variations. Clarida, Gali, and Gertler (2000), however, argue that the deviation is quantitatively almost negligible. In Woodford (2008), the correspondence is unchanged unless, in addition to an interest rate response to output variations, inflation does not respond one-for-one to changes in expected inflation. Davig and Leeper (2007) generalize the Taylor principle in the context of a model where the coefficients of the monetary policy rule evolve according to a Markov switching process. They show that policy can produce determinate rational expectations equilibrium even if there are substantial deviations from the Taylor principle for short periods or modest deviations for prolonged periods.

[6] The history of various types of Phillips curves id discussed in Gordon (2009). Additional lags of inflation can be added as long as they sum to unity.

4. A Markov Switching Model for Inflation

We first showed that the preponderance of empirical evidence does not support either stationarity or unit root behavior for the full sample of U.S. inflation. We then demonstrated that the hypothesis that inflation switches between stationary and unit root states is consistent with a "textbook" macro model if the policy followed by the Fed switches between following and ignoring the Taylor principle. We will now investigate whether the behavior of inflation is consistent with switching between stationary and unit root states.

To capture a possible switch in inflation persistence, we estimate a two state Markov Switching autoregressive model for the ex post inflation rate. Since we are focusing on persistence, we estimate an Augmented Dickey-Fuller representation with *k* lags, which is equivalent to an AR(k-1) model. The ADF specification is attractive since the sum of the AR coefficients minus one enters as the coefficient on lagged inflation:

$$\Delta\pi_t = \mu_{s_t} + \gamma_{s_t}\pi_{t-1} + \sum_{i=1}^{k}\psi_{s_t,i}\Delta\pi_{t-i} + \varepsilon_t \tag{5}$$

The main parameter of interest is γ_{S_t}. A negative and significant value of γ_{S_t} would imply a stationary inflation rate, while a value of zero would imply that inflation contains a unit root. The unobserved state variable takes on the values zero or one: $S_t = \{0,1\}$. We specify Gaussian innovations, with state dependent variances,

$$\varepsilon_t \sim N(0,\sigma_S^2),$$

where the unobserved state variable is governed by the following transition probabilities:

$$\Pr[S_t = 0 \mid S_{t-1} = 0] = q$$

$$\Pr[S_t = 1 \mid S_{t-1} = 1] = p.$$

To measure inflation, we use the ex post GDP deflator.[7] Our sample runs from 1954:3 – 2007:1. We maximize the exact log likelihood function using Hamilton's (1989) algorithm.

We choose an AR(2) model for inflation, which corresponds to $k = 1$ in equation (5). We also estimated AR(1) through AR(5) models as a robustness check. The residuals from the AR(1) model display significant autocorrelation, while the results of higher order AR models are similar to those of the AR(2) model.

---

[7] Specifically, we calculate inflation as the difference between the quarterly seasonally adjusted annual rates of "GDP percent change based on current dollars" and "GDP percent change based on chained 2000 dollars" available from the BEA website at http://bea.gov/bea/dn/gdpchg.xls

Our parameter estimates are presented in Table 1. The top panel of Figure 1 plots the inflation rate, with the shaded areas corresponding to $S_t = 0$.[8] Our estimates suggest that there are two persistent states of inflation. State zero occurs from the beginning of the sample through 1959:3, and for most of the period from 1967:3 – 1981:1, which contains the so called Great Inflation. Inflation is generally high or growing in this state. We estimate inflation to be in state one from 1954:4 – 1967:2, briefly from 1975:2 – 1976:3, and then permanently beginning the 2nd quarter of 1981. All 3 of these subsamples are periods where inflation is low and/or falling. The volatility of inflation, as measured by the estimated standard deviation, is nearly twice as large in the higher inflation state.

Since the level and growth rate of inflation appear to be regime dependent, we now turn to the question of whether or not the persistence of inflation varies across these 2 regimes. The estimates suggest that inflation was unstable in state zero. The parameter γ_0 is not statistically significantly different from zero, which is consistent with a unit root in inflation. In addition, γ_1 is negative and significant, which implies that inflation is stationary in state one. Thus, our results are consistent with inflation switching between stationary and unit root states, where the states correspond both to periods of low and high inflation and low and high inflation variability.[9]

For the real time Taylor rule estimates in the following section, our sample begins in 1965:4. Therefore, we also estimate a Markov Switching AR(2) model for inflation for the 1965:4 – 2007:1 subsample. The bottom panel of Figure 1 plots the inflation rate and the parameter estimates are reported in Table 1. The message for this subsample is identical to that of the full sample. State zero lasts through the 1970s, again with the exception of the 1975:2 – 1976:3 period where inflation briefly fell, and the switch to state one occurs in 1981:2. As with the full sample, the estimated values of γ_{S_t} imply that inflation has a unit root for most of the Great Inflation period, switched to a stationary process in the early 1980s, and continued as a stationary process through the 1980s, 1990s, and 2000s.

5. A Markov Switching Model for the Taylor Rule

5.1 Model

Our goal in this section is to test whether the hypothesis that inflation switches between stationary and unit root regimes is consistent with a "textbook" macro model if the policy followed by the Fed switches from satisfying to not satisfying the Taylor principle. We first demonstrate that our estimates from a Markov switching Taylor rule suggest two separate regimes. We then determine that the Taylor

[8] Throughout the paper, we compute smoothed probabilities of being in state zero or one.

[9] Evans and Wachtel (1993) estimate a Markov Switching model of inflation. They restrict one of the states to be a driftless random walk and the other to follow an AR(1). We do not impose that either state is a random walk, allow for (but do not find) drift in the random walk state, and find that the stationary state is better described by an AR (2).

rule parameter, δ, in equation (1) is indistinguishable from zero in one of the regimes and significantly positive in another. Finally, we illustrate how closely the relationship between the periods characterized by the state where the Taylor principle is not satisfied coincides with the periods where inflation is characterized by a unit root.

Before proceeding with the estimation, we modify equation (2) in accordance with previous research on the Taylor rule. We consider forward looking Taylor rules, so that the Fed's interest rate target responds to expectations of current and future inflation:

$$r_t^* = \mu + (1+\delta)E_t\pi_{t+h} + \omega\hat{y}_t \tag{6}$$

where $E_t\pi_{t+h}$ is the expectation of the inflation rate at time $t+h$ formed at time t. We use the period t expectation of inflation in time t, rather than the inflation rate itself, because the inflation rate is not contemporaneously known to policymakers.

Rather than making an instantaneous adjustment of the Federal Funds Rate towards its target level, the Fed tends to smooth changes in the interest rate. As is common practice, we assume AR(1) smoothing, so that the actual Federal Funds Rate r_t is the following function of its target level r_t^*:

$$r_t = (1-\rho)r_t^* + \rho r_{t-1} + \varepsilon_t \tag{7}$$

where ρ is the degree of smoothing. The more instantaneous the response to the shocks, the more ρ tends to zero. Substituting (6) into (7) and allowing the parameters to switch between the two regimes, we get the following two state specification for the nominal interest rate:

$$r_t = (1-\rho_{S_t})\{\mu_{S_t} + (1+\delta_{S_t})E_t\pi_{t+h} + \omega_{S_t}\ \hat{y}_t\} + \rho_{S_t} r_{t-1} + \varepsilon_t . \tag{8}$$

Sims and Zha (2006) argue that if the variance is assumed to be constant, one may find spurious structural change in the slope coefficients in monetary policy rules. We allow the Gaussian errors to be heteroskedastic to sidestep this problem.

5.2 Data

Our real time inflation forecasts come from the Greenbook dataset, which is available from the Philadelphia Fed website.[10] The Greenbook forecasts are published with a five year lag, and as of the writing of this paper, end in 2001:4. We extend the Greenbook forecasts through 2007:1 by splicing it with inflation forecasts from the Survey of Professional Forecasters (SPF).[11] The inflation forecasts are predictions of the annualized quarter-over-quarter growth rate of the GNP/GDP price level. To estimate a Taylor rule, we need year-over-year inflation rate forecasts. We thus transform the Greenbook/SPF data by taking the average of four consecutive quarter-over-quarter forecasts. We then have $E_t\pi_{t+h}$ for h = 0,

[10] http://www.philadelphiafed.org/econ/forecast/greenbook-data/phila-data-set.cfm
[11] http://www.philadelphiafed.org:80/econ/spf/index.cfm

1,…, 4. Since inflation at time *t* is not available in real time, $h = 0$ is a forecast of current inflation, or a "nowcast." It is based on four quarterly forecasts, from $t-3$, $t-2$, $t-1$, and *t*, the first three of which are actual realized values of inflation. For $h = 2$, $E_t\pi_{t+2}$ is the average of $t+2$ and $t+1$ forecasts, the time *t* nowcast, and the $t-1$ realized inflation rate. Only the $h = 3$ and $h = 4$ year-over-year inflation forecasts are based entirely on unrealized values of inflation. The starting dates for the Greenbook inflation forecasts are 1965:4 for $h = 0$ and $h = 1$ and 1968:4, 1973:2, and 1974:2 for h = 2, 3, and 4 respectively.

For the output gap, we first consider the real-time measure used by Orphanides (2004), which is based in part on estimates from the Council of Economic Advisors (CEA) and the Commerce Department. Orphanides' data ends in 1998:4. We update the output gap series through 2007:1 using OECD real-time output gap estimates which are published in the OECD *Economic Outlook*. We convert the annual estimates to quarterly data using quadratic interpolation. We also compute output gaps as percentage deviations from quadratic and Hodrick-Prescott trends. For these measures, we use real-time GDP data compiled by the Philadelphia Fed. The vintages start in 1965:4 and end in 2007:1, and the data for each vintage starts in 1947:1. For each quarter starting in 1965:4, the real-time output gap is computed as the percentage deviation from trend at the end of the sample, using all data that was available at the time to estimate the trend.

5.3 Empirical Results

We estimate Equation (8) using Hamilton's (1989) algorithm for the nowcast and forecasts of inflation. We use the average Federal Funds Rates of the final month of the quarter as our nominal interest rate. We allow the constant term, as well as the coefficients on expected inflation and the output gap, the interest rate smoothing parameter, and innovation variance, to be regime dependent.

Our results are reported in Table 2. Figure 2 plots the Fed Funds Rate, the nowcast of inflation, and Orphanides' real-time measure of the output gap. The shaded area corresponds to $\hat{S}_t = 0$. The parameter estimates and estimated state distributions are consistent across the five inflation forecasts. We estimate that what will be seen as the destabilizing Taylor rule state, state zero, occurs from 1973:1 – 1975:1 and again from 1979:4 – 1985:3. State one occurs from the beginning of the sample through 1972:4, from 1975:2 – 1979:3, and again from 1985:4 through the end of the sample.

In state zero, the coefficient on inflation, $\hat{\delta}$, is insignificant for every inflation forecast. The Fed was not raising the nominal interest rate more than point for point in response to higher inflation. Indeed, as is visually evident in Figure 2, the Taylor principle was not satisfied during the shaded periods. There were a number of times when the nominal interest rate fell as inflation rose. This probably explains why the estimates of δ are all negative in state zero, albeit insignificant.

In contrast, state one implies a significant and positive value of δ for every inflation forecast, suggesting that the Fed followed a stabilizing Taylor rule. The parameter $\hat{\delta}_1$ ranges from 0.91 to 1.11, which implies that the Fed was keeping inflation in check by increasing the nominal interest rate by around 2 percentage points when inflation increased by 1 percent.

How do we reconcile the timing of our Taylor rule regimes with the univariate inflation results from the previous section? Recall that we estimate inflation to be an unstable (unit root) process for most of the 1970s, except for the six quarter 1975:2 – 1976:3 subsample, and to be stable beginning in 1981:2. This timing is certainly related to the timing of our estimate states for the Taylor rule, but not exact. In particular, we estimate that the 1975:2 – 1979:3 period is characterized as a stabilizing Taylor rule state, even though our univariate inflation estimates from the previous section suggest inflation contains a unit root in the latter half of this subsample. Monetary policy during the four years preceding Paul Volcker's tenure is not generally regarded as being consistent with a stabilizing Taylor rule. However, while inflation was rising during this period, the Federal Funds Rate was, in fact, rising by more than point for point.

We also estimate that the Taylor rule was destabilizing from 1979:4 – 1985:3. This is of course the period during which the Fed, under Chairman Paul Volcker, lowered inflation. This disinflation came about via targeting nonborrowed reserves, not through an explicit interest rate target. Indeed, while disinflation occurred through most of the period, nominal interest rates were quite erratic, experiencing their highest levels and largest volatility. We would surely not expect our estimates to suggest that the Fed was pulling down inflation via the increasing the Fed Funds rate. Finally, beginning in 1985:4 and lasting through the rest of the sample, we estimate that the Taylor principle held. This is the time frame of what has come to be permanently lower inflation. The switch to this state accords with the beginning of the Great Moderation.

The second major component of the Taylor rule is that the Fed raises/lowers the nominal interest rate when the output gap is positive/negative. We find that the response of the interest rate to the output gap across all inflation forecast horizons was much stronger when the Taylor principle held. In State 1, the coefficient $\hat{\omega}$ ranges from 0.65 to 0.77 and is always highly significant while, in State 0, $\hat{\omega}$ ranges from 0.31 to 0.51 and is most often marginally significant.

We find that there is much more interest rate smoothing in the stable Taylor rule state. The typical $\hat{\rho}$ in state zero is about 0.5, compared to around 0.8 when the Fed follows the Taylor principle. Not surprisingly, the estimated innovation standard deviation is about 4 times larger in state zero than in the stable state one. We also report estimates of the implied inflation target π^*. Since the constant term depends on the inflation coefficient, the inflation target, and the equilibrium real interest rate, we assume that the equilibrium real interest rate equals 2.5% and back out an implied inflation target using the estimated inflation coefficients. When the Fed was actively targeting inflation via changes in the Federal Funds rate, we get estimates of π^* between 2% and 2.5%. In contrast, when the Fed does not follow the Taylor principle, the estimates of π^* range from 21% to 35%. These numbers are so large that they suggest that the Fed did not have a target level of inflation during those periods.

Taylor (2000), Cecchetti et al. (2007), and Levin and Taylor (2009) have argued that the real-time CEA output gap estimates from Orphanides (2004) that we utilize in Table 2 were affected by political influence during the 1970s and that neither economic analysts nor policymakers paid serious attention to these estimates. For these reasons, we consider two alternative real-time measures of the output gap based on quadratic detrending, which has become a fairly standard method of constructing output gaps for Taylor rules. We construct our first output gap as deviations from a quadratic trend, with a rolling window of 20 years. We also compute recursive deviations from a quadratic trend. For both output gaps, the observation at time t uses data up through time t – 1, so that both measures were available to the policy maker in real time.

We present our parameter results for the rolling and recursive output gaps in Tables 3 and 4 respectively. Figure 3 and 4 plot the Fed Funds rate, output gap, and the nowcast of inflation, again with shaded areas corresponding to $\hat{S}_t = 0$. The quadratic detrended output gap measures are much smaller than the CEA output gap measures during the recessions of the mid-1970s and early 1980s. The largest negative output gap occurs in 1975 for all three measures, but falls from -16.15 percent for the CEA measure to -11.39 percent and -10.42 percent for the rolling and recursive quadratic detrended measures, respectively. The same pattern, although with less negative numbers, occurs in 1982 during the trough of the early 1980s recession. By 1990, however, the pattern disappears, and the largest negative output gap during 1992 is about the same among the three measures.

Despite substantial differences between CEA and quadratic detrended output gap measures, the parameter estimates in Tables 3 and 4 convey the same message as in Table 2. The timing of the state distribution for the Taylor rule is identical among the three measures. For every inflation forecast, $\hat{\delta}$ is insignificant in state zero, and positive and significant in state one. For the rolling window output gap, the estimates of $(1+\delta)$ are closer to Taylor's (1993) value of 1.5 than we see in Table 2. They range from 1.49 to 1.80. For the recursive output gap, $(1+\hat{\delta})$ ranges from 1.77 to 1.87 for h = 0, 1, and 2. For h = 3 and 4, $(1+\hat{\delta})$ is 2.45 and 2.65 respectively. These estimates for the longer horizons are quite high, and the standard errors on $\hat{\delta}$ are more than twice as large as the lower horizons, which probably reflects the shorter samples for h = 3 and 4.

Turning to the output gap, the results in Tables 3 and 4 are nearly identical to those in Table 2 for the stabilizing Taylor rule state. The coefficient $\hat{\omega}$ on the output gap ranges from 0.67 to 0.81 and is significant for all inflation forecast horizons. For the destabilizing Taylor rule state, there is no evidence that the Fed responded to the output gap. The coefficient $\hat{\omega}$ is much smaller than in Table 2, ranging from 0.07 to 0.34, and is almost never significant. The parameter estimates for the interest rate smoothing coefficient and the innovation standard deviation display no significant differences from Table 2.

In response to the concerns discussed above regarding the CEA measured output gap, Cecchetti et al. (2007) and Levin and Taylor (2009) utilize a one-sided Hodrick-Prescott (HP) filtered real-time output gap measure, using a smoothing parameter of 1600. We implement this measure in Table 5 and Figure 5. The most negative HP filtered output gap is -6.63 percent for 1975, considerably smaller than for the other measures. While the HP filtered gap is also less negative during the recession of the early 1980s, the measures converge by the early 1990s. The timing of the state distributions is similar to those in Figures 2 – 4 with two exceptions. State 0 does not continue as far into the 1980s and there are two single-quarter switches from State 1 to State 0 in 1969 and 1984.

We present parameter estimates for the one-sided HP filtered output gap in Table 5. The estimates are much worse than those for either the Greenbook or the quadratic detrended output gaps. Most importantly, for every inflation forecast, $\hat{\delta}$ is insignificant in both state zero and state one. While the coefficients are larger in state one than in state zero, there is no statistical evidence that the Taylor principle was followed in either state. The coefficients $\hat{\omega}$ on the output gap are insignificant in state 0 and unreasonably large in state 1, and the smoothing parameter $\hat{\rho}$ is larger than in Tables 2 – 4.

Baxter and King (1999) show that the one-sided HP filter does not exhibit good behavior of cyclical components near the end of the sample. Watson (2007) discusses this problem in the context of real-time data where, by construction, every output gap estimate is at the end of the sample. We take account of the end-of-sample problem by forecasting and backcasting the GDP series by 12 quarters in both directions, assuming that growth rates follow an AR(4) process. As depicted in Figure 6, the most negative output gap is -5.55 percent for 1975, even smaller than for the one-sided HP filtered output gap estimates, and the measures again converge by the early 1990s. The timing of the state distributions is similar to those in Figures 2 – 4 with the exception of a single-quarter switch from State 1 to State 0 in 1969.

The parameter estimates for the HP filtered output gap with forecasting and backcasting, reported in Table 6, are not much better than those for the one-sided HP filtered output gap. The parameter $\hat{\delta}$ is insignificant in both state zero and state one for every inflation forecast, failing to provide any statistical evidence that the Taylor principle was followed in either state. While the coefficients $\hat{\omega}$ on the output gap are smaller in state 1 than with the one-sided filter, they are still unreasonably large. The estimates of the smoothing parameter ρ, in contrast, are similar to those reported in Tables 2 – 4.

Why are the parameter estimates with the HP filtered output gaps so much worse than with the other output gap measures? Why we obviously cannot provide a definitive answer, one possibility is that, since the methodology for computing HP detrended data was not available until 1980, HP filtered output gaps do not constitute real-time data for the 1970s. This is discussed in both Cecchetti et al. (2007) and Levin and Taylor (2009), who justify the use of the HP method on the basis that it corresponds well with less formal procedures economists used to compute trends. Our results are not in accord with this assessment. The two leading methods used to compute output gaps in the 1970s were linear and quadratic detrending. The maximum negative output gap in 1975 with linear detrending is -10.81 percent, comparable to the -11.39 percent and -10.42 percent estimates for the quadratic detrended output gaps.[12]

While the maximum negative output gap in 1975 with quadratic detrending is larger than with HP filtering, it is much smaller than with the CEA estimates used by Orphanides. Since the CEA output gaps are too large to be viewed as believable at the time, and the HP filtered output gaps do not constitute real-time data, we fell that the quadratic detrended output gaps are the preferred alternative.

5.4 The View from the Trenches and Beyond

It is useful to compare our results to Orphanides (2004). Using data from 1965:4 to 1995:4, he estimates forward looking Taylor rules for h = 1 – 4.[13] He splits the sample into pre and post-Volcker periods, with the change occurring between 1979:2 and 1979:3, and concludes that there was no significant change in the Fed's response to inflation before and after Volcker. In both regimes the Fed was estimated to have followed a stabilizing Taylor rule. The parameter $(1+\delta)$ is estimated to be about 1.5 pre-Volcker and about 2.0 after 1979:3. The one significant change he finds is with respect to the output gap: the Fed responded to deviations of output from its potential before, but not after Volcker became Chair.

Our two main results, the change in the Federal Reserve's response to inflation and the output gap, and their correspondence to the stability of inflation, are noticeably different from Orphanides' findings. Orphanides splits his sample after 1979:2. While this is an intuitive break date, it is chosen exogenously and implies only two regimes. Our results suggest that when the break date is endogenized via Markov switching, each of Orphanides' "regimes" contains periods where the Federal Reserve did and did not follow the Taylor principle. We find that not only did the Federal Reserve change their response to

[12] Linear detrending, however, is no longer an appropriate method to measure U.S. postwar output gaps. Because growth rates in the 1950s and 1960s were higher than in the 1970s and afterwards, every output gap after 1973 is negative.

[13] He uses AR (2) smoothing in the published version, although AR(1) smoothing in a working paper version leads to the same conclusions.

inflation throughout the entire sample, but that the timing of these changes in not simply pre and post-Volcker. Indeed, for the Volcker years, we conclude that it was not until he had less than two years remaining in his term that monetary policy permanently switched to a stabilizing Taylor rule. This starkly contrasts with the conclusion that $(1+\delta) > 1$ for the entire sample. While Orphanides concludes that the response to the output gap is regime dependent, we find that the regime dependence is a function of whether or not the Fed is trying to stabilize inflation, not whether or not Paul Volcker had yet taken office.

To determine if the difference between our results and Orphanides (2004) is due to endogenizing the timing of the regime switches, or merely an artifact of using a larger sample, we re-estimate our Markov switching Taylor rule for Orphanides' sample ending in 1995:4. The parameter estimates are reported in Table 5 and Figure 5 plots the data and estimated state distribution. The estimated dates of the unstable state are identical to those of the full sample. For every inflation forecast, the estimated value of δ is insignificant in state zero and significant in state one, with $(1+\hat{\delta})$ around 1.5. As in Table 2, which is identical to Table 5 except for the end date, we find that the output gap coefficient is only significant in the stable Taylor rule state (again with $h = 4$ as the exception). Since we are using the exact same data as in Orphanides (2004), we are left with the conclusion that Orphanides' (2004) claim that the Federal Reserve has not changed its response to inflation since 1965 is the result of assuming that the date of a possible regime change coincided with Paul Volcker taking over as Chairman of the Fed.

We also compare our results to Boivin (2006). He estimates forward looking Taylor rules with real time data, time varying policy coefficients, and heteroskedasticity. Fixing the break date of the variance of the policy shock to October 1979, he finds that the Fed's response to inflation changed throughout the 1970s. In the early part of the decade $(1+\hat{\delta})$ was well above unity, fell below unity from 1975 to 1979, but then rose above unity in 1980 where it remained until the end of his sample. These results differ from both Orphanides' and ours. Boivin's estimated destabilizing Taylor rule from 1975-1979 contrasts with our estimates, which suggest that the Taylor principle was followed during this period. Again, while this period is not usually thought of as one where the Taylor principle was being followed, the visual evidence is compelling. Also in contrast to Boivin, we estimate that the Taylor principle was not followed from the beginning of Volcker's reign through the third quarter of 1985.

Regarding the output gap, Boivin's results are closer to Orphanides than ours.[14] He estimates a gradually decreasing but significantly positive response from 1970 until Volcker's appointment, then a statistically insignificant response until 1986, after which the effect is smaller than the pre-Volcker period

[14] Boivin (2006) uses an unemployment gap which is the difference between unemployment and its estimated natural rate.

but significant. Boivin also allows for two changes (three regimes) in the variance of the policy shock; 1979.10 and 1982.10. His results for the time varying response to inflation and output are qualitatively unchanged.

Time varying parameter (Boivin) and Markov switching (our) models each have advantages and disadvantages. While Boivin's coefficients are allowed to evolve gradually, ours are restricted to two regimes with endogenously determined break dates. If the policy coefficients evolve gradually, Markov switching models will produce discrete estimates of the smooth change, with the switch occurring when the probability of changing states exceeds 50 percent. If the change in policy coefficients is discrete, the time varying parameters model will produce smooth estimates of the discrete change, with the estimated change in the parameters starting before the actual change occurs. In addition, we restrict the switches in inflation and output gap coefficients to occur simultaneously, where Boivin does not, but our variance switches are chosen endogenously, whereas Boivin's variance break dates are exogenous.

6. Conclusions

The purpose of this paper is to investigate the relationship between the conduct of monetary policy and the persistence of inflation. In the context of a "textbook" macroeconomic model with an IS curve, a Phillips curve, and a Taylor rule, inflation will be stationary if and only if the Taylor rule obeys the Taylor principle so that the real interest rate is increased when inflation rises above the target inflation rate. Since there is no reason to presume that monetary policy is either always stabilizing or always not stabilizing, it is plausible to think that inflation might switch from stationary to unit root behavior.

We proceed to estimate a Markov switching model for inflation, and show that inflation is best characterized by two states, one stationary and the other with a unit root. The unit root state spans most of the period from the 1967 – 1981, and inflation appears stable beginning in 1981:2. Finally, we estimate a Markov switching model for various real-time forward looking Taylor rules. The estimated Taylor rule equation switches between states where the Fed does and does try to stabilize inflation by following the Taylor Principle. We find that the pre and post-Volcker subsamples each contain multiple Taylor rule regimes. In particular, for most of Volcker's tenure at the Fed we find that the Fed did not follow a Taylor rule, but switched to a stabilizing Taylor rule state in 1985:4, which has endured to the present. This is in contrast to Orphanides (2004) who, using real-time data, finds that the Fed's response to inflation has been time invariant.

References

1. Andrews, Donald, 1993. "Exactly median-unbiased estimation of first order autoregressive/unit root models," *Econometrica*, vol. 61(1), pages 139-65.
2. Bai, Jushan and Serena Ng, 2004. "A PANIC attack on unit roots and cointegration," *Econometrica*, vol. 72(4), pages 1127-1177.
3. Baillie, Richard, Ching-Fan Chung, and Margie Tieslau, 1996. "Analysing inflation by the fractionally integrated ARFIMA-GARCH model," *Journal of Applied Econometrics*, vol. 11(1), pages 23-40.
4. Barsky, Robert, 1987. "The Fisher hypothesis and the forecastability and persistence of inflation," *Journal of Monetary Economics*, vol. 19(1), pages 3-24.
5. Baxter, Marianne, and Robert King, 1999. "Measuring Business Cycles: Approximate Band-Pass Filters for Economic Time Series," *The Review of Economics and Statistics*, vol. 81, pages 575-593.
6. Benati, Luca, 2008. "Investigating Inflation Persistence Across Monetary Regimes," *The Quarterly Journal of Economics*, vol. 123(3), pages 1005-1060.
7. Boivin, Jean, 2006. "Has U.S. monetary policy changed? Evidence from drifting coefficients and real-time data" *Journal of Money, Credit and Banking*, vol. 38, pages 1149-1179.
8. Brunner, Allan and Gregory Hess 1993. "Are higher levels of inflation less predictable? A State-dependent conditional heteroskedasticity approach," *Journal of Business and Economic Statistics*, vol. 11, No 2.
9. Cecchetti, Stephen, Peter Hooper, Brucce Kasman, Kermit Schoenholtz, and Mark Watson, 2007. "Understanding the evolving inflation process," U.S. Monetary Policy Forum.
10. Clarida, Richard, Jordi Gali, and Mark Gertler, 1998. "Monetary policy rules in practice: Some international evidence," *European Economic Review*, vol. 42, pages 1033-1067.
11. Clarida, Richard, Jordi Gali, and Mark Gertler, 2000. "Monetary policy rules and macroeconomic stability: Evidence and some theory," *Quarterly Journal of Economics*, vol. 115(1), pages 147-180.
12. Cogley, Timothy and Thomas Sargent, 2001. "Evolving post World War II U.S. inflation dynamics," *NBER Macroeconomics Annual*, vol. 16, pages 331-373.
13. Cogley, Timothy and Thomas Sargent, 2005. "Drifts and volatilities: Monetary policies and outcomes in the post WWII U.S.," *Review of Economic Dynamics*, vol. 8, pages 262-302.
14. Cogley, Timothy and Argia Sbordone, 2008, "Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips curve,"*American Economic Review* 98: 2101-2126.
15. Culver, Sarah and David Papell, 1997. "Is there a unit root in the inflation rate? Evidence from sequential break and panel data models," *Journal of Applied Econometrics*, issue 4, pages: 435-444
16. Davig, Troy and Eric Leeper, 2007, "Generalizing the Taylor principle," *American Economic Review*, vol. 97, pages 6-7 – 635.
17. Evans, Martin and Paul Wachtel, 1993. "Inflation regimes and the sources of inflation uncertainty," *Journal of Money, Credit and Banking*, vol. 25, pages 475-511.
18. Favero, Carlo and Tommaso Monacelli, "Fiscal Policy Rules and Regime (In)Stability: Evidence from the U.S., IGIER Working Paper No. 282, January 2005
19. Garcia, René, 1998. "Asymptotic null distribution of the likelihood ratio test in Markov switching models," *International Economic Review*, vol. 39, pages 763-788.
20. Goodfriend, Marvin, 2007. "How the World Achieved Consensus on Monetary Policy." *Journal of Economic Perspectives*, 21: 47–68.
21. Gordon, Robert, 2009. "The History of the Phillips Curve: Consensus and Bifurcation," forthcoming, *Economica*

22. Greenspan, Alan, 2004. “Risk and uncertainty in monetary policy,” *American Economic Review*, American Economic Association, vol. 94(2), pages 33-40.
23. Hall, Robert and John Taylor, 1997. *Macroeconomics*, 5th edition, (New York: WW Norton)
24. Hamilton, James, 1989. “A new approach to the economic analysis of nonstationary time series and the business cycle,” *Econometrica*, vol. 57 (2).
25. Hansen Bruce, 1992. “The likelihood ratio test under nonstandard conditions: testing the Markov switching model of GNP,” *Journal of Applied Econometrics*, vol. 7.
26. Henry, Ólan and Kalvinder Shields, 2004. “Is there a unit root in inflation?” *Journal of Macroeconomics*, March, pages 481-500.
27. Inoue, Atsushi and Lutz Kilian, 2005. “How useful is bagging in forecasting economic time series? A case study of U.S. CPI inflation,” CEPR Discussion Paper No. 5304.
28. Ireland, Peter, 1999. “Does the time-consistency problem explain the behavior of inflation in the United States?” *Journal of Monetary Economics*, vol. 44(2), pages 279-291.
29. Kim, Chang-Jin and Charles Nelson, 2006. “Estimation of a forward-looking monetary policy rule: A time-varying parameter model using ex post data,” *Journal of Monetary Economics*, vol. 53(8), pages 1949-1966.
30. Kim, Chang-Jin, Kundan Kishor and Charles R Nelson, 2006. “A time-varying parameter model for a forward-looking monetary policy rule based on real-time data,” Working Papers UWEC-2007-32, University of Washington, Department of Economics.
31. Lahiri, Soumendra, 1999. “Theoretical comparisons of block bootstrap methods,” *Annals of Statistics*, vol. 27, pages 386-404.
32. Levin, Andrew and Jeremy Piger, 2003. "Is Inflation Persistence Intrinsic in Industrial Economies?" *Computing in Economics and Finance*, Issue 298.
33. Levin, Andrew and Jeremy Piger, 2008, “Bayesian Model Selection for Structural Break Models,” working paper, University of Oregon.
34. Levin, Andrew and John Taylor, 2009, “Falling Behind the Curve: A Positive Analysis of Stop-Start Monetary Policies and the Great Inflation,” forthcoming in Michael Bordo and Athanasios Orphanides, eds., *The Great Inflation*, University of Chicago Press.
35. Marriott, F.H.C. and J.A. Pope, 1954. “Bias in the estimation of autocorrelations,” *Biometrics*, issue 41, pages 390-402.
36. McCulloch, Huston and Jeffery Stec, 2000. “Proxying inflation forecasts with Fuller/Roy-type median unbiased near unit root coefficient estimates,” *Computing in Economics and Finance*, issue 295.
37. Murray, Christian and Charles R. Nelson, 2002. “The great depression and output persistence,” *Journal of Money, Credit and Banking*, issue 34, pages 1090-1098.
38. Nelson, Charles and William Schwert, 1977. “Short-term interest rates as predictors of inflation: On testing the hypothesis that the real rate of interest is constant,” *American Economic Review*, vol. 3, pages 478-86.
39. Neusser, Klaus, 1991. “Testing the long-run implications of the neoclassical growth model,” *Journal of Monetary Economics*, issue 1, pages 3-37.
40. Ng, Serena and Perron Pierre, 1995. “Unit root tests in ARMA models with data-dependent methods for the selection of the truncation lag,” *Journal of the American Statistical Association*, issue 90, pages 268-281.
41. Orphanides, Athanasios, 2001. “Monetary policy rules based on real-time data,” *American Economic Review*, vol. 91(4), pages 964-985.
42. Orphanides, Athanasios, 2004. “Monetary policy rules, macroeconomic stability, and inflation: A view from the trenches,” *Journal of Money, Credit, and Banking*, issue 36, pages 151-175.
43. Pivetta, Frederic and Ricardo Reis, 2007. "The persistence of inflation in the United States," *Journal of Economic Dynamics and Control*, vol. 31(4), pages 1326-1358, April.
44. Primiceri, Giorgio, 2005. “Time varying structural vector autoregressions and monetary policy,” *Review of Economic Studies*, vol. 72, pages 821-852.

45. Rose, Andrew, 1988. "Is the real interest rate stable?" *Journal of Finance*, vol. 43, issue 5, pages 1095-1112.
46. Rudebusch, Glen, 1993. "The uncertain unit root in real GNP," *American Economic Review*, vol. 83 pages 264-72.
47. Shaman, Paul and Robert Stine, 1988. "The bias of autoregressive coefficient estimators," *Journal of the American Statistical Association*, vol. 83, pages 842–848.
48. Simon, John, 1996. "A Markov switching model of inflation in Australia," Reserve Bank of Australia, Discussion Paper 9611.
49. Sims, Christopher and Tao Zha, 2006. "Were there regime switches in U.S monetary policy?" *American Economic Review*, vol. 96(1), pages 54-81.
50. Stock, James and Mark Watson , 1999. "Forecasting inflation," *Journal of Monetary Economics*, vol. 44(2), pages 293-335.
51. Taylor, John, 1979. "Staggered wage setting in the macro model," *American Economic Review*, American Economic Association, vol. 69(2), pages 108-13.
52. Taylor, John, 1993. "Discretion versus policy rules in practice," *Carnegie-Rochester Conference Series on Public Policy*, vol. 39(1), pages 195-214.
53. Taylor, John, 1999. "A historical analysis of monetary policy rules," in John Taylor, ed., *Monetary Policy Rules*, University of Chicago Press, pages 319-347.
54. Taylor, John, 2000. "Comments on Athanasios Orphanides' The quest for prosperity without inflation," unpublished, Stanford University.
55. Vogel , Richard and Amy Shallcross, 1996. "The moving blocks bootstrap versus parametric time series models," *Water Resource Research*, vol. 32, pages 1875–1882.
56. Watson, Mark, 2007. "How Accurate are Real-Time Estimates of Output Trends and Gaps," *Federal Reserve Bank of Richmond Economic Quarterly*, vol. 93(2), pages 143-161.
57. Woodford, Michael, 2008. "How important is money in the conduct of monetary policy?" *Journal of Money, Credit, and Banking*, vol. 40, pages 1561-1598.

Appendix: Evolution of Conclusions about US Inflation Series Properties

Year	Author(s)	Framework	Findings about Inflation
1977	Nelson and Schwert	Analysis of autocorrelation structure	Nonstationary behavior of inflation
1987	Barsky	Estimation of autocorrelations	I(0) until 1960 and I(1) thereafter
1988	Rose	Dickey-Fuller tests	I(0)
1991	Neusser	Cointegration tests	I(0)
1993	Brunner and Hess	Dickey-Fuller-type test with bootstrapped critical values	I(0) from 1947 to 1959, and I(0) from 1960 to 1992
1993	Evans and Wachtel	Markov Switching	I(1) during 1965-1985, I(0) elsewhere
1996	Baillie et al	ARFIMA	Long memory process with mean reversion
1997	Culver and Papell	Panel unit root tests	I(0) for 3 countries out of 13 using UR test with breaks, I(1) for 7 of them; the last 3 countries are marginal
1999	Ireland	Phillips-Perron tests	the unit root hypothesis for inflation can be rejected, but only at the 0.10 significance level; in the post-1970 sample, the unit root hypothesis cannot be rejected.
1999	Stock and Watson	DF-GLS tests	p-values are larger that 10% for both CPI and PCE inflations before 1982, and less than 10% after 1985
2000	McCulloch and Stec	ARIMA	In the early portion of our period, a unit root in inflation may be rejected, while in the later portion, it generally cannot be. Whole period: Jan. 1959 - May, 1999
2001	Bai and Ng	PANIC	Cannot reject a UR at 5%
2003	Henry and Shields	Two regime TUR	Cannot reject a UR for the US inflation rate
2003	Levin and Piger	AR with an exogenous break	Break in the intercept, no break in persistence; reject the unit root
2007	Pivetta and Reis	Various classical and Bayesian methods	Persistence is constant and high. Cannot reject the unit root.
2008	Benati	AR(p) with median-unbiased estimator of the sum of the autoregressive coefficients.	Cannot reject the unit root for US inflation with either the GDP deflator or the PCE after 1951.

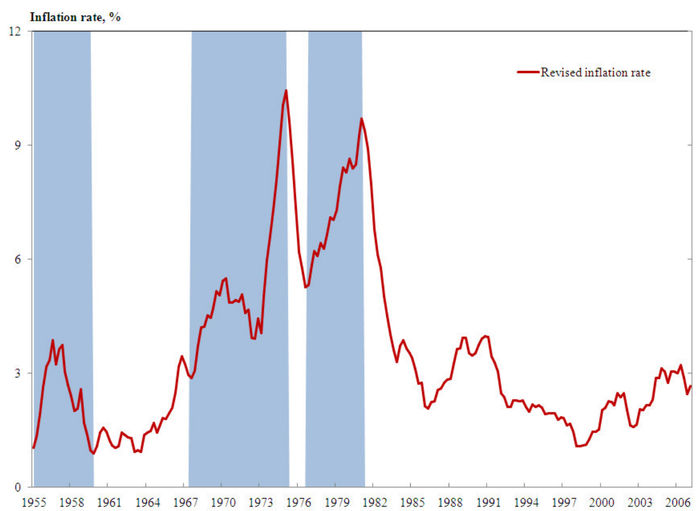
Note: The table contains the finding of various authors in different times. The right column shows their conclusions about the stationarity of inflation.

Table 1 Markov Switching Model for Inflation:

$$\Delta\pi_t = \mu_{s_t} + \gamma_{s_t}\pi_{t-1} + \psi_{s,i}\Delta\pi_{t-1} + \varepsilon_t$$

	1954:3 – 2007:1		1965:4 – 2007:1	
State S={0,1}	0	1	0	1
Persistence γ	0.03	-0.09***	0.01	-0.10***
	(0.03)	(0.01)	(0.03)	(0.01)
serial corr. ψ	-0.26***	-0.35***	-0.30***	-0.33***
	(0.12)	(0.07)	(0.14)	(0.07)
St Dev σ	0.40***	0.22***	0.37***	0.22***
	(0.04)	(0.01)	(0.03)	(0.01)
Const μ	0.00	0.22***	0.08	0.24***
	(0.12)	(0.04)	(0.17)	(0.04)
$P[S_t=i \mid S_{t-1}=i]$	0.95***	0.97***	0.97***	0.98***
	(0.03)	(0.02)	(0.04)	(0.01)

Notes: Inflation is defined as the year-over-year GDP deflator growth rate. The lag length p=1.



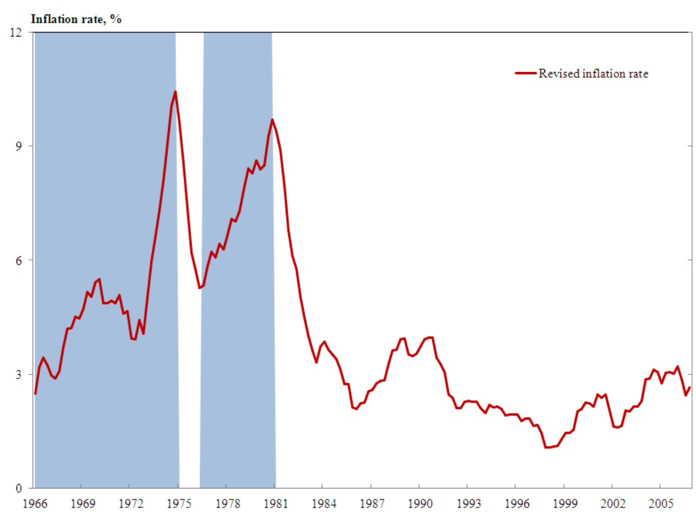


Figure 1 Revised GDP deflator inflation and the state distribution over the 1954:3 – 2007:1 sample (top) and the 1965:4 – 2007:1 sample (bottom)

Table 2 Taylor Rule Estimates with Real-Time Greenbook Output Gaps:

$$r_t = (1-\rho_{S_t})\{\mu_{S_t} + (1+\delta_{S_t})E_t\pi_{t+h} + \omega_{S_t}\ \hat{y}_t\} + \rho_{S_t} r_{t-1} + \varepsilon_t$$

	h=0		h=1		H=2		H=3		h=4	
State S={0,1}	0	1	0	1	0	1	0	1	0	1
Inflation δ	-0.36	0.91	-0.27	0.95	-0.30	0.98	-0.13	1.17	-0.24	1.11
	(0.33)	(0.28)	(0.33)	(0.22)	(0.36)	(0.23)	(0.31)	(0.23)	(0.35)	(0.22)
Output gap ω	0.50	0.70	0.45	0.67	0.40	0.65	0.31	0.77	0.51	0.73
	(0.26)	(0.13)	(0.26)	(0.10)	(0.25)	(0.10)	(0.22)	(0.11)	(0.23)	(0.11)
Smoothing ρ	0.47	0.83	0.50	0.80	0.53	0.80	0.54	0.79	0.38	0.81
	(0.16)	(0.04)	(0.14)	(0.04)	(0.14)	(0.03)	(0.13)	(0.03)	(0.18)	(0.03)
St Dev σ	2.37	0.55	2.30	0.52	2.28	0.49	2.20	0.39	2.34	0.44
	(0.30)	(0.04)	(0.28)	(0.04)	(0.27)	(0.04)	(0.25)	(0.04)	(0.30)	(0.03)
Const μ	10.11	0.55	9.05	0.38	8.98	0.18	7.02	-0.47	10.21	-0.27
	(2.91)	(0.76)	(2.95)	(0.64)	(3.03)	(0.63)	(2.62)	(0.62)	(3.37)	(0.63)
$P[S_t=i \mid S_{t-1}=i]$	0.93	0.98	0.93	0.98	0.94	0.98	0.96	0.98	0.95	0.98
	(0.04)	(0.01)	(0.04)	(0.01)	(0.04)	(0.02)	(0.03)	(0.02)	(0.04)	(0.01)
Implied π^*	21.27	2.13	24.41	2.24	21.25	2.37	35.40	2.55	32.39	2.50

Notes: The interest rate r_t is the average Federal Funds rate in the last month of the quarter. Inflation is defined as the year-over-year GDP deflator growth rate. The Greenbook inflation forecasts starting dates are 1965:4, 1968:3, 1968:4, 1973:3, 1974:2 for inflation forecast horizons h=0,…,4 respectively. The Greenbook output gap series comes from Orphanides (2004). The 1999:1-2007:1 output gap series is the OECD real-time estimates of the US production slack; inflation forecasts are from SPF. The equilibrium real interest rate is assumed to be 2.5%.

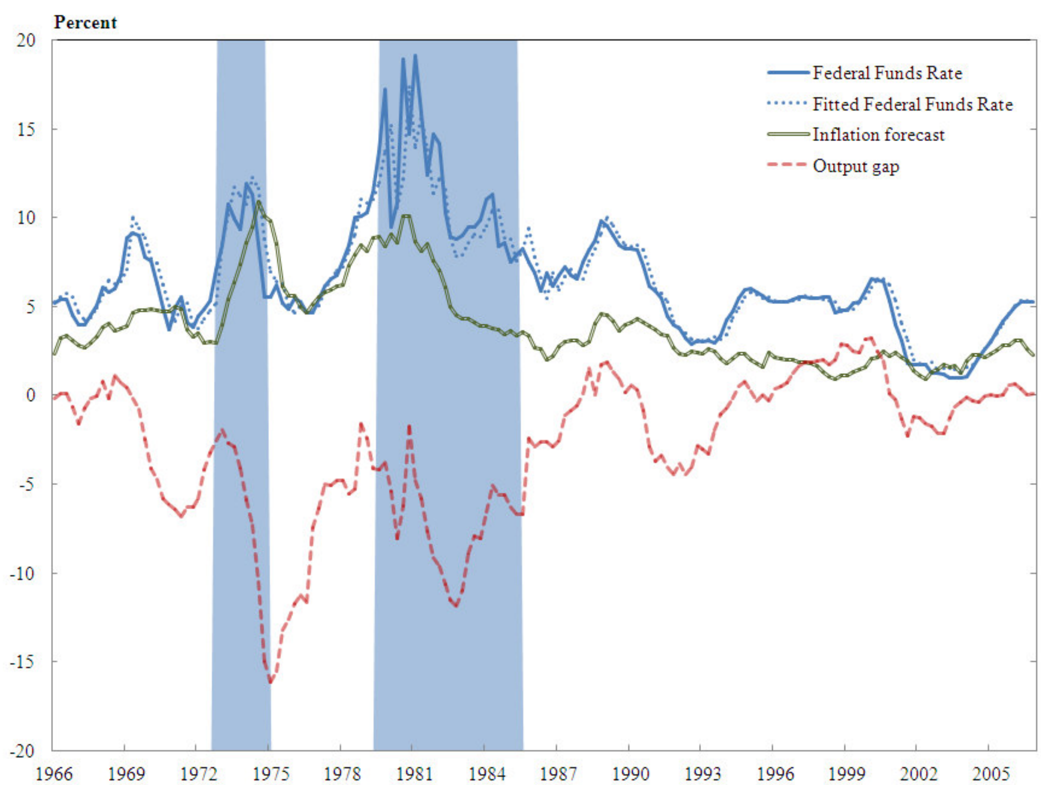


Figure 2 Taylor rule state distributions with the "nowcast" of inflation and real-time Greenbook output gaps estimated over the 1965:4-2007:1 sample

Table 3 Taylor Rule Estimates with Real-Time Rolling Window Quadratic Detrended Output Gaps:

$$r_t = (1-\rho_{S_t})\{\mu_{S_t} + (1+\delta_{S_t})E_t\pi_{t+h} + \omega_{S_t}\ \hat{y}_t\} + \rho_{S_t} r_{t-1} + \varepsilon_t$$

	h=0		H=1		h=2		h=3		h=4	
State S={0,1}	0	1	0	1	0	1	0	1	0	1
Inflation δ	-0.40	0.49	-0.29	0.58	-0.33	0.63	-0.17	0.78	-0.02	0.80
	(0.43)	(0.28)	(0.45)	(0.20)	(0.47)	(0.19)	(0.41)	(0.23)	(1.56)	(0.12)
Output gap ω	0.17	0.67	0.15	0.75	0.17	0.77	0.07	0.75	0.21	0.77
	(0.36)	(0.16)	(0.37)	(0.12)	(0.37)	(0.12)	(0.38)	(0.13)	(0.12)	(0.18)
Smoothing ρ	0.53	0.86	0.53	0.80	0.54	0.78	0.45	0.83	0.46	0.82
	(0.18)	(0.04)	(0.18)	(0.04)	(0.17)	(0.04)	(0.19)	(0.03)	(0.13)	(0.03)
St Dev σ	2.58	0.58	2.57	0.56	2.61	0.55	2.63	0.48	2.69	0.48
	(0.33)	(0.04)	(0.33)	(0.04)	(0.35)	(0.04)	(0.35)	(0.03)	(0.38)	(0.04)
Const μ	7.57	0.73	6.76	0.66	7.18	0.50	6.03	0.09	5.91	0.01
	(3.03)	(0.95)	(3.39)	(0.67)	(3.54)	(0.62)	(3.27)	(0.75)	(11.97)	(0.52)
$P[S_t=i\|S_{t-1}=i]$	0.92	0.98	0.92	0.98	0.92	0.98	0.95	0.98	0.94	0.98
	(0.05)	(0.01)	(0.05)	(0.01)	(0.05)	(0.01)	(0.04)	(0.01)	(0.05)	(0.01)
Implied π^*	12.59	3.63	14.49	3.21	14.18	3.17	20.98	3.10	172.24	3.11

Notes: The interest rate r_t is the average Federal Funds rate for the last month in the quarter. Inflation is defined as the year-over-year GDP deflator growth rate. The Greenbook inflation forecasts starting dates are 1965:4, 1968:3, 1968:4, 1973:3, 1974:2 for inflation forecast horizons h=0..4 respectively. The 1999:1-2007:1 inflation forecasts come from the Survey of Professional Forecasters. The size of the moving window is 20 years. The equilibrium real interest rate is assumed to be 2.5%.

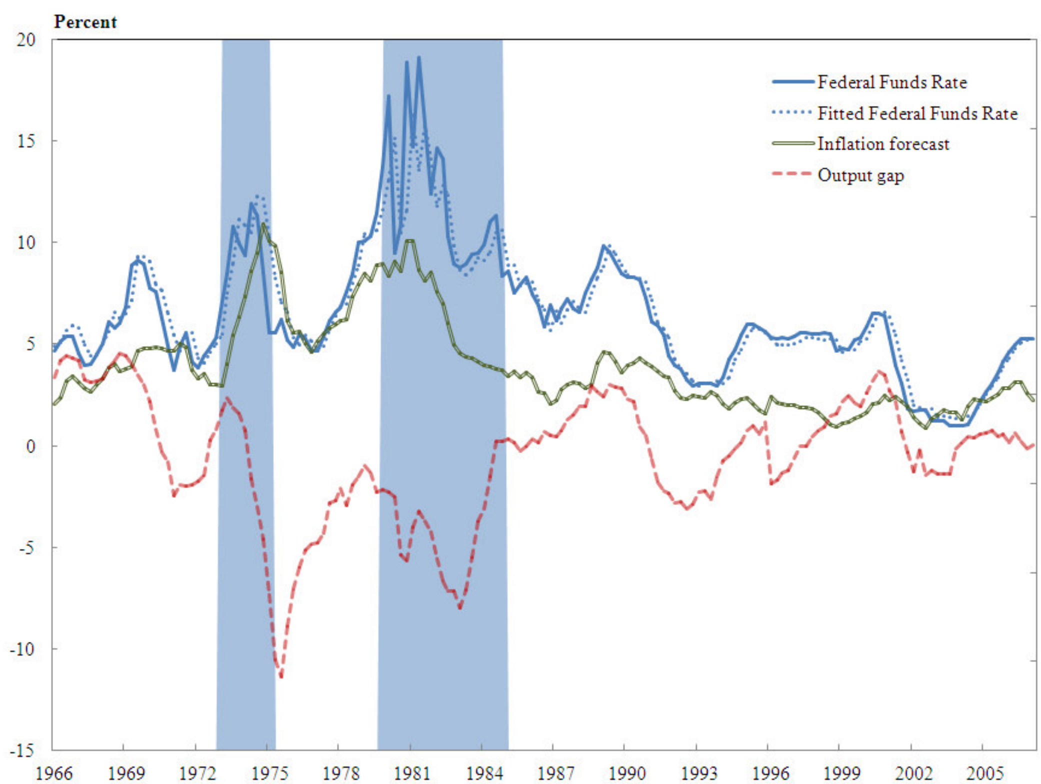


Figure 3 Taylor rule state distributions with the "nowcast" of inflation and rolling window quadratic detrended output gaps estimated over the 1965:4-2007:1 sample

Table 4 Taylor Rule Estimates with Real-Time Recursive Quadratic Detrended Output Gaps

$$r_t = (1-\rho_{S_t})\{\mu_{S_t} + (1+\delta_{S_t})E_t\pi_{t+h} + \omega_{S_t}\ \hat{y}_t\} + \rho_{S_t} r_{t-1} + \varepsilon_t$$

	h=0		h=1		h=2		h=3		h=4	
State S={0,1}	0	1	0	1	0	1	0	1	0	1
Inflation δ	-0.37	0.77	-0.29	0.87	-0.32	0.87	-0.06	1.45	0.18	1.65
	(0.41)	(0.37)	(0.42)	(0.33)	(0.43)	(0.32)	(0.57)	(0.88)	(0.83)	(0.84)
Output gap ω	0.34	0.79	0.28	0.81	0.24	0.74	0.17	0.67	0.12	0.69
	(0.39)	(0.22)	(0.39)	(0.19)	(0.37)	(0.18)	(0.50)	(0.34)	(0.63)	(0.34)
Smoothing ρ	0.52	0.88	0.52	0.86	0.53	0.86	0.45	0.93	0.45	0.93
	(0.17)	(0.03)	(0.16)	(0.03)	(0.16)	(0.03)	(0.22)	(0.03)	(0.25)	(0.03)
St Dev σ	2.54	0.57	2.52	0.56	2.50	0.54	2.94	0.52	3.12	0.52
	(0.33)	(0.04)	(0.32)	(0.04)	(0.32)	(0.04)	(0.51)	(0.04)	(0.55)	(0.04)
Const μ	7.76	-0.86	6.99	-1.06	7.24	-1.12	5.35	-2.53	3.88	-3.07
	(2.97)	(1.37)	(3.16)	(1.19)	(3.13)	(1.15)	(4.82)	(2.81)	(7.17)	(2.79)
$P[S_t=i\|S_{t-1}=i]$	0.92	0.98	0.92	0.98	0.93	0.98	0.88	0.97	0.97	0.86
	(0.05)	(0.01)	(0.05)	(0.01)	(0.05)	(0.01)	(0.09)	(0.02)	(0.02)	(0.10)
Implied π^*	14.07	4.38	15.71	4.10	14.77	4.16	51.71	3.47	-7.70	3.38

Notes: The interest rate r_t is the average Federal Funds rate for the last month in the quarter. Inflation is defined as the year-over-year GDP deflator growth rate. The Greenbook inflation forecasts starting dates are 1965:4, 1968:3, 1968:4, 1973:3, 1974:2 for inflation forecast horizons h=0..4 respectively. The 1999:1-2007:1 inflation forecasts come from the Survey of Professional Forecasters. The equilibrium real interest rate is assumed to be 2.5%.

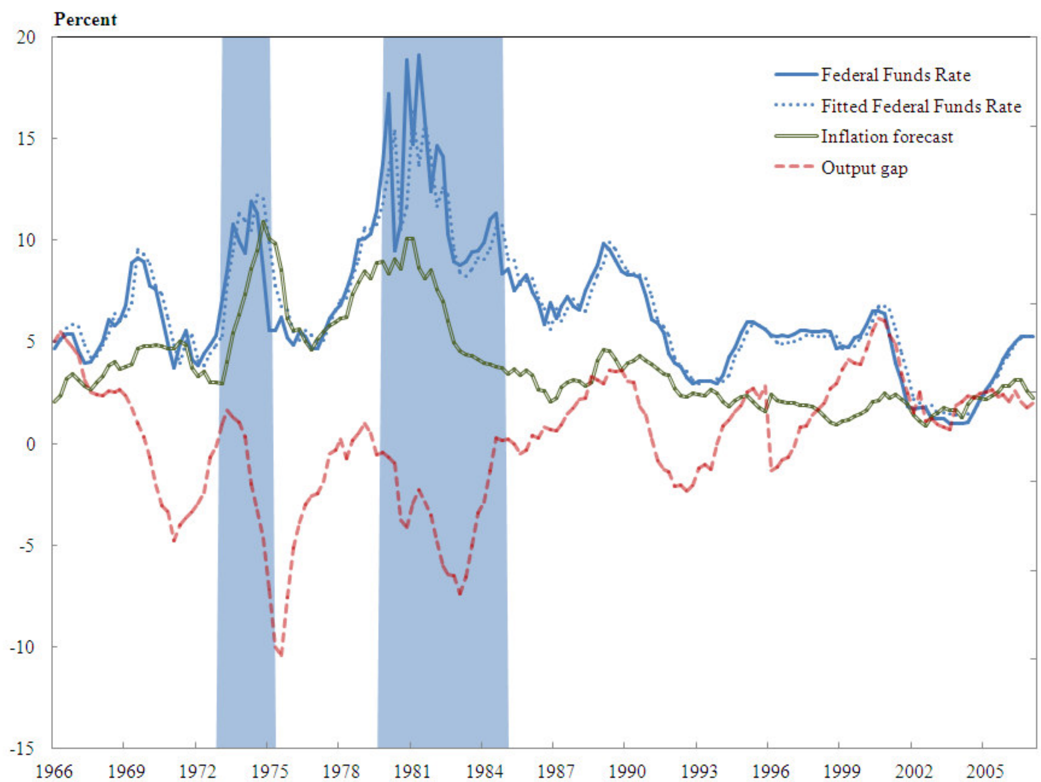


Figure 4 Taylor rule state distributions with the "nowcast" of inflation and recursive window detrended output gaps estimated over the 1965:4-2007:1 sample

Table 5 Taylor rule Estimates for One-Sided HP-Filtered Output Gaps:

$$r_t = (1-\rho_{S_t})\{\mu_{S_t} + (1+\delta_{S_t})E_t\pi_{t+h} + \omega_{S_t}\ \hat{y}_t\} + \rho_{S_t} r_{t-1} + \varepsilon_t$$

	h=0		h=1		h=2		h=3		h=4	
State S={0,1}	0	1	0	1	0	1	0	1	0	1
Inflation δ	-0.07	0.77	0.22	0.84	0.10	0.87	0.29	0.77	0.45	0.82
	(0.73)	(0.49)	(0.57)	(0.75)	(0.54)	(0.69)	(0.65)	(0.79)	(0.72)	(0.74)
Output gap ω	0.49	2.83	0.63	4.50	0.46	4.49	0.38	4.82	0.38	4.53
	(0.78)	(1.18)	(0.53)	(2.59)	(0.49)	(2.55)	(0.52)	(2.73)	(0.57)	(2.42)
Smoothing ρ	0.54	0.92	0.56	0.94	0.57	0.94	0.52	0.95	0.52	0.95
	(0.19)	(0.02)	(0.14)	(0.03)	(0.15)	(0.03)	(0.18)	(0.02)	(0.09)	(0.02)
St Dev σ	2.82	0.52	2.61	0.49	2.67	0.48	2.79	0.46	2.94	0.45
	(0.42)	(0.04)	(0.39)	(0.05)	(0.40)	(0.04)	(0.42)	(0.03)	(0.48)	(0.03)
Const μ	4.84	0.18	2.75	-0.51	3.59	-0.73	2.31	-0.61	1.70	-0.77
	(5.11)	(1.57)	(3.91)	(2.62)	(3.85)	(2.43)	(4.77)	(2.74)	(5.34)	(2.61)
$P[S_t=i \mid S_{t-1}=i]$	0.83	0.97	0.84	0.96	0.86	0.96	0.90	0.97	0.86	0.97
	(0.08)	(0.02)	(0.08)	(0.03)	(0.07)	(0.02)	(0.06)	(0.02)	(0.08)	(0.02)
Implied π^*	33.42	1.98	-1.13	3.58	-10.90	3.71	0.66	4.03	1.77	3.98

Notes: The interest rate r_t is the average Federal Funds rate for the last month in the quarter. Inflation is defined as the year-over-year GDP deflator growth rate. The Greenbook inflation forecasts starting dates are 1965:4, 1968:3, 1968:4, 1973:3, 1974:2 for inflation horizons h=0..4 respectively. The 1999:1-2007:1 inflation forecasts come from the Survey of Professional Forecasters. The equilibrium real interest rate is assumed to be 2.5%.

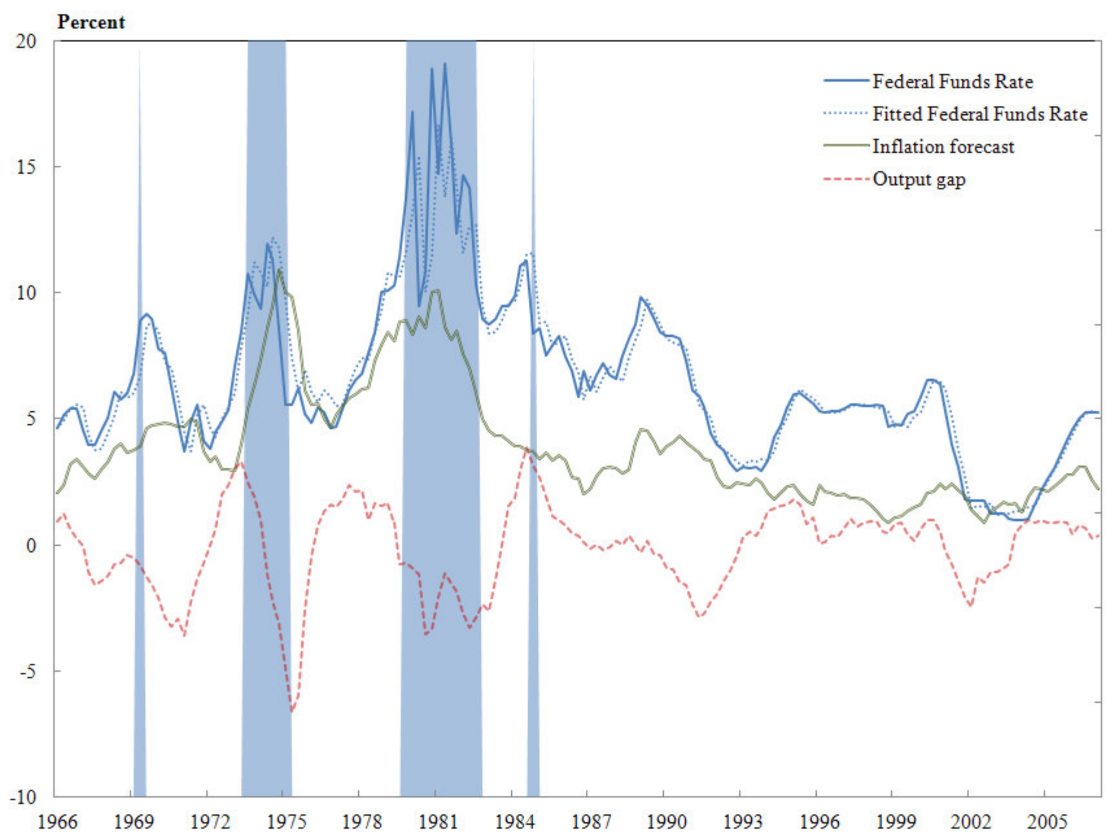


Figure 5 Taylor rule state distributions with the "nowcast" of inflation and one-sided HP-filtered output gaps estimated over the 1965:4-2007:1 sample

Table 6 Taylor Rule Estimates for Two-Sided HP-Filtered Output Gaps:

$$r_t = (1-\rho_{S_t})\{\mu_{S_t} + (1+\delta_{S_t})E_t\pi_{t+h} + \omega_{S_t}\ \hat{y}_t\} + \rho_{S_t} r_{t-1} + \varepsilon_t$$

	h=0		h=1		h=2		h=3		h=4	
State S={0,1}	0	1	0	1	0	1	0	1	0	1
Inflation δ	-0.37	0.39	-0.20	0.34	-0.21	0.34	-0.08	0.35	-0.20	0.34
	(0.46)	(0.27)	(0.48)	(0.24)	(0.52)	(0.24)	(0.47)	(0.26)	(0.48)	(0.25)
Output gap ω	0.37	2.11	0.60	2.45	0.53	2.47	0.41	2.53	0.61	2.45
	(0.74)	(0.49)	(0.63)	(0.57)	(0.61)	(0.64)	(0.58)	(0.59)	(0.63)	(0.57)
Smoothing ρ	0.53	0.86	0.58	0.86	0.58	0.86	0.53	0.87	0.58	0.85
	(0.17)	(0.03)	(0.14)	(0.02)	(0.14)	(0.02)	(0.16)	(0.03)	(0.14)	(0.03)
St Dev σ	2.57	0.52	2.48	0.49	2.48	0.48	2.56	0.45	2.48	0.49
	(0.34)	(0.04)	(0.32)	(0.04)	(0.32)	(0.04)	(0.33)	(0.03)	(0.32)	(0.05)
Const μ	7.20	1.71	6.05	2.02	6.20	1.92	5.33	1.73	6.05	2.02
	(3.11)	(0.81)	(3.28)	(0.80)	(3.63)	(0.80)	(3.32)	(0.87)	(3.28)	(0.80)
$P[S_t=i \mid S_{t-1}=i]$	0.90	0.98	0.91	0.97	0.92	0.97	0.95	0.97	0.91	0.97
	(0.06)	(0.01)	(0.05)	(0.02)	(0.05)	(0.02)	(0.04)	(0.01)	(0.06)	(0.02)
Implied π^*	12.70	2.00	17.75	1.45	17.61	1.71	35.38	2.20	17.75	1.41

Notes: The interest rate r_t is the average Federal Funds rate for the last month in the quarter. Inflation is defined as the year-over-year GDP deflator growth rate. The Greenbook inflation forecasts starting dates are 1965:4, 1968:3, 1968:4, 1973:3, 1974:2 for inflation forecast horizons h=0..4 respectively. The 1999:1-2007:1 inflation forecasts come from the Survey of Professional Forecasters. The equilibrium real interest rate is assumed to be 2.5%.

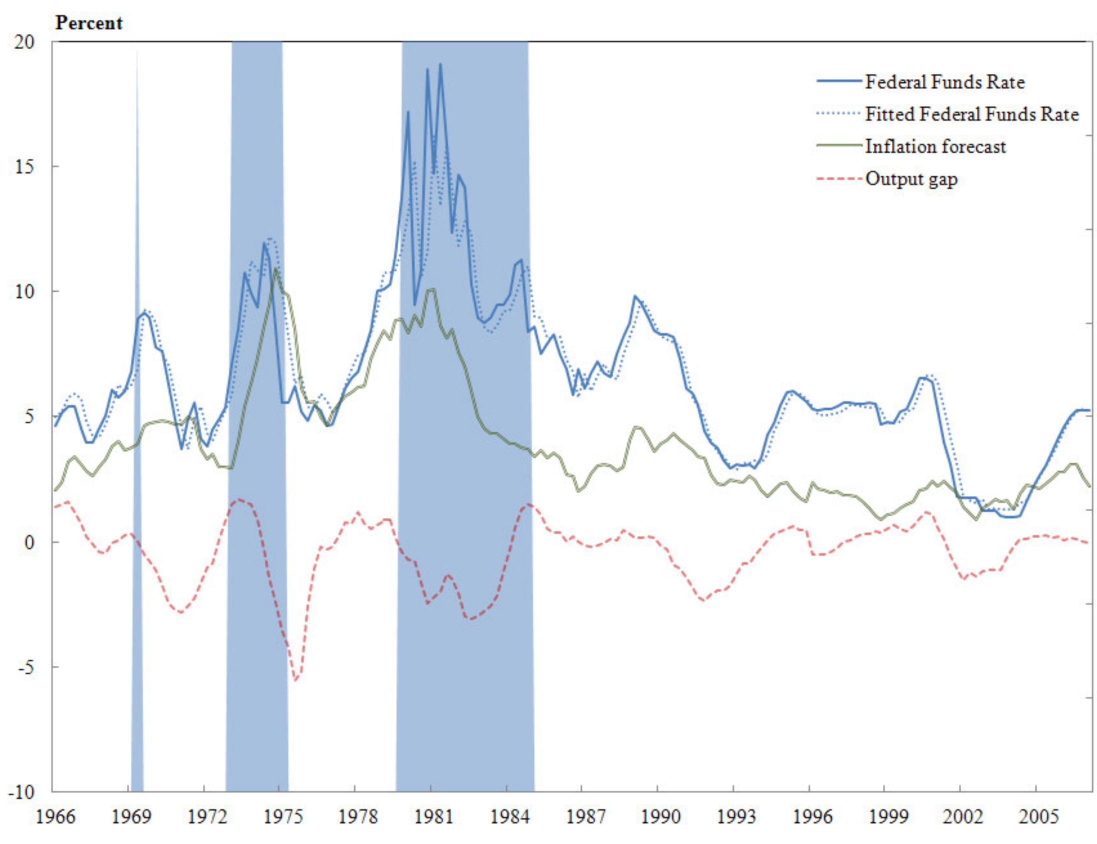


Figure 6 Taylor rule state distributions with the "nowcast" of inflation and two-sided HP-filtered output gaps estimated over 1965:4-2007:1 sample

Table 7 Taylor rule estimates with Greenbook real-time output gaps over the 1965:4-1995:4 sample:

$$r_t = (1-\rho_{S_t})\{\mu_{S_t} + (1+\delta_{S_t})E_t\pi_{t+h} + \omega_{S_t}\ \hat{y}_t\} + \rho_{S_t} r_{t-1} + \varepsilon_t$$

	h=0		h=1		h=2		h=3		h=4	
State S={0,1}	0	1	0	1	0	1	0	1	0	1
Inflation δ	-0.39	0.42	-0.30	0.37	-0.35	0.43	-0.50	0.55	-0.24	0.53
	(0.33)	(0.25)	(0.31)	(0.17)	(0.35)	(0.19)	(0.36)	(0.33)	(0.34)	(0.20)
Output gap ω	0.42	0.52	0.47	0.53	0.44	0.52	0.55	0.47	0.51	0.54
	(0.26)	(0.26)	(0.25)	(0.07)	(0.25)	(0.09)	(0.27)	(0.12)	(0.21)	(0.09)
Smoothing ρ	0.46	0.78	0.48	0.70	0.50	0.71	0.30	0.82	0.36	0.74
	(0.15)	(0.06)	(0.14)	(0.05)	(0.15)	(0.05)	(0.20)	(0.05)	(0.17)	(0.06)
St Dev σ	2.38	0.61	2.30	0.56	2.32	0.56	2.46	0.53	2.35	0.47
	(0.30)	(0.05)	(0.27)	(0.05)	(0.28)	(0.06)	(0.34)	(0.05)	(0.31)	(0.06)
Const μ	10.46	2.37	9.51	2.53	9.67	2.31	12.41	1.73	10.35	1.79
	(2.96)	(086)	(2.82)	(0.63)	(3.08)	(0.74)	(3.98)	(1.18)	(3.18)	(0.75)
$P[S_t=i \mid S_{t-1}=i]$	0.93	0.98	0.93	0.98	0.93	0.97	0.93	0.97	0.95	0.97
	(0.05)	(0.01)	(0.04)	(0.02)	(0.04)	(0.02)	(0.05)	(0.02)	(0.04)	(0.02)
Implied π^*	20.51	0.30	23.33	-0.08	20.63	0.46	19.68	1.37	32.32	1.33

Notes: The interest rate r_t is the average Federal Funds rate for the last month in the quarter. Inflation is defined as the year-over-year GDP deflator growth rate. The Greenbook inflation forecasts starting dates are 1965:4, 1968:3, 1968:4, 1973:3, 1974:2 for inflation forecast horizons h=0..4 respectively. The Greenbook output gap series comes from Orphanides (2004). The equilibrium real interest rate is assumed to be 2.5%.

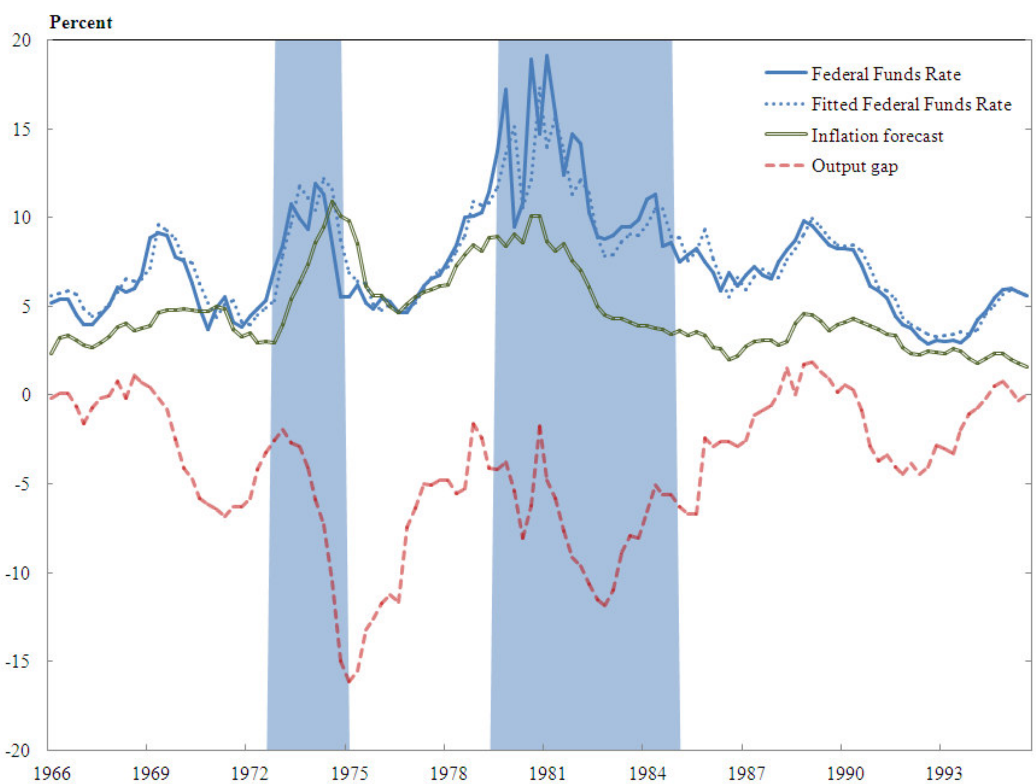


Figure 7 Taylor rule state distributions with the "nowcast" of inflation and real-time Greenbook output gaps estimated over the 1965:4-1995:4 sample