

The Taylor Principles^{*}

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Abstract

We use tests for structural change to identify periods of low, positive, and negative Taylor rule deviations, the difference between the federal funds rate and the rate prescribed by the original Taylor rule. The tests define four monetary policy eras: a negative deviations era during the Great Inflation from 1965 to 1979, a positive deviations era during the Volcker disinflation from 1980 to 1987, a low deviations era during the Great Moderation from 1987 to 2000, and another negative deviations era from 2001 to 2013. We then estimate Taylor rules for the different eras. The most important violations of the Taylor principles, the four elements that comprise the Taylor rule, are that the coefficient on inflation was too low during the Great Inflation and that the coefficient on the output gap was too low during the Volcker disinflation. We then analyze deviations from several alterations of the original Taylor rule, which identify a negative deviations era from 2001 to 2006 and a low deviations era from 2007 to 2013. Between 2001 and 2006, Fed policy cannot be explained by any variant of the Taylor rule while, between 2007 and 2013, Fed policy is consistent with a rule where the federal funds rate responds to the output gap, does not respond to inflation, and incorporates a time-varying equilibrium real interest rate.

^{*} The data used in the paper can be downloaded at
https://sites.google.com/site/alexrzhevskyy/files/data_rules_principles.zip

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*“All happy families are alike; each unhappy family is unhappy in its own way”
Leo Tolstoy, Anna Karenina*

1. Introduction

The Taylor principle that the nominal interest rate should be raised more than point-for-point when inflation rises, so that the real interest rate increases, has become a central tenet of monetary policy. Satisfying the Taylor principle is both necessary and sufficient for stabilizing inflation in a “textbook” model with an IS Curve, Phillips Curve, and Taylor rule, and is the dominant factor for determinacy of inflation in a model with a forward-looking IS Curve, a New Keynesian Phillips Curve, and a Taylor rule.¹

The Taylor principle is embedded in the Taylor (1993) rule. According to the Taylor rule, the policy interest rate (the federal funds rate in the U.S.) equals the inflation rate plus 0.5 times the inflation gap, inflation minus the target inflation rate, plus 0.5 times the output gap, the percentage difference between GDP and potential GDP, plus the equilibrium real interest rate. With the target inflation rate and the equilibrium real interest rate both set equal to 2.0, the rule simplifies to the policy rate = 1.0 + 1.5 * inflation + 0.5 * output gap. With the coefficient on inflation being greater than one, the Taylor rule necessarily satisfies the Taylor principle.

The converse, however, is not correct, as satisfying the Taylor principle is necessary, but not sufficient, for adhering to the Taylor rule. There are four elements in the Taylor rule, which we call the “Taylor principles”. The first element, discussed above, is that the coefficient on inflation equals 1.5. Following standard practice, we say that the first Taylor principle is satisfied if the coefficient on inflation is greater than and significantly different from one. The second element is that the coefficient on the output gap equals 0.5, so that the nominal (and real) interest rate increases when the output gap rises. While there is no standard practice, we will say that the second Taylor principle is satisfied if the coefficient on the output gap is greater than zero, less than one, and significantly different from both zero and one. Both the first and second principles are symmetric, so that the real interest rate decreases when inflation and/or the output gap falls. Satisfying the first and second principles serves to stabilize business cycle fluctuations.

The third element is that the target inflation rate equals 2.0 percent. This target has been adopted either implicitly or explicitly by many central banks, and has been an explicit target of the Fed since January 2012. The fourth element is that the equilibrium real interest rate be

¹ Hall and Taylor (1997) and Woodford (2003) develop textbook and New Keynesian models.

constant and equal to 2.0 percent. Because neither the inflation target nor the equilibrium real interest rate are estimated, the criteria for satisfying the third and fourth Taylor principles will not have an exact statistical interpretation.

Until recently, most research on Taylor rules focused on the first principle. Starting with Taylor (1999) and Clarida, Gali, and Gertler (2000), many researchers have found that the Taylor principle was satisfied in the 1980s and 1990s, but not in the 1960s and 1970s. The second principle became prominent following the Great Recession. Yellen (2012) argued that a modified Taylor rule, with a coefficient of 1.0 instead of 0.5 on the output gap, was preferable to the original Taylor rule. In contrast to the original Taylor rule, the modified rule implies negative policy rates starting in 2009 which, combined with the zero lower bound on the federal funds rate, provides a justification for quantitative easing and forward guidance. The third principle, that the target inflation rate equals 2.0 percent, has been questioned in the aftermath of the Great Recession by, among others, Williams (2009), who argues that a 2 percent inflation target may provide an inadequate buffer against the zero lower bound. Although a time-varying equilibrium real interest rate is central for optimal monetary policy in King (2000) and Woodford (2003), the fourth principle, that the equilibrium real interest rate equals 2.0 percent, has received relatively little attention in the policy analysis literature until recently. This has changed, however, as Summers (2013,2014) and McCulley (2014) have advocated conducting policy based on an equilibrium real interest rate that is zero or even negative.

There is an extensive literature that estimates Taylor rules. Rudebusch (2006) estimates a Taylor rule from 1978 to 2004 and finds that the Taylor principle was satisfied. Taylor (1999) and Clarida, Gali, and Gertler (2000) estimate Taylor rules for the pre-Volcker and Volcker-Greenspan periods and find that the Taylor principle is satisfied only for the latter period. Orphanides (2004) uses real-time data that was available to policymakers and finds that the Taylor principle holds during both periods. More recent research divides the periods endogenously. Boivin (2006) and Kim and Nelson (2006) use time-varying coefficient methods and find a change towards a stabilizing Taylor rule in 1980. Davig and Leeper (2006, 2011) estimate a Markov-switching Taylor rule embedded in a New Keynesian DSGE model, and find that the Taylor principle is satisfied for most years between 1980 and 2000, but neither before nor after. Murray, Nikolsko-Rzhevskyy, and Papell (2014) use Markov-switching methods with

real-time data starting in 1965 and find that the Taylor principle holds except for 1973 – 1974 and 1980-1985,

This paper takes a different approach to Taylor rule estimation. Instead of choosing periods exogenously or on the basis of changes in estimated parameters, we first define Taylor rule deviations as the difference between the federal funds rate and the policy rate prescribed by the original Taylor rule described above. Next, using structural change tests, we divide the sample into various periods and estimate Taylor rules over the periods. Finally, we investigate the implications of altering the original Taylor rule to incorporate a higher coefficient on the output gap and/or a time-varying equilibrium real interest rate. We use real-time data on real GDP and the GDP deflator from 1965:4 – 2013:4, and construct output gaps using real-time quadratic detrending. We replace the federal funds rate with the shadow federal funds rate calculated by Wu and Xia (2014) starting in 2009:Q1, when the federal funds rate was constrained by the zero lower bound.

The structural change tests provide evidence of four distinct eras. There is a low deviations era, where the federal funds rate is close to the prescribed Taylor rule rate, during the Great Moderation period from 1987 to 2000, two negative deviations eras, where the federal funds rate was below the prescribed Taylor rule rate, during the Great Inflation period from 1965 to 1979 and during the period that Taylor (2013) calls the Great Deviation and the Not-So-Great Recovery from 2001 to 2013, and a positive deviations era, where the federal funds rate is above the prescribed Taylor rule rate, during the Volcker disinflation period from 1980 to 1987. Our results are broadly, although not exactly, in accord with Taylor (2012), who uses narrative methods to identify the late 1960s and 1970s as a period of discretionary policy, 1980 to 1984 as a transition, 1985 to 2003 as the rules-based era, and 2003 to 2012 as the ad hoc era.

We estimate Taylor rules for the various eras. The coefficient on inflation is greater than and significantly different from one, so that the first Taylor principle holds, for the 1979 – 1987 and 1987 – 2000 periods. Between 1965 and 1979, the coefficient on inflation is close to and not significantly different from one, so that the first Taylor principle is not satisfied. This is in accord with much previous research, and reinforces the evidence that the violation of the Taylor principle was an important contributing factor to the high inflation in the 1970s. Between 2000 and 2013, the coefficient on inflation is greater than but not significantly different from one.

The coefficient on the output gap is relatively close to Taylor's postulated value of 0.50 and significantly different from both zero and one for all eras except for the Volcker disinflation period, where it is small and not significantly different from zero. Since the output gap was negative during most of 1980 – 1987, a larger response to the output gap would have lowered the policy rate and decreased the size of the Taylor rule deviations.

The largest differences in the estimates across the eras are in the intercept. According to the Taylor rule, the intercept is positively correlated with the equilibrium real interest rate and negatively correlated with the coefficient on inflation and the inflation target. Because the inflation target and equilibrium real interest rate both affect the intercept, they cannot be separately identified. The value of the intercept is only consistent with Taylor's postulated values for the inflation target and equilibrium real interest rate during the low deviations era from 1987 to 2000. For the positive deviations era from 1980 to 1987, the value of the intercept implies either a much higher equilibrium real interest rate or a negative inflation target, neither of which is plausible. For the negative deviations era from 2001 to 2013, the value of the intercept implies either a very high inflation target, which is implausible, or a near-zero equilibrium real interest rate. While the latter might make sense after 2008, a low equilibrium real interest rate is an implausible explanation of departures from the Taylor rule in the early-to-mid 2000s.

The results of the structural change tests illustrate the importance of all four Taylor principles. Monetary policy in the 1987-2000 period is well-explained by the original Taylor rule. Violations of the first Taylor principle that the coefficient on inflation should be greater than one are important for explaining deviations from the Taylor rule, but only for 1965 – 1979. Violations of the second Taylor principle, that the coefficient on the output gap equals 0.5, contribute to the large deviations during 1980 – 1987. Finally, the large deviations during 2001 – 2013 are difficult to understand in the context of violations of the Taylor principles.

By estimating Taylor rules for the low, positive, and negative deviations eras, we have identified how violations of one or more of the four Taylor principles contributed towards the Taylor rule deviations in the various eras. We proceed to analyze deviations from several alterations of the Taylor rule where one of the Taylor principles is violated. If the alteration results in a switch from either a positive or negative deviations era to a low deviations era, we can say that the violation of the principle not only contributed to, but can account for, the Taylor rule deviations.

We first conduct structural change tests on deviations from the modified Taylor rule with a higher output gap coefficient of one. The major difference is that there is an additional break at the end of 2006, producing a negative deviations era from 2000- 2006 and a low deviations era from 2007 – 2013. Because the first three break dates are very similar to those with the original Taylor rule, there are only minor changes between the original and the modified Taylor rules for the first three eras. Between 2000 and 2006, while the coefficient on inflation is great than one (although not significantly) and the coefficient on the output gap is not significantly different from one, there are very large deviations from the modified Taylor rule. The value of the intercept is consistent with either an extremely high inflation target or a negative equilibrium real interest rate, neither of which are remotely plausible. Between 2007 and 2013 the policy rate responded strongly to the output gap and didn't respond at all to inflation. While these results are arguably in accord with Fed policies during an era of high unemployment and very low inflation, they are not consistent with the modified Taylor rule because the first Taylor principle is not satisfied. The estimates are consistent with either a low inflation target and/or a low equilibrium real interest rate.

We proceed to conduct structural change tests on deviations from the original Taylor rule with a time-varying equilibrium real interest rate. We proxy the unobservable equilibrium real interest rate with two measures – the growth rate of real GDP and the estimates in Laubach and Williams (2003,2014). The break dates and resultant monetary policy eras are very similar to the results with the modified Taylor rule. Because the equilibrium real interest rate is exogenous, we can back out a unique target inflation rate. Incorporating a time-varying equilibrium real interest rate is not useful for analyzing Fed policy during the first four eras, as the implied inflation targets are all implausible. In contrast, the deviations are very low and Fed policy during 2007 – 2013 can be well-explained by a Taylor rule with a time varying equilibrium real interest rate using the Laubach and Williams estimates. As with the modified Taylor rule, the policy rate responded strongly to the output gap and didn't respond at all to inflation. Strikingly, the implied inflation target is 1.61 percent, which seems remarkably consistent with Fed policy.

The *Anna Karenina principle* applies to an endeavor where a deficiency in any of its factors dooms it to failure. It was popularized by Jared Diamond in his book, *Guns, Germs, and Steel*, who used it to illustrate why so few wild animals have been successfully domesticated. In the context of monetary policy evaluation, the failure of any of the four Taylor principles can

cause large deviations from the Taylor rule. While policy evaluation in the context of the Taylor rule has been almost entirely conducted on the basis of the first Taylor principle that the nominal interest rate should be raised by more than point-for-point when inflation increases, departures from the other Taylor principles are also important for understanding Taylor rule deviations.

2. Policy Rule Deviations with Real-Time Data

Taylor (1993) proposed the following monetary policy rule,

$$i_t = \pi_t + \phi(\pi_t - \pi^*) + \gamma y_t + R^* \quad (1)$$

where i_t is the target level of the short-term nominal interest rate, π_t is the inflation rate, π^* is the target level of inflation, y_t is the output gap, the percent deviation of actual real GDP from an estimate of its potential level, and R^* is the equilibrium level of the real interest rate. Combining terms,

$$i_t = \mu + \alpha\pi_t + \gamma y_t, \quad (2)$$

where $\alpha = 1 + \phi$ and $\mu = R^* - \phi\pi^*$.

Taylor postulated that the output and inflation gaps enter the central bank's reaction function with equal weights of 0.5 and that the equilibrium level of the real interest rate and the inflation target were both equal to 2 percent, producing the following equation,

$$i_t = 1.0 + 1.5\pi_t + 0.5y_t \quad (3)$$

We define Taylor rule deviations as the difference between the actual federal funds rate and the interest rate target implied by the original Taylor rule with the above coefficients.²

2.1 Real-Time Data

The implied Taylor rule interest rate is calculated from data on inflation and the output gap. Following Orphanides (2001), the vast majority of research on the Taylor rule uses real-time data that was available to policymakers at the time that interest rate setting decisions were made. The Real-Time Data Set for Macroeconomists, originated by Croushore and Stark (2001) and maintained by the Philadelphia Fed, contains vintages of nominal GDP, real GDP, and the GDP

² In Nikolsko-Rzhevskyy, Papell, and Prodan (2014a,b) we define Taylor (and other policy) rule deviations as the absolute value of the difference between the actual federal funds rate and the interest rate target implied by the various policy rules. While this allows us to distinguish between “rules-based” and “discretionary” eras, it does not differentiate between positive and negative deviations and, therefore, does not allow us to investigate the causes of the deviations by estimating policy rules.

deflator (GNP before December 1991) data starting in 1965:4, with the data in each vintage extending back to 1947:1.

We construct inflation rates as the year-over-year change in the GDP Deflator, the ratio of nominal to real GDP. While the Fed has emphasized different inflation rates at different points in time, real-time GDP inflation is by far the longest available real-time inflation series. An alternative would be to splice together a series from the emphasized inflation measures at different points in time. Even if it was possible to construct such a series with real-time data (and it is not), this would risk finding spurious evidence of different eras based on spliced data.

In order to construct the output gap, the percentage deviation of real GDP around potential GDP, the real GDP data needs to be detrended. We use real-time detrending, where the trend is calculated from 1947:1 through the vintage date. For example, the output gap for 1965:4 is the deviation from a trend calculated from 1947:Q1 to 1965:Q3, the output gap for 1966:Q1 is the deviation from a trend calculated from 1947:Q1 to 1965:Q4, and so on, replicating the information available to policymakers.³

The three leading methods of detrending are linear, quadratic, and Hodrick-Prescott (HP). Real-time output gaps using these methods are depicted in Figure 1. In contrast with output gaps constructed using revised data, where the trends are estimated for the entire sample, there is no necessity for the positive output gaps to equal the negative output gaps. While there are considerable differences among the gaps, the negative output gaps correspond closely with NBER recession dates for all three methods.

Which real-time output gap best approximates the perceptions of policymakers over this period? We can immediately rule out real-time linear detrending, as the output gap becomes negative in 1974 and stays consistently negative through 2013. The choice between real-time quadratic and HP detrended gaps requires more investigation. Nikolsko-Rzhevskyy and Papell (2012) and Nikolsko-Rzhevskyy, Papell, and Prodan (2014a,b) use Okun's Law, which states that the output gap equals a (negative) coefficient times the difference between current unemployment and the natural rate of unemployment, to construct "rule-of-thumb" output gaps based on real-time unemployment rates, perceptions of the natural rate of unemployment, and perceptions of the Okun's Law coefficient. Focusing on the quarters of peak unemployment

³ The lag reflects the fact that GDP data for a given quarter is not known until after the end of the quarter. While it would be preferable to use internal Fed (Greenbook) output gaps, these are only available from 1987 to 2007.

associated with the recessions in the 1970s and 1980s, the congruence between real-time Okun's Law output gaps and real-time quadratic detrended output gaps is fairly close while the real-time HP detrended output gaps are always too small.

Additional support for using quadratic detrended output gaps comes from the past few years. According to the HP detrended output gaps, the recovery from the Great Recession has been V-shaped, with the output gap positive since 2011. With the quadratic detrended output gaps, the recovery from the Great Recession has been flat, with the output gap between negative five and six percent since 2009.⁴ For these reasons, we use real-time quadratic detrending to construct the output gaps for the Taylor rule for the entire sample.

The policy rate is the effective (average of daily) federal funds rate for the quarter. Between March and July of 1980, President Carter imposed credit controls. Although the Fed cooperated with the controls, Paul Volcker had opposed them and the effects on the federal funds rate were clearly not a result of Fed policy. Between 1987:Q2 and 1980:Q1, the effective federal funds rate rose each quarter from 10.18 percent to 15.05 percent. It then fell to 12.69 percent in 1980:Q2 and 9.84 percent in 1980:Q3 before rising to 15.85 percent in 1980:Q4. Since we do not want our results to be affected by the credit controls, we replace the actual values for 1980:Q2 and 1980:Q3 with values interpolated between 1980:Q1 and 1980:Q4.⁵

The federal funds rate is constrained by the zero lower bound starting in 2009:Q1 and is therefore not a good measure of Fed policy. Between 2009:Q1 and 2013:Q4 we use the shadow federal funds rate of Wu and Xia (2014). The shadow rate is calculated using a nonlinear term structure model that incorporates the effect of quantitative easing and forward guidance. The shadow rate is consistently negative between 2009:Q3 and 2013:Q4.

2.2 Taylor Rule Deviations

Deviations from the original Taylor rule are depicted in Figure 2. Panel A shows the actual federal funds rate through 2008:Q4, the shadow federal funds rate from 2009:Q1-2013:Q4, and the Taylor rule rate implied by Equation (3). Panel B depicts the Taylor rule deviations, the difference between the actual and implied rates. Figure 2 summarizes some well-known results from research that uses Taylor rules to conduct normative monetary policy evaluation. Compared to the implied Taylor rule rate, the actual federal funds rate is too low in

⁴ The quadratic detrended output gaps since 2009 are, on average, about one percentage point larger than the CBO output gaps reported in Weidner and Williams (2014).

⁵ Schreft (1990) provides an extensive analysis of the credit controls.

the mid-to-late 1970s, too high in the early 1980s, and too low in the early-to-mid 2000s. This is consistent with Taylor (1999, 2007). The shadow federal funds rate is below the implied Taylor rule rate for 2010 – 2013.

The most widely used alternative to the original Taylor rule increases the size of the coefficient on the output gap from 0.5 to 1.0, producing the following specification.

$$i_t = 1.0 + 1.5\pi_t + 1.0y_t \quad (4)$$

We call this rule the modified Taylor rule. Rudebusch (2010) and Yellen (2012) use variants of this rule to justify unconventional policies after the federal funds rate hit the zero lower bound.⁶

Deviations from the modified Taylor rule are depicted in Figure 3. Panel A shows the federal funds rate (actual and shadow) and the modified Taylor rule rate implied by Equation (4). Panel B depicts the modified Taylor rule deviations, the difference between the actual and implied rates. While there are several differences between the deviations from the original and modified Taylor rules the most important is that, following the recession of 2008-2009, the shadow federal funds rate is below the rate implied by the original Taylor rule but above the rate implied by the modified Taylor rule.

Woodford (2003) develops a New Keynesian model with a forward-looking IS curve, a New Keynesian Phillips curve, and a Taylor rule. In his version of the Taylor rule, the equilibrium real interest rate can change each period, and so the Fed would raise or lower the federal funds rate point-for-point with changes in the equilibrium real interest rate. With Taylor’s original coefficients on inflation and the output gap and a 2.0 percent inflation target, the resultant equation becomes.

$$i_t = R_t - 1.0 + 1.5\pi_t + 0.5y_t \quad (5)$$

We call this rule the time-varying Taylor rule. If the equilibrium real interest rate is constant and equal to 2.0, Equations (3) and (5) are identical.

Since the equilibrium real interest rate is unobservable, there is no consensus about how it should be measured. Taylor (1993) choose 2.0 percent as a number close to the trend growth rate of real GDP, which he estimated as 2.2 percent from 1984:1 – 1992:3. Following Taylor’s methodology, we calculate a time-varying equilibrium real interest rate as the trend growth of

⁶ Yellen (2012) called this rule the “balanced-approach” rule. We use the term “modified” in order to utilize more neutral language.

real GDP over the previous 35 quarters. This methodology has the advantage of producing a real-time measure that could have been used by policymakers.

Deviations from the time-varying (trend growth) Taylor rule are depicted in Figure 4. Panel A shows the federal funds rate (actual and shadow) and the time-varying Taylor rule rate implied by Equation (5) with the equilibrium real interest rate calculated as the trend growth of real GDP. Panel B depicts the time-varying Taylor rule deviations, the difference between the actual and implied rates. Between 1965 and 2007, the time varying (trend growth) Taylor rule deviations are close to the original Taylor rule deviations. Following the recession of 2008-2009, the shadow federal funds rate is close to the rate implied by the trend growth Taylor rule.

In Woodford (2003), the equilibrium (or natural) rate of interest is the real interest rate required to keep aggregate demand equal at all times to the natural rate of output or, equivalently, keep the output gap equal to zero. Laubach and Williams (2003) apply the Kalman filter to jointly estimate time-varying natural rates of interest and output and trend growth. While there are not real-time estimates because the full sample is used in estimating the model parameters, we use the one-sided estimates that are closer to “real-time” because only current and past observations are used in estimating the state.⁷ We use their updated estimates through 2013 as reported in Laubach and Williams (2014).

Deviations from the time-varying (estimated) Taylor rule are depicted in Figure 5. Panel A shows the federal funds rate (actual and shadow) and the time-varying Taylor rule rate implied by Equation (5) with the equilibrium real interest rate calculated in Laubach and Williams (2014). Panel B depicts the time-varying Taylor rule deviations, the difference between the actual and implied rates. Between 1965 and 2007, the time varying (estimated) Taylor rule deviations are close to the original Taylor rule deviations. Following the recession of 2008-2009, the shadow federal funds rate is very close to the rate implied by the time-varying estimated Taylor rule.

2.3 Full Sample Estimates

In order to provide a benchmark for our later results, we estimate, using real-time data, a Taylor rule from 1965:4 – 2013:4. The estimated rule is as follows,

⁷ Clark and Kozicki (2005) estimated equilibrium real interest rates in real time, and reported considerable real-time measurement error (as did Laubach and Williams). Nevertheless, we attempted to use the Laubach and Williams methods to estimate real-time equilibrium real interest rates, but could not get the programs to converge before 1984.

$$i_t = 0.26 + 1.54\pi_t + 0.47y_t \quad (6)$$

(0.31) (0.07) (0.05)

with standard errors in parentheses. The coefficients on inflation and the output gap are remarkably close to the coefficients of the original Taylor rule. The intercept, however, is much smaller than the intercept in the original rule. With an estimated Taylor rule, you cannot independently identify the inflation target and the equilibrium real interest rate in Equation (1) from the estimates in Equation (6). If, however, you are willing to assume a value for the equilibrium real interest rate, you can back out a value for the inflation target (or vice versa). Assuming that the equilibrium real interest rate equals Taylor's postulated value of 2 percent, the implied inflation target is 3.22 percent, considerably larger than Taylor's 2 percent inflation target. Conversely, assuming that the inflation target equals 2 percent, the implied equilibrium real interest rate is 1.34, considerably lower than Taylor's 2 percent postulated value.

When estimating Taylor rules, it is common practice to have a weighted average of the lagged federal funds rate and the Taylor rule variables. Our purpose, however, is to investigate why policy deviated from the Taylor rule benchmark at various times, not to estimate interest rate reaction functions that produce the best fit. In order to investigate the sources of the deviations, we need for the estimated policy rules to be consistent with the postulated policy rules, which preclude adding lagged interest rates to the Taylor rule.

3. Estimates with Structural Change

In order to identify monetary policy eras, we use Bai and Perron (1998, 2003) tests for multiple structural breaks, allowing for changes in the mean of the policy rule deviations. We consider the following multiple linear regressions with m structural breaks ($m+1$ regimes):

$$d_t = \gamma_0 + \gamma_1 DU_{1t} + \gamma_2 DU_{2t} + \dots + \gamma_m DU_{mt} + u_t, \quad (7)$$

where d_t are the policy rule deviations from Equations (3) – (5) and $DU_{mt} = 1$ if $t > Tb_t$ and 0 otherwise, for all values of the break points Tb_t .

The estimated break points are obtained by a global minimization of the sum of squared residuals (SSR). We consider the sequential test of l versus $l+1$ breaks, labeled $Ft(l+1|l)$. For this test the first l breaks are estimated and taken as given. The statistic $\sup Ft(l+1|l)$ is then

calculated as the maximum of the F -statistics for testing no further structural change against the alternative of one additional change in the mean when the break date is varied over all possible dates. The procedure for estimating the number of breaks suggested by Bai and Perron is based on the sequential application of the $\sup F_t(l+1|l)$ test. The procedure can be summarized as follows. Begin with a test of no-breaks versus a single break. If the null hypothesis of no breaks is rejected, proceed to test the null of a single break versus two breaks, and so forth. This process is repeated until the statistics fail to reject the null hypothesis of no additional breaks. The estimated number of breaks is equal to the number of rejections. Following Bai and Perron's (2003b) recommendation to achieve test with correct size in finite samples, we use a value of the trimming parameter $\varepsilon = 0.15$ and a maximum number of breaks $m = 5$. The test has a nonstandard asymptotic distribution and critical values are provided in Bai and Perron (2003b).⁸

3.1 Taylor Rule Deviations

Using the Bai and Perron test we find three significant breaks in the mean of the Taylor rule deviations and, therefore, four regimes. The break dates, 1979:Q2, 1987:Q2, and 2000:Q3, as well as their associated confidence intervals are reported in Table 1 and illustrated in Figure 6, Panel A. Because the confidence intervals do not overlap, we can identify each regime as a monetary policy era.

There is a low deviations era from 1987:Q3 to 2000:Q3, two negative deviations eras from 1965:Q4 to 1979:Q3 and 2000:Q4 to 2013:Q4, and a positive deviations era from 1979:Q4 to 1987:Q2. The largest deviations are during the Volcker disinflation period, where the federal funds rate is, on average, almost three percentage points above the prescribed Taylor rule rate. The smallest deviations are during the Great Moderation, which are close to zero on average. During the late 1960s, 1970s, and 2000s, the average policy rate is almost two percentage points below the prescribed rate, with the average deviations for the late 1960s and 1970s approximately equal to the average deviations for the 2000s.

We estimate Taylor rules for each of the four eras. Between 1965 and 1979, the coefficient on inflation is 1.04 and not significantly different from one, so that the first Taylor principle is not satisfied. This is in accord with much previous research, and reinforces the evidence that the violation of the Taylor principle was an important contributing factor to the

⁸ Bai and Perron (2003a) use an efficient algorithm for estimating the break points based on dynamic programming techniques. They also propose a methodology for identifying breaks if the no-break null is not rejected against the single-break methodology, which is not needed for this paper.

high inflation in the 1970s. The coefficient on the output gap, 0.46, is very close to Taylor's postulated coefficient of 0.50 and is significantly different from both zero and one. Using the estimates of the intercept and the coefficient on inflation, you can back out an estimate for the inflation target by assuming that the equilibrium real interest rate equals two and can back out an estimate for the equilibrium real interest rate by assuming that the inflation target equals two, but you cannot identify both parameters independently. If the first Taylor principle does not hold, however, the model does not identify an inflation target as the Fed simply increases the policy rate point-for-point with inflation. Since the estimated coefficient on inflation is close to and not significantly different from one, the very high inflation target of 12.5 percent reported in Table 1 reflects the lack of an operative inflation target during this period.

The first Taylor principle, however, is not violated for the other three periods. For the low deviations era during the Great Moderation from 1987 to 2000, the estimates are broadly consistent with Taylor's original coefficients, with the intercept equal to 1.15, the coefficient on inflation equal to 1.32 and the coefficient on the output gap equal to 0.68. Assuming that the equilibrium real interest rate equals two, the implied inflation target is 2.63 percent, somewhat above Taylor's postulated value of 2.0 and, assuming that the inflation target equals two, the implied equilibrium real interest rate is 1.79 percent, close to Taylor's postulated value of 2.0.

For the positive deviations era during the Volcker disinflation from 1979 to 1987, the coefficient on inflation of 1.43 is close to Taylor's postulated value of 0.50. The coefficient on the output gap of 0.10 is much lower than the postulated value and not significantly different from zero. This is the only era for which the second Taylor principle fails to hold. Since the average output gap from 1979:4 to 1987:2 is -2.2 percent, the average Taylor rule deviation would have been 2.0 percent instead of 2.9 percent if the coefficient on the output gap was 0.50 instead of 0.10. The positive deviations during the Volcker disinflation cannot be accounted for by violations of the first and second Taylor principles.

During this period, the intercept of 3.38 is much higher than the postulated value. With a two percent inflation target, these coefficients imply a 4.24 percent equilibrium real interest rate. A two percent inflation target, however, seems unrealistically low for the period. With an inflation target of four percent, which is arguably more plausible, the implied equilibrium real interest rate is 5.10. Since the average equilibrium real interest rate for the period is 2.50 for the trend growth estimates and 3.21 for the Laubach and Williams estimates, these equilibrium rates

do not appear to be plausible. Alternatively, with a two percent equilibrium real interest rate, the coefficients imply a -3.23 percent inflation target, which is obviously implausible. The magnitude of the Taylor rule deviations during the Volcker disinflation period cannot be explained by a combination of any or all of the Taylor principles. One interpretation of these results, suggested by Taylor (1999), is that Volcker needed to raise the federal funds rate above the implied Taylor rule rate to establish Fed credibility and to keep expectations of inflation from rising.

Although the average deviations for the 2000s are approximately equal to the average deviations during the Great Inflation of the late 1960s and 1970s, the estimated policy rules are very different. For the negative deviations era from 2001 to 2013, the coefficients on inflation and the output gap are 1.20 and 0.42, the former significantly greater than one and the latter close to Taylor's postulated value. The intercept, however, is -0.41, much lower than either Taylor's postulated value or the estimated intercept during the Great Inflation. With an equilibrium real interest rate of two, the results are consistent with a very high inflation target of 11.86 percent, which is obviously implausible during an era of low inflation. Alternatively, with an inflation target of two percent, the results are consistent with a near-zero equilibrium real interest rate. While this makes sense after 2008, a low equilibrium real interest rate is an implausible explanation of departures from the Taylor rule in the early-to-mid 2000s.

The results of the structural change tests illustrate the importance of going beyond the first Taylor principle in order to understand deviations from the Taylor rule. Violations of the first Taylor principle that the coefficient on inflation should be greater than one are important for explaining deviations from the Taylor rule, but only for 1965 – 1979. Monetary policy in the 1987-2000 period is well-explained by the original Taylor rule. Violations of the second Taylor principle, that the coefficient on the output gap equals 0.5, are only important for 1980 - 1987. Finally, the deviations during 2001 – 2013 can only be understood in the context of violations of the third and fourth Taylor principles, that the inflation target and the equilibrium real interest rate equal 2.0.

3.2 Modified Taylor Rule Deviations

Applying the Bai and Perron test to the modified Taylor rule deviations in Equation (4), we identify four significant breaks in the mean of the Taylor rule deviations and, therefore, five regimes. The results are reported in Table 2 and illustrated in Figure 6, Panel B. The most

important difference between the results for the original and modified Taylor rule deviations is that, for the latter, there is a break in 2000:Q6 which produces an additional low deviations era from 2007:Q1 – 2013:Q4. There is a low deviations era from 1988:Q1 to 1999:Q3, two negative deviations eras from 1965:Q4 to 1979:Q4 and 1999:Q4 to 2006:Q4, and a positive deviations era from 1980:Q1 to 1987:Q4. The largest deviations are during the 1980 – 1987 and 2000 – 2006 periods. The smallest deviations are during the 2007 – 2013 period, followed by the 1988 – 1999 period. The low deviations during 2007 – 2013 are in accord with the perception that Fed policy during and following the Great Recession is better characterized by the modified Taylor rule than by the original Taylor rule.

We estimate Taylor rules for all five eras. Because the federal funds rate is the dependent variable and inflation and the output gap are the independent variables for both the original and the modified Taylor rule specifications, the estimates can only differ if the break dates that define the eras are different. The results for the Great inflation and Volcker disinflation eras are similar to those when the eras are defined by the original Taylor rule. With the modified Taylor rule, the low deviations era during the Great Moderation starts two quarters later and ends four quarters earlier than with the original Taylor rule. The average deviation, while small in comparison to the positive and negative deviations eras, is larger than with the original Taylor rule. While the first Taylor principle is still satisfied, the coefficient on inflation falls, the coefficient on the output gap rises, and the intercept is almost the same as with the original Taylor rule. Assuming that the equilibrium real interest rate equals two, the implied inflation target is 3.27 percent and, assuming that the inflation target equals two, the implied equilibrium real interest rate is 1.66 percent. While these are still relatively close to Taylor's postulated value of 2.0, they are not as close as with the original Taylor rule.

The more striking differences between monetary policy eras defined by the original and modified Taylor rules come from the 2000 – 2013 period. With the original Taylor rule, the entire period is a negative deviations era. With the modified Taylor rule, 2000 – 2006 is a negative deviations era while 2007 – 2013 is a low deviations era. The estimates for 2000 – 2006 with the modified Taylor rule deviations produce much larger negative deviations than the estimates for 2000 – 2013 with the original Taylor rule deviations. While the inflation coefficients are greater than but not significantly different from one, the coefficient on the output gap is larger and the intercept is more negative with the modified Taylor rule. Assuming that the

equilibrium real interest rate equals two, the implied inflation target is 20.65 percent and, assuming that the inflation target equals two, the implied equilibrium real interest rate is -1.27 percent. Neither of these values is remotely plausible, and show that Fed policy from 2000 – 2006 cannot be well-described by the modified Taylor rule.

The estimates for 2007 – 2013 are very different from those of the previous eras. The inflation coefficient is virtually equal to zero, the output gap coefficient equals 0.74, and the intercept equals 3.12. In order for the inflation coefficient α in Equation (2) to equal zero, the coefficient on the difference between inflation and target inflation ϕ in Equation (1) equals -1.0. In that case, Equation (1) reduces to:

$$i_t = \pi^* + \gamma y_t + R^* \quad (8)$$

so that the nominal interest rate differs from the equilibrium nominal interest rate, the sum of the equilibrium real interest rate and the inflation target, by an amount depending on the output gap. Assuming that the equilibrium real interest rate equals two, the implied inflation target is 1.12 percent and, assuming that the inflation target equals two, the implied equilibrium real interest rate is 1.12 percent. These results are in accord with a view of monetary policy during and following the Great Recession that, because inflation was low and close to target and unemployment was high and persistent, the Fed didn't respond at all to small movements in inflation but responded strongly to the output gap.

An alternative interpretation of this result comes from the models of King (2000) and Woodford (2003), where the first term in the Taylor rule is the inflation target rather than the inflation rate.

$$i_t = \pi^* + \phi(\pi_t - \pi^*) + \gamma y_t + R^* \quad (9)$$

In this formulation, the coefficient on the difference between inflation and target inflation ϕ in Equation (9) needs to be greater than one for the first Taylor principle to hold. If the Fed doesn't respond to small movements in inflation, the coefficient $\phi = 0$ and Equation (9) becomes Equation (8). While this is algebraically identical to the result above, a coefficient of $\phi = 0$ in Equation (9) seems more intuitive than a coefficient of $\phi = -1.0$ in Equation (1).

3.3 Taylor Rule Deviations with a Time-Varying Equilibrium Real Interest Rate

An important characteristic of the New Keynesian model is a time-varying equilibrium real interest rate in the Taylor rule, so that the policy rate responds to changes in the equilibrium

real rate independently of changes to inflation and the output gap. We evaluate monetary policy in the context of such a rule by testing for structural change in the deviations from the time-varying equilibrium real rate Taylor rule described by Equation (5). We calculate the equilibrium real interest rate by using the trend growth rate and by the estimates in Laubach and Williams (2003, 2014) (LW).

The results of the Bai and Perron tests are reported in Table 3 and 4 and illustrated in Figure 6, Panels C and D. The break dates and resultant monetary policy eras are very similar to those with the modified Taylor rule. With the time-varying (trend growth) Taylor rule, there are low deviations eras from 1988:Q1 to 1999:Q4 and 2007:Q1 to 2013:Q4, two negative deviations eras from 1965:Q4 to 1979:Q3 and 2000:Q1 to 2006:Q4, and a positive deviations era from 1979:Q4 to 1987:Q4. With the time-varying (LW) Taylor rule, the only difference is that the break following the positive deviations era is in 1987:Q2 instead of 1987:Q4.

We estimate Taylor rules with a time-varying equilibrium real interest rate for all five eras. Because the dependent variable is the federal funds rate minus the time-varying equilibrium real interest rate, the estimates can differ from those with the original and modified Taylor rules even if the eras are identical. The estimates provide very little support for specifying a Taylor rule with a time-varying equilibrium real interest rate. The first Taylor principle, that the coefficient on inflation is significantly greater than one, holds for only three of the ten eras, 2000 to 2006 for both the trend growth and LW rates and 1980 to 1987 for the trend growth rate, and none of the three are low deviations eras. The second Taylor principle, that the coefficient on the output gap be significantly greater than zero and significantly less than one, holds for all eras except for the Volcker disinflation era.

Because the time-varying equilibrium real interest rate is subtracted from the federal funds rate to form the dependent variable, the inflation target is uniquely defined by the intercept and the coefficient on inflation. As reported in Table 3, the implied inflation targets are 15.49 and 24.20 percent for the 1965 to 1979 era, negative for the 1979 to 1987 and 1988 to 1999 eras, and 8.06 and 7.35 percent for the 2000 to 2006 era. None of these inflation targets are remotely plausible, and they provide no support for specifying a Taylor rule with a time-varying equilibrium real interest rate.

The most interesting result with a time-varying equilibrium real interest rate comes from the 2007 to 2013 period with the LW rate. Like the modified Taylor rule, the estimated inflation

coefficient is virtually zero, producing the rule described by Equation (8) but with a time-varying equilibrium real interest rate. The coefficient on the output gap, 0.49, is virtually identical to Taylor's postulated coefficient of 0.50. If the inflation coefficient was literally equal to zero, the intercept would equal the inflation target. In this case, the intercept is 1.59 and the inflation coefficient is 0.01, producing an implied inflation target of 1.61 percent. Since the 1.61 percent implied inflation target with the LW time-varying equilibrium real interest rate is closer to the 2.0 percent inflation target of the Fed than the 1.12 percent implied inflation target with the modified Taylor rule, this provides even stronger evidence that the Fed didn't respond at all to small movements in inflation but responded strongly to the output gap.

4. Conclusions

Monetary policy analysis is typically conducted by estimating Taylor rules over various periods, either as a single equation or in the context of a DSGE model. The periods are either chosen exogenously or selected based on changes in the estimated policy coefficients. The innovation in this paper is to estimate Taylor rules over monetary policy eras that are defined, using structural change tests, based on the deviations of the federal funds rate from the rate prescribed by the original Taylor rule, a modified Taylor rule with a higher output gap coefficient, and a version of the Taylor rule with a time-varying equilibrium real interest rate.

Adherence to and departures from the Taylor rule are typically analyzed in terms of the Taylor principle that the coefficient on inflation should be greater than and significantly different from one. The Taylor rule, however, consists of four elements, which we call the Taylor principles, and departures from any of the principles can cause deviations from the rule. The first Taylor principle is described above. The second Taylor principle is that the coefficient on the output gap should be greater than zero, less than one, and significantly different than both. The third Taylor principle is that the inflation target should equal 2.0 and the fourth Taylor principle is that the equilibrium real interest rate should also equal 2.0.

The structural change tests on deviations from the original Taylor rule identify four monetary policy eras. The only low deviations era is the Great Moderation from 1987 to 2000 when all four Taylor principles are satisfied. There is one positive deviations era, the Volcker disinflation from 1980 to 1987. While the first Taylor principle is satisfied, the second is not, and the combination of raising the interest rate to fight inflation and not mitigating the increases

when high unemployment caused a large negative output gap resulted in the federal funds rate being higher than the prescribed Taylor rule rate. There are two negative deviations eras. While the deviations during the Great Inflation from 1965 to 1979 can be explained by departures from the first Taylor principle, estimation of monetary policy rules based on Taylor rule deviations does not provide a satisfactory explanation for the deviations during 2000 to 2013.

We proceed to conduct structural change tests and estimate Taylor rules for monetary policy eras defined by alterations of the Taylor rule with a larger output gap coefficient, so that the second Taylor principle is violated, or a time-varying equilibrium real interest rate, so that the fourth Taylor principle is violated. These structural change tests divide the 2000 to 2013 period into two monetary policy eras, a negative deviations era from 2000 to 2006 and a low deviations era from 2007 to 2013. All four Taylor principles were violated during the negative deviations era from 2000 to 2006, and the results cannot be explained by either alteration of the Taylor rule.

The period from 2007 to 2013, in contrast, is a negative deviations era from the perspective of the original Taylor rule and a low deviations era from the perspective of the alterations. In particular, incorporating a time-varying equilibrium real interest rate defined by the Laubach and Williams (2014) estimates produces a very low deviations era with a near-zero inflation coefficient, a coefficient on the output gap that is close to Taylor's postulated value, and an implied inflation target of 1.61 percent.

The *Anna Karenina principle*, that a deficiency in any factor of an endeavor dooms it to failure, provides a construct for monetary policy evaluation. None of the Taylor principles were violated during the low deviations era during the Great Moderation from 1987 to 2000. In contrast, the first Taylor principle was violated during the negative deviations era from 1965 to 1979 and the second Taylor principle was violated during the positive deviations era from 1980 to 1987. All four Taylor principles were violated between 2000 and 2006, while the deviations between 2007 and 2013 are consistent with violations of the first and either the second or the fourth Taylor principle. While the low deviations era is characterized by adherence to all four Taylor principles, the violations of the Taylor principles for each high deviations era are different in its own way.

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Table 1. Original Taylor Rule Deviations

a) Tests for Multiple Structural Changes

$$d_t = \gamma_0 + \gamma_1 DU_{1t} + \gamma_2 DU_{2t} + \gamma_3 DU_{3t} + u_t$$

SupF test (sequential method)	Critical values (1%)	Break dates	Coefficients	95% Confidence Intervals
			$\gamma_0 = -1.87$	
SupF(1 0) = 38.41*	12.29	1979:Q3	$\gamma_1 = 4.74$	1979:Q3 - 1980:Q2
SupF(2 1) = 154.87*	13.89	1987:Q2	$\gamma_2 = -2.84$	1987:Q1 - 1988:Q1
SupF(3 2) = 80.08*	14.80	2000:Q3	$\gamma_3 = -1.85$	1999:Q1 - 2001:Q1

b) Taylor Rule estimates

$$i_t = \mu + \alpha \pi_t + \gamma r_t, \text{ where } \phi = \alpha - 1, \pi^* = \frac{(R^* - \mu)}{\phi} \text{ and } R^* = \mu + \phi \pi^*$$

	μ	α	γ	$\pi^* (R^*=2)$	$R^* (\pi^* = 2)$
1965:Q4-1979:Q3	1.48 (0.64)	1.04 (0.12)	0.46 (0.08)	12.49	1.56
1979:Q4-1987:Q2	3.38 (0.52)	1.43 (0.10)	0.10 (0.09)	-3.20	4.24
1987:Q3-2000:Q3	1.15 (0.33)	1.32 (0.11)	0.68 (0.06)	2.63	1.79
2000:Q4-2013:Q4	-0.41 (0.53)	1.20 (0.26)	0.42 (0.04)	11.86	-0.01

Table 2. Modified Taylor Rule Deviations

a) Tests for Multiple Structural Changes

$$d_t = \gamma_0 + \gamma_1 DU_{1t} + \gamma_2 DU_{2t} + \gamma_3 DU_{3t} + u_t$$

SupF test (sequential method)	Critical values (1%)	Break dates	Coefficients	95% Confidence Intervals
			$\gamma_0 = -1.50$	
SupF(2 1) = 100.06*	13.89	1979:Q4	$\gamma_1 = 5.35$	1979:Q1 - 1980:Q2
SupF(1 0) = 16.05*	12.29	1987:Q4	$\gamma_2 = -4.61$	1987:Q3 - 1988:Q4
SupF(4 3) = 190.48*	15.28	1999:Q3	$\gamma_3 = -2.84$	1999:Q1 - 1999:Q4
SupF(3 2) = 33.80*	14.80	2006:Q4	$\gamma_3 = 4.07$	2006:Q1 - 2007:Q1

b) Taylor Rule estimates

$$i_t = \mu + \alpha\pi_t + \gamma y_t, \text{ where } \phi = \alpha - 1, \pi^* = \frac{(R^* - \mu)}{\phi} \text{ and } R^* = \mu + \phi\pi^*$$

	μ	α	γ	$\pi^* (R^*=2)$	$R^* (\pi^* = 2)$
1965:Q4-1979:Q4	1.17 (0.64)	1.12 (0.12)	0.49 (0.08)	7.13	1.40
1980:Q1-1987:Q4	3.11 (0.47)	1.43 (0.09)	0.10 (0.09)	-2.25	4.09
1988:Q1-1999:Q3	1.12 (0.29)	1.27 (0.10)	0.82 (0.06)	3.27	1.66
1999:Q4-2006:Q4	-1.62 (0.66)	1.18 (0.29)	0.89 (0.11)	20.65	-1.27
2007:Q1-2013:Q4	3.12 (0.83)	0.01 (0.34)	0.74 (0.07)	1.12	1.12

Table 3. Taylor Rule Deviations with a Time-Varying (Trend Growth) Equilibrium Real Interest Rate

a) Tests for Multiple Structural Changes

$$d_t = \gamma_0 + \gamma_1 DU_{1t} + \gamma_2 DU_{2t} + \gamma_3 DU_{3t} + u_t$$

SupF test (sequential method)	Critical values (1%)	Break dates	Coefficients	95% Confidence Intervals
			$\gamma_0 = -3.47$	
SupF(1 0) = 95.38*	12.29	1979:Q3	$\gamma_1 = 5.72$	1979:Q2 - 1979:Q4
SupF(2 1) = 165.81*	13.89	1987:Q4	$\gamma_2 = -2.84$	1987:Q2 - 1988:Q3
SupF(3 2) = 47.76*	14.80	1999:Q4	$\gamma_3 = -2.97$	1999:Q2 - 2000:Q2
SupF(4 3) = 72.97*	15.28	2006:Q4	$\gamma_3 = 2.37$	2006:Q1 - 2007:Q3

b) Taylor Rule estimates

$$i_t = \mu + \alpha \pi_t + \gamma_t, \text{ where } \phi = \alpha - 1 \text{ and } \pi^* = \frac{-\mu}{\phi}$$

	μ	α	γ	π^*
1965:Q4-1979:Q3	-2.92 (0.67)	1.19 (0.13)	0.40 (0.08)	15.49
1979:Q4-1987:Q4	1.45 (0.48)	1.33 (0.09)	0.13 (0.09)	-4.47
1988:Q1-1999:Q4	-0.29 (0.36)	0.91 (0.11)	0.64 (0.07)	-3.20
2000:Q1-2006:Q4	-5.44 (0.72)	1.68 (0.32)	0.69 (0.12)	8.06
2007:Q1-2013:Q4	-0.04 (0.77)	0.31 (0.32)	0.52 (0.07)	-0.06

Table 4. Taylor Rule Deviations with a Time-Varying (Laubach and Williams) Equilibrium Real Interest Rate

a) Tests for Multiple Structural Changes

$$d_t = \gamma_0 + \gamma_1 DU_{1t} + \gamma_2 DU_{2t} + \gamma_3 DU_{3t} + u_t$$

SupF test (sequential method)	Critical values (1%)	Break dates	Coefficients	95% Confidence Intervals
			$\gamma_0 = -4.18$	
SupF(1 0) = 188.44*	12.29	1979:Q3	$\gamma_1 = 5.84$	1979:Q2 - 1979:Q4
SupF(2 1) = 71.47*	13.89	1987:Q2	$\gamma_2 = -2.28$	1986:Q4 - 1988:Q4
SupF(4 3) = 98.58*	15.28	1999:Q4	$\gamma_3 = -2.30$	1999:Q2 - 2000:Q2
SupF(3 2) = 30.20*	14.80	2006:Q4	$\gamma_3 = 2.94$	2006:Q2 - 2007:Q1

b) Taylor Rule estimates

$$i_t = \mu + \alpha\pi_t + \gamma_t, \text{ where } \phi = \alpha - 1 \text{ and } \pi^* = \frac{-\mu}{\phi}$$

	μ	α	γ	π^*
1965:Q4-1979:Q3	-3.38 (0.66)	1.14 (0.13)	0.41 (0.08)	24.20
1979:Q4-1987:Q2	1.19 (1.78)	1.15 (0.88)	-0.01 (-0.19)	-7.93
1987:Q3-1999:Q4	-0.52 (0.34)	0.98 (0.11)	0.64 (0.07)	-34.04
2000:Q1-2006:Q4	-4.70 (0.69)	1.64 (0.31)	0.68 (0.12)	7.34
2007:Q1-2013:Q4	1.59 (0.57)	0.01 (0.24)	0.49 (0.52)	1.61

Figure 1. Real-time Output Gaps using Linear, Quadratic, and Hodrick-Prescott Detrending

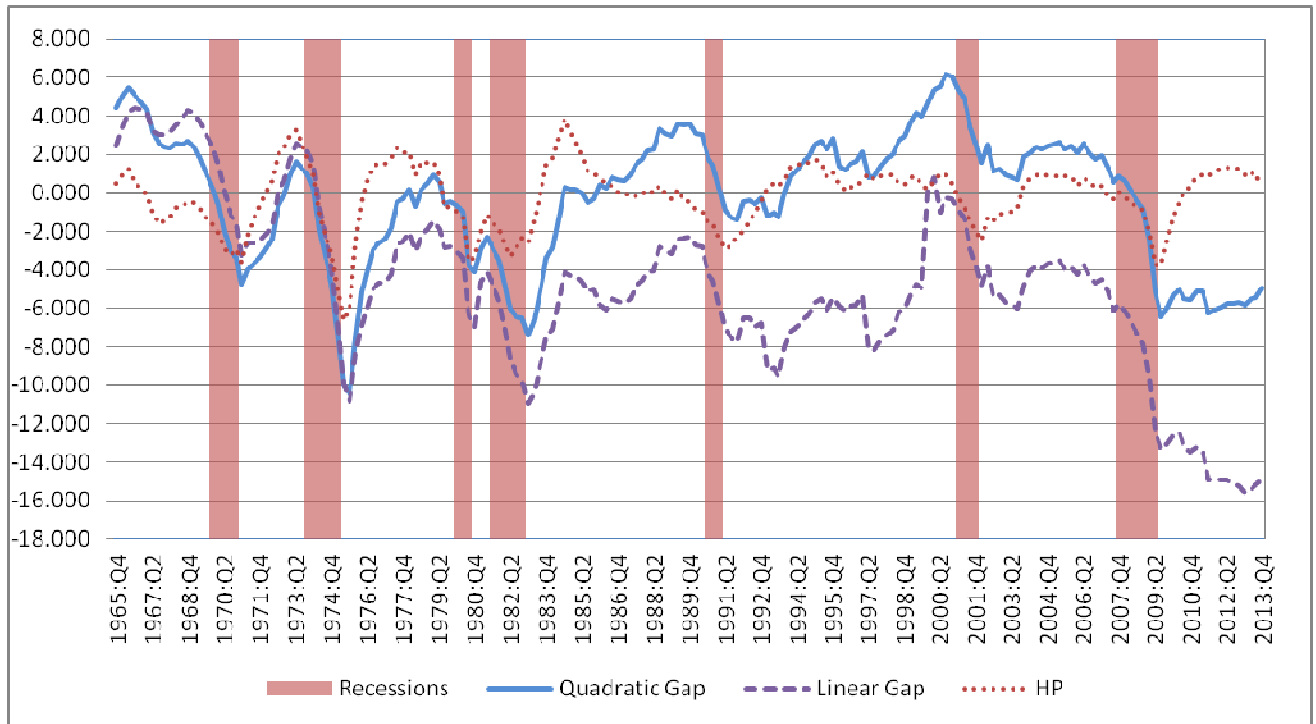
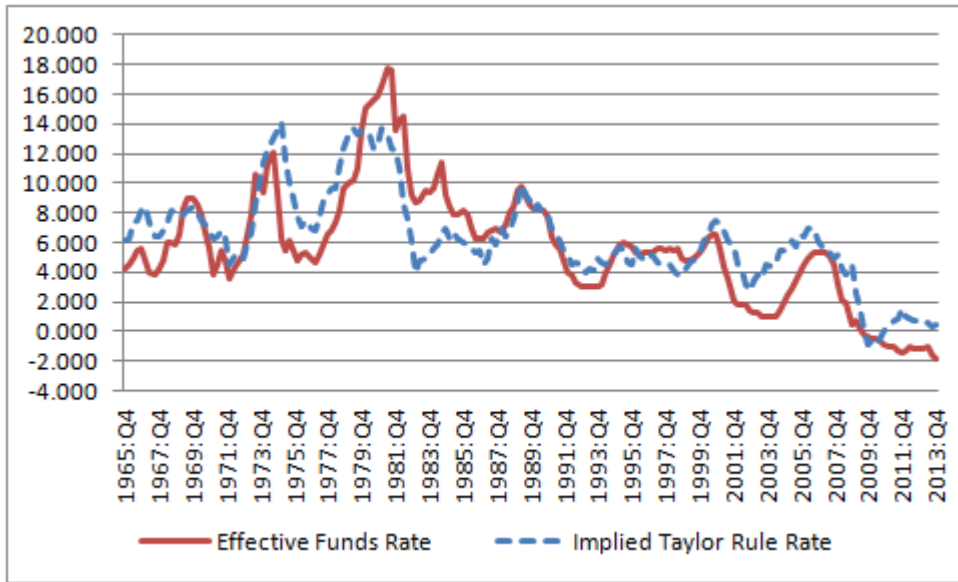


Figure 2. Deviations from the Original Taylor Rule

Panel A. The Federal Funds Rate and the Implied Rate



Panel B. Deviations from the Original Taylor Rule

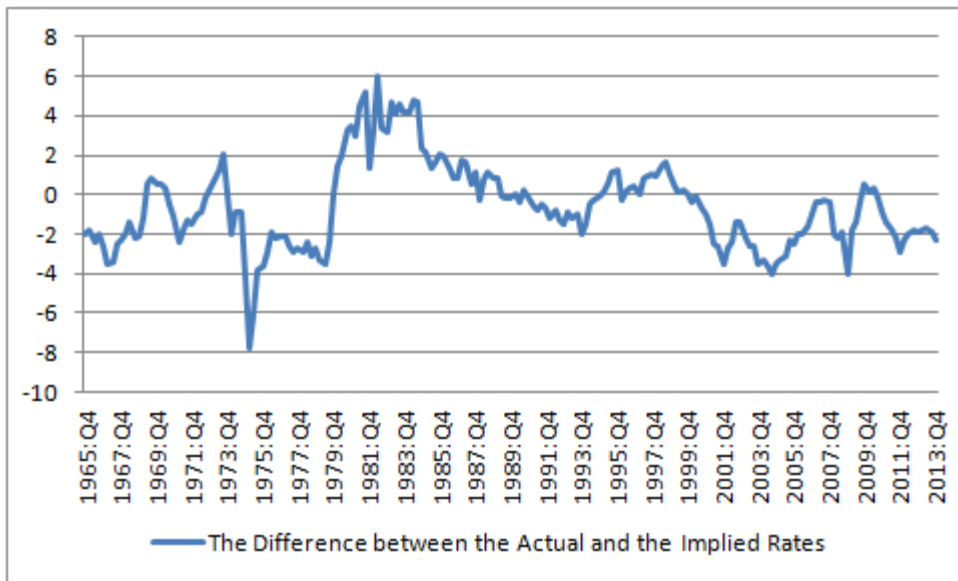
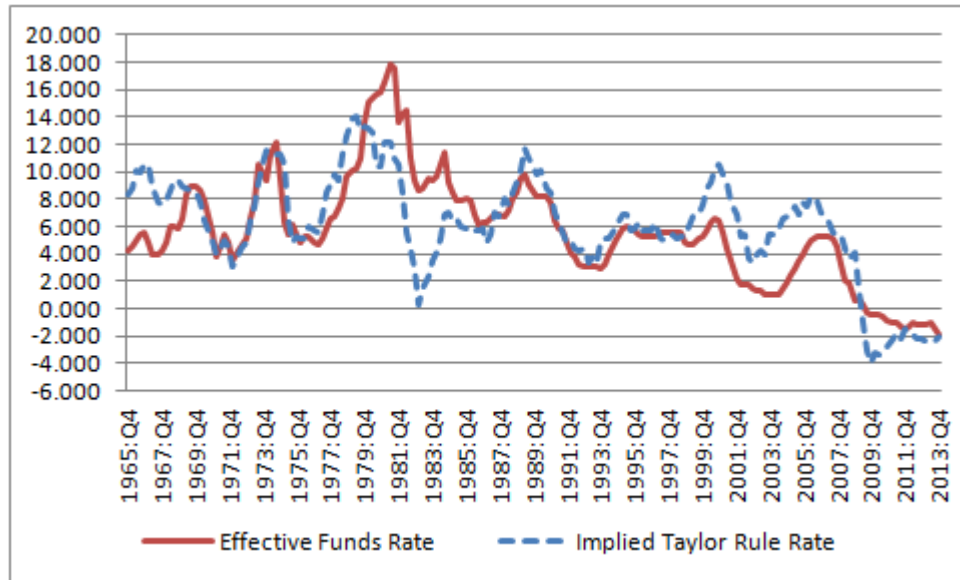


Figure 3. Deviations from the Modified Taylor Rule

Panel A. The Federal Funds Rate and the Modified Implied Rate



Panel B. Deviations from the Modified Taylor Rule

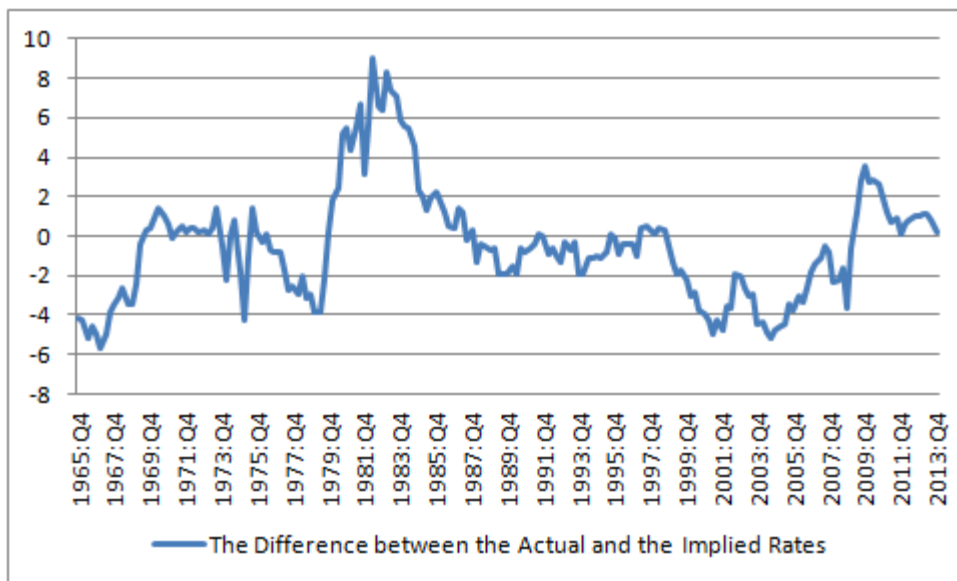
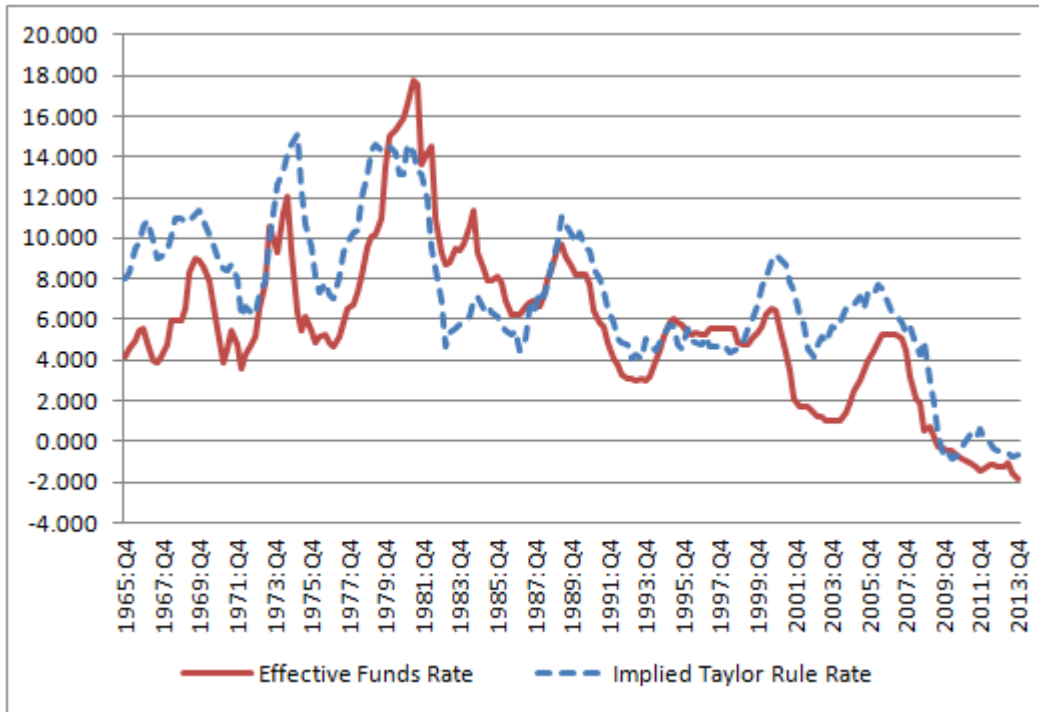


Figure 4. Deviations from the Time-Varying (Trend Growth) Taylor rule

Panel A. The Federal Funds Rate and the Time-Varying (Trend Growth) Implied Rate



Panel B. Deviations from the Time-Varying (Trend Growth) Taylor rule

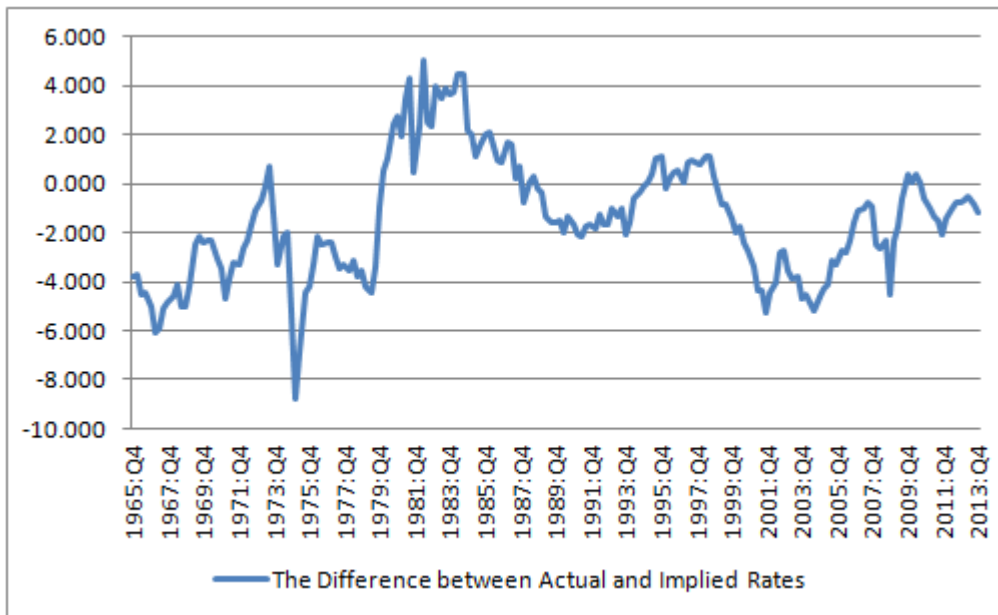
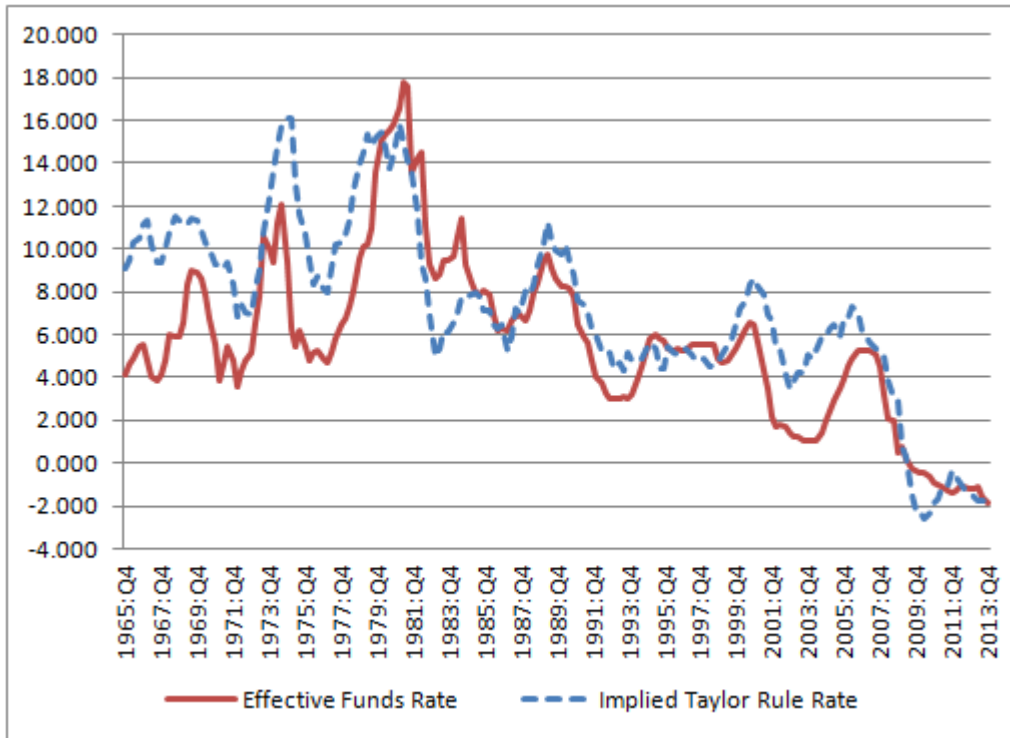


Figure 5. Deviations from the Time-Varying (Laubach-Williams) Taylor rule

Panel A. The Federal Funds Rate and the Time-Varying (Laubach-Williams) Implied Rate



Panel B. Deviations from the Time-Varying (Laubach-Williams) Taylor rule

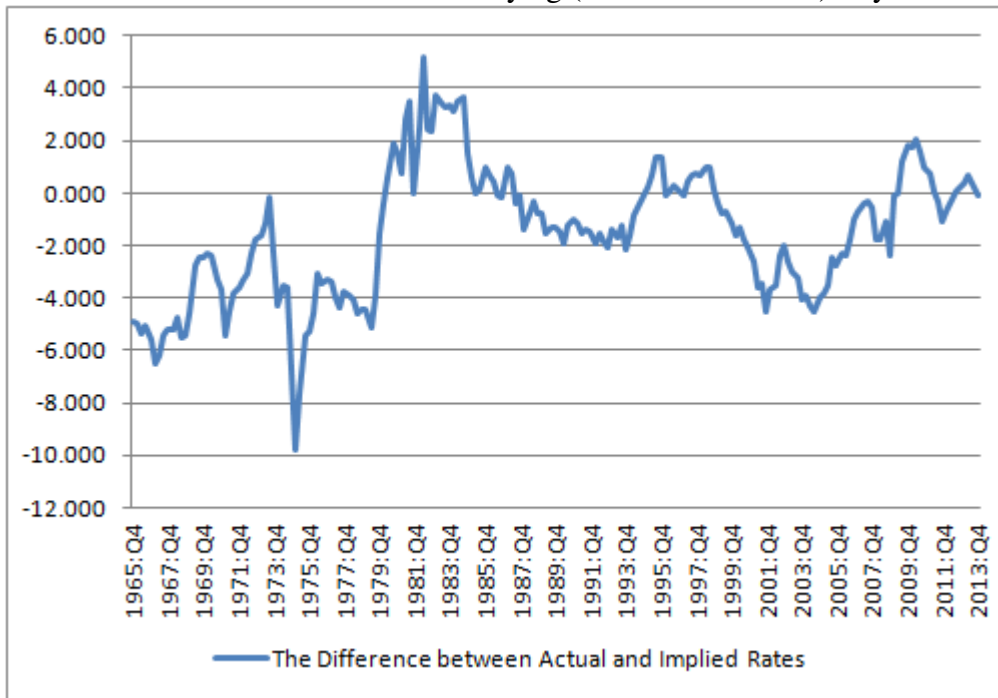
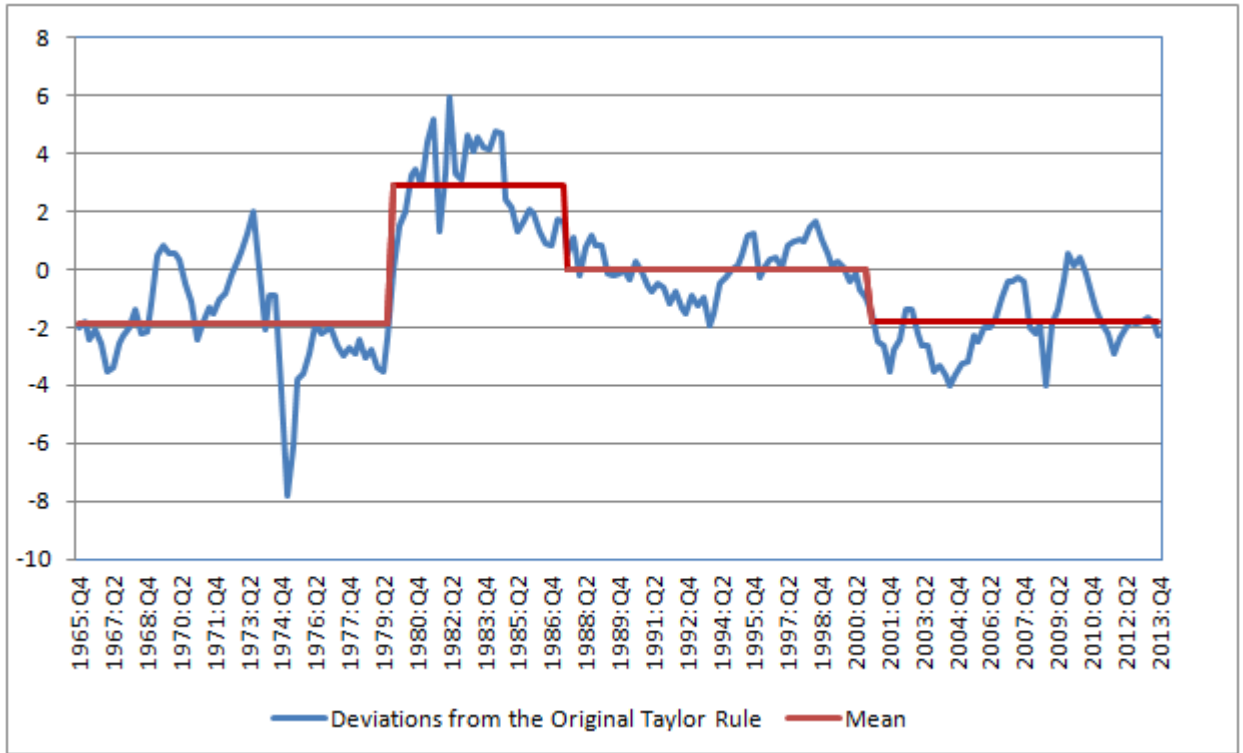
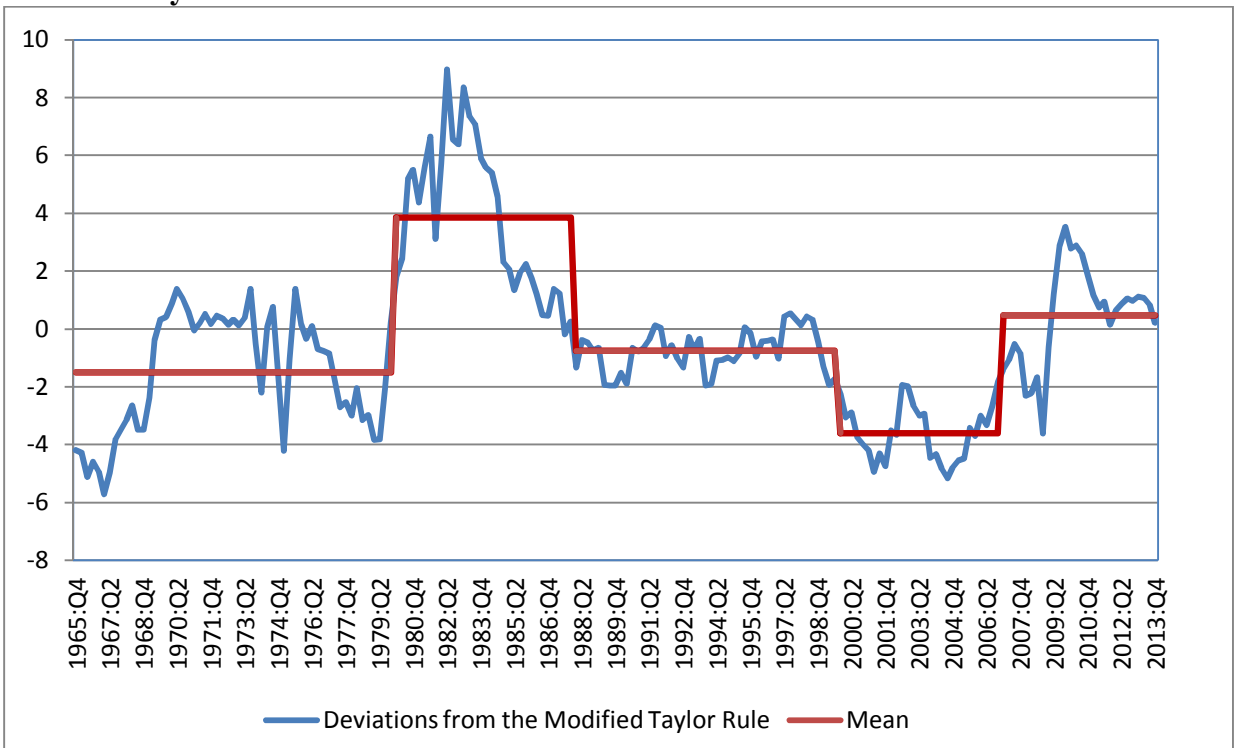


Figure 6. Structural Change Tests for Taylor Rule Deviations

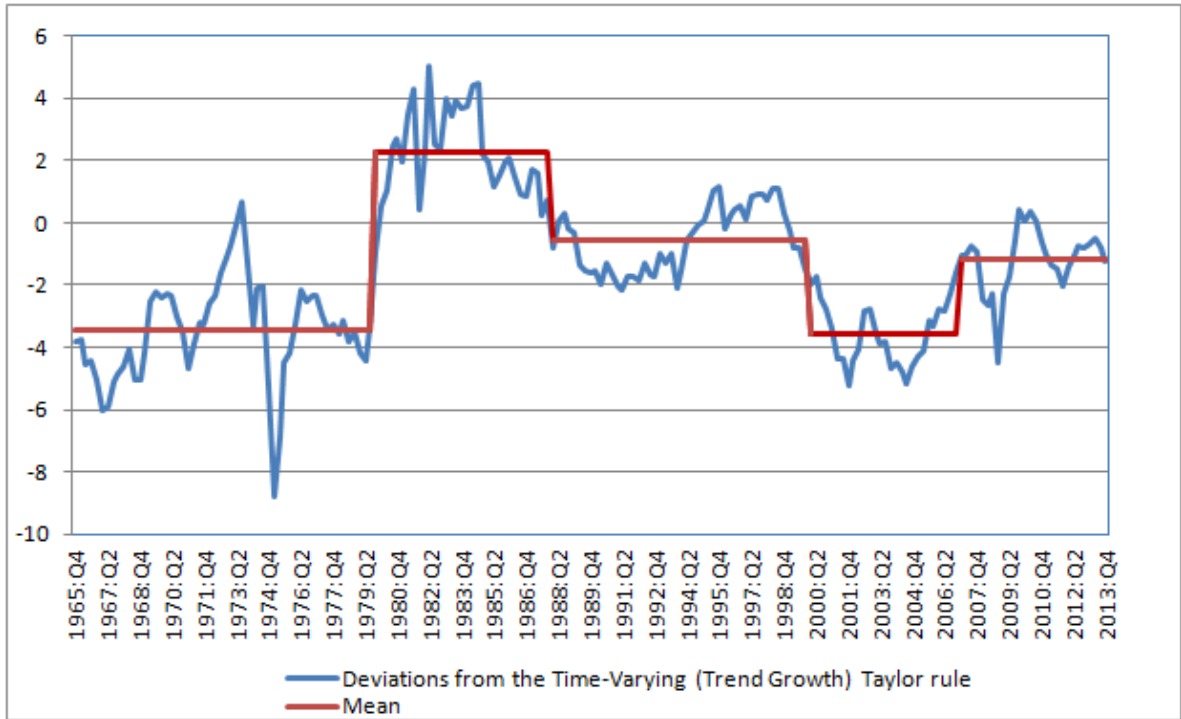
A. Original Taylor Rule Deviations



B. Modified Taylor Rule Deviations



C. Taylor Rule Deviations with a Time-Varying (Trend Growth) Equilibrium Real Interest Rate



D. Taylor Rule Deviations with a Time-Varying (Laubach-Williams) Equilibrium Real Interest Rate

