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The Taylor Rule with real-time data and an analysis of its impact on historical policy analysis

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Abstract

The Federal Reserve system (the Fed) is the United States monetary policy authority and is mandated by Congress to pursue two goals: 1) maximum sustainable output and employment and 2) stable prices. Among the actions the Fed can take to achieve these goals is the ability to set the target federal funds rate. Simple policy rules that set the level of funds rate in response to changes in economic variables have gained attention as a means to more effective monetary policy. One of the most researched and cited rules is that proposed by economist John Taylor in 1993. Taylor's rule is simple and intuitive, and it was found to be surprisingly accurate during the period from 1987 to 1992. However, this analysis is based on impractical assumptions about the amount of accurate data available to a policymaker at the moment of his or her decision.

I explore the differences in policy rules using real-time data – that is, data available to a policymaker at the moment of policy decision, versus ex-post data – that is, data that has been fully revised and is accepted as the most accurate representation of an economic variable. Within this analysis, I also evaluate differences in policy rules between Fed Chairmen. While analysis using ex-post data by Judd and Rudebusch (1998) has found statistically significant differences in reaction functions between Fed Chairmen, I find that not only does a real-time Taylor rule recommend different levels of the federal funds rate than an ex-post Taylor rule, but also Fed Chairman is not necessarily a determinant of structural change in policy formation. I conclude that monetary policy rules in real-time seem to describe "eras" of economic events and recommendations generated within these "eras" do not differ from actual observations as much as Taylor found using his rule.

I. Introduction

The Federal Reserve System (the Fed) is the United States' monetary policy authority. The Fed is mandated by Congress to pursue two goals: 1) maximum sustainable output and employment and 2) stable prices. The Fed fulfills this dual mandate by setting a target for the federal funds rate – that is, the interest rate financial institutions charge one another for overnight loans of reserves. Effectively, the fed funds rate is a benchmark for other short-term interest rates and broadly influences credit conditions. A "reaction function" is a model that describes how the Fed alters monetary policy (i.e., changes the target funds rate) in response to economic developments.

The reaction function provides a basis for evaluating Fed policy and the effects of other policy actions (i.e., fiscal) or economic shocks (i.e., the subprime mortgage crisis), explaining patterns in interest rates (i.e., rates in the 1980s versus those seen before 2007), and ultimately predicting the Fed's policy decisions before announced. As such, many economists have estimated unique reaction functions. Taylor (1993) estimated a rule that specifies the real federal funds rate reacts to two key goal variables – deviations of contemporaneous inflation from a target and deviations of real output from its long-run potential level. In this specification, equal weights of 0.5 are assigned to the inflation and output gaps, and 2 percent is assumed as the long run target for the natural rate of inflation and interest. In another specification, Judd and Rudebusch (1998) expand upon Taylor's rule by using historical data to econometrically estimate the actual weights on the inflation and output gap. The pair also calculates historical averages for the target interest and inflation rate instead of assuming a constant target of 2 percent.

While these reaction functions differ in exact parameter specification, each uses finalized economic data – that is, data that has undergone multiple revisions and is accepted as the most accurate representation of a certain variable. This type of data is referred to as ex-post data. Taylor's rule follows the actual federal funds rate closely, and some economists argue for basing the target rate on the rule's prescription instead of discretion. For example, Judd and Trehan (1995) show during the Burns period, the funds rate was consistently lower than the rule's recommendation, which is consistent with the overall increase in inflation during the period, and confirms the rule with an explicit 2 percent inflation target, might have held inflation to a much lower level than the actual policy did.

The caveat to these analyses, however, is ex-post data is not representative of the data available to the Fed when deciding how to conduct monetary policy. In my specification of the Fed's reaction function, I utilize real-time data to evaluate how the use of sometimes preliminary and unrevised data affects previous findings of Taylor-type rules. The difference between the recommendations generated using real-time data and ex-post data will provide an analysis of how fully revised data can yield misleading descriptions of historical policy. Analysis of the deviations will provide a new basis for explaining, evaluating, and perhaps predicting monetary policy. Lastly, while the Taylor rule has been found to accurately describe Fed behavior, Taylor rule type reaction functions have been shown to differ significantly across Fed Chairmen (Judd and Rudebusch 1998). This research has been conducted using ex post data, and my thesis will focus on this same topic using real-time data.

II. Literature Review

A large amount of economic research is devoted to the evaluation of monetary policy. As the amount of research has grown over time, economists have focused analyses on specific facets of policy. Consequently, these individual topics have emerged as unique areas of research, and the literature within each topic has grown in volume and depth. One of those topics is the development of "rules" or formulas telling the Fed how to set monetary policy. An example of early research in the area is Friedman's (1959) proposal that the Fed increase the money supply a constant 4 percent each year to eliminate inflation and avoid destabilizing the economy.

Since Friedman's proposal, policy rules evolved to permit the Fed to respond to economic conditions. For example, McCallum (1988) developed a rule that determined how much money growth should change when nominal GDP deviated from its target, Feldstein and Stock (1993) proposed a rule that uses the M2 money stock to target the quarterly rate of growth of GDP, Hall and Mankiw (1993) suggested three different types of nominal income targeting, and Taylor (1993) advised the federal funds respond to changes in inflation and real GDP.

Taylor designed his rule to recommend the Federal Reserve adjust the federal funds target with equal response to deviation of inflation from a target and deviation of real output from a target. Taylor found this rule fit actual policy performance during the 1987-1992 period surprisingly well. Taylor (2012) additionally determined monetary policy from 1985 to 2003 was primarily "rules-based," and following 2003, policy was primarily "discretion-based."

The applicability of Taylor's rule advanced research devoted exclusively to analyzing the historical relationship between the Taylor rule and policy decisions. Orphanides (2003) defined both a "narrow" and "broad" interpretation of the Taylor rule to examine Federal Reserve policies using Taylor's classic rule and an adaptation that allowed the use of forecasts in setting policy. The research provided evidence that not only has the Fed historically relied on short-term interest rates as its primary policy instrument, but policymakers have also exhibited consistency in interpreting operational objectives regarding price stability and economic growth. Judd and

Rudebusch (1998) econometrically estimated individual reaction functions for Fed Chairmen Burns, Volcker, and Greenspan and found the Fed's reaction function has differed by Chairman, indicating structural changes in the function over time. This area of research allows economists to interpret possible caveats to the rule and to better understand how historical policy decisions can guide future policy.

Because Taylor's rule relies on the measurement of economic variables, it is also important to distinguish the degree of information available to a policymaker at a given time when analyzing historical decisions. McCallum (1993) pointed out Taylor's formulation was not "operational" because it required information about current and recent quarter observations that the policymaker did not necessarily have at his disposal. Orphanides (1997) adds analysis of Taylor's simple policy rule is based on unrealistic assumptions about the timeliness of data availability. Taylor exclusively used ex-post data in his 1993 specification of the rule, or fully revised, final estimates of data, which is consequently not representative of the information available to a policymaker at the moment of his or her decision. This observation prompted analysis of Taylor's rule using real-time data. Orphanides (1997) reconstructs Taylor's original rule and finds not only do real-time policy recommendations differ widely from those obtained with revised published data but also the recommendations did not follow the actual federal funds rate nearly as closely as Taylor's predictions. This research provides a caveat to simply relying on rules to evaluate historical policy. It suggests policy rule analysis does not always place the proper emphasis on the informational problem associated with it.

My research aims to further analyze Judd and Rudebusch's (1998) claims of statistically significant differences in reaction functions between Fed Chairmen by using real-time data instead of ex-post data. My goal is to first determine if differences in reaction functions between

Chairmen still exist when accounting for the informal problem. Second, if the reaction functions still differ between Chairmen, I use real-time data to econometrically estimate functions for each Fed Chairman. From this, I will analyze how differences in functions compare to those found by Judd and Rudebusch. Through this analysis, I determine which real-time specification of Taylor's rule describes Fed behavior most accurately by estimating potential output using 3 different methods (linear, quadratic, and HP filter) and using a range of different inflation and interest rate targets. This research effectively combines the ideas that differences in policy decisions emerge due to different administrations as well as informational issues. The resulting findings will provide further limitations to the evaluation of historical policy by using simple policy rules.

III. Data and Notation

The data consist of the real-time observations compiled by Croushore and Stark (2001) in The Real-Time Data Set for Macroeconomists. The data set includes data as they existed in the middle of each quarter, for vintage dates 1965:Q4 through 2014:Q3. For each vintage, there exists a time series of data that begins in 1947:Q1 and extends to one quarter prior to a given vintage date. The complete data set includes a large number of economic variables, but my research is limited to a subset of those. I use quarterly observations of real GNP or GDP and the price index for GNP/GDP. The output variable is GNP in vintages before February 1992 but GDP in vintages from February 1992 on.[1] In addition to the real-time data, I also use quarterly observations of the effective federal funds rate from 1965:Q4 to 2014:Q3. The data is summarized in Table 1.

[1] Croushoure and Stark constructed the data set to be consistent with the "headline" variable, or the variable that is listed in Tables 1.1 and 1.2 in the *Survey of Current Business* and is the focus of the discussion about aggregate economic activity

In the context of the Taylor rule, there is a distinction when using ex-post instead of real-time data. With ex-post data, contemporaneous values are used for inflation and the output gap. With real-time data, the variables are not known contemporaneously, and one-quarter lagged values are used. Hence, at vintage date t, policymakers use data measured through time t-1. To make this distinction, each real-time variable is defined as X_{t-1} in my notation. I add a second distinction to allow for flexibility in the analysis. I add t+i to denote the vintage. Accordingly, for analysis of the Taylor rule, $X_{t-1,\ t+i}$ represents the data available for vintage t as of vintage t+i, where i = 0. Further analysis could focus on a given date and set i = 0, 1, 2, 3… to estimate different Taylor rules for each vintage t+i after first estimates of the data have been revised. In the context of the Taylor rule, the notation signals two changes. The first is that the measure of average inflation equals the prior four-quarter average inflation, instead of the contemporaneous and prior three quarter average. The second is potential output differs for each vintage date. The process of calculating the gap is a two-step process. First, I detrend the data for each vintage date from 1947:Q1 through one quarter prior to the given vintage date. Second, I calculate the output gap for each time-series observation within each vintage date. I then use the most recent observation of the output gap from each vintage date as the measure of the output gap in my analysis.

IV. Empirical Model

To begin my analysis, I apply Taylor's (1993) original rule to the real-time data set to determine if the rule predicts the federal funds rate in real-time as well as Taylor found it to in his ex-post analysis. Taylor suggests a simple rule for monetary policy that sets the level of the nominal federal funds rate equal to the rate of inflation plus an "equilibrium" real funds rate plus an equally weighted average of two gaps: (1) the four-quarter moving average of actual inflation less a target rate, and (2) the percent deviation of real GDP from an estimate of its potential level. The following rule is updated with the real-time notation:

$$(1)\ i_t^* = \pi_{t-1,\,t+i} + r^* + 0.5(\pi_{t-1,\,t+i} - \pi^*) + 0.5(y_{t-1,\,t+i})$$

Where: i_t^* = recommended quarterly federal funds rate
$\pi_{t-1,\,t+i}$ = average inflation rate over the prior four quarters (GDP deflator)
r^* = equilibrium real federal funds rate
π^* = target inflation rate
$y_{t-1\ t+i}$ = output gap (100·(real GDP – potential GDP)÷potential GDP)[2]

Taylor assumed the weights the Fed gives to deviations of inflation and output are both equal to 0.5 instead of econometrically estimating the equation. He also assumed the equilibrium real funds rate and inflation target are both equal to 2 percent. Using these same assumptions, I calculate the predicted federal funds rate using the real-time data. A comparison of the actual funds rate, Taylor's predictions, and the real-time predictions are shown in Figure 1. The figure shows while Taylor's predictions follow the actual funds rate closely, the real-time predictions differ significantly. In fact, the real-time predictions are consistently lower than both the actual funds rate and Taylor's predictions. This finding establishes the idea either Taylor's weights on the respective gaps or his estimates for target inflation and the equilibrium funds rate do not describe the real-time data as well. Accordingly, either adjusting the relative weighting of the gaps or increasing the target and/or equilibrium rates will help correct the discrepancy.

To continue, I choose to econometrically estimate the weights on the inflation and output gap. I replace the pre-selected weights in Taylor's original equation with coefficients λ_1 and λ_2 as shown in equation (2):

$$(2)\ i_t = \pi_{t-1,\,t+i} + r^* + \lambda_1(\pi_{t-1,\,t+i} - \pi^*) + \lambda_2(y_{t-1,\,t+i}) + \mu_t$$

Where: i_t = Observed quarterly federal funds rate
λ_1 = Weight given to the inflation gap

[2] Taylor (1993) uses a log linear trend of real GDP from 1984:Q1 to 1992:Q3 as the measure of potential GDP. I use a log linear trend from 1965:Q4 to 2014:Q3 to follow the data.

λ_2 = Weight given to the output gap

I add an error term in this specification to capture deviations from the rule, or in this case, deviations from what was actually observed. Again, I assume the inflation target and equilibrium real funds rate are equal to 2 percent. I use ordinary least squares (OLS) to estimate coefficients λ_1 and λ_2 as 0.069 and 0.231 respectively. The full model is shown in Table 2. Econometric estimation shows that in real-time, not only are the inflation and output gap not given equal weight, but the output gap is given more than three times the weight of the inflation gap. A comparison of the actual federal funds rate, Taylor's predictions, and the predictions from equation (2) are shown in Figure 2. As can be seen from the figure, rates predicted by equation (2) follow the actual fed funds rate much more closely than the rates predicted by equation (1). Similarly, rates predicted by equation (2) follow Taylor's predictions more than those predicted by equation (1) and Taylor's original specifications. This finding demonstrates that while a predetermined policy rule may follow actual policy closely given ex-post data, the rule does not fit as well when using the data available to policymakers in real-time. Although equation (2) describes the actual federal funds rate more precisely, the R^2 appears low at 0.178. Therefore, the use of one equation to describe the entire time period merits further investigation. In all of the subsequent analysis, I follow Judd and Rudebusch's (1998) procedure closely. The authors use a Taylor type rule to prove reaction functions differ between Fed Chairmen, so I use the same rule to analyze whether Fed Chairman is a significant factor in describing monetary policy in real-time.

In Judd and Rudebusch's (1998) analysis of changes in Fed behavior, the authors note central banks appear to adjust interest rates in a gradual fashion. In estimating separate reaction functions for Burns, Volcker, and Greenspan, the two specify a Taylor rule in the context of an error correction model that allows for interest rate smoothing. Equation (2) is replaced with

$$(3)\ i_t^* = \pi_{t-1,\,t+i} + r^* + \lambda_1(\pi_{t-1,\,t+i} - \pi^*) + \lambda_2(y_{t-1,\,t+i}) + \lambda_3(y_{t-2,\,t+i})$$

where i_t^* is the federal funds rate achieved through gradual adjustment and an additional lagged gap term is included to allow for the possibility that the Fed responds to revisions of monetary policy targets as more data becomes available. The notation used in equation (3) already reflects the use of real-time data for my subsequent analysis. The dynamics of adjustment of the actual level of the funds rate to i_t are given by:

$$(4)\ \Delta i_t = \gamma(i_t - i_{t-1}^*) + \rho\Delta i_{t-1}$$

Meaning, the change in the funds rate at time t corrects the "error" between last period's setting and the current recommended level (shown by the first term) while maintaining "momentum" from last period's funds rate (shown by the second term). By substituting equation (3) into (4), the equation to be estimated is obtained:

$$(5)\ \Delta i_t = \gamma\alpha - \gamma i_{t-1} + \gamma(1 + \lambda_1)\pi_{t-1,\,t+i} + \gamma\lambda_2(y_{t-1,\,t+i}) + \gamma\lambda_3(y_{t-2,\,t+i}) + \rho\Delta i_{t-1} + \mu_t$$

Where $\alpha = r^* - \lambda_1\pi^*$. Again, equation (5) has already been changed to reflect the use of real-time data in my analysis. The authors find statistically different estimates for each of the above variables for each of the Fed Chairmen. Thus, they conclude Fed Chairman is a contributing factor to the change in Federal Reserve behavior over time. I apply the same methodology to real-time data to observe if reaction functions are still statistically different between Chairmen and how the differences compare to conclusions found using ex-post data.

One of the "issues" in estimating Taylor's rule includes determining r^* and π^* and estimating potential real GDP. As shown in equation (5), estimation cannot determine both the equilibrium real funds rate and the inflation target simultaneously. Judd and Rudebusch use historical observations to estimate equation (5) under a variety of assumptions. I apply two of these methods to the real-time data set. The first method is to set the equilibrium real funds rate or the target inflation rate equal to the average rate that prevailed over each individual Chairman's term. The second method is to set the equilibrium real funds rate or the target inflation target equal to the average rate that prevailed over the entire sample. When using these methods, it is important to note the average levels of inflation over the samples are less plausible than the assumptions of the real funds rate given the persistence of inflation. Policymakers may "inherit" persistent inflation rates much different from their own target rate, thus skewing sample averages. Setting the inflation target equal to average inflation over the entire sample tries to combat this possible bias. The calculations are summarized in Table 3.

The next issue to consider is estimation of the real output gap. Taylor (1993) uses a log-linear method while Judd and Rudebusch (1998) use a structural definition of potential GDP that was developed by the Congressional Budget Office. With unrevised data, there is a bias around business cycle turning points, thus output gap estimates in real-time are less reliable than estimates using ex-post data (Orphanides and van Norden 1999). While Orphanides and van Norden (1999) present an extensive examination of output detrending methods using Croushore and Stark's (2001) real-time data set, I choose three for my analysis: (1) A linear trend, (2) a quadratic trend, and (3) the Hodrick Prescott (HP) filter. Figure 3 displays a comparison of the gaps. The Figure shows that the quadratic estimation follows the actual estimate most closely. Because of this observation, I present my conclusions regarding the different reaction functions of the Fed Chairmen using the quadratic estimate of the output gap. Results using the alternative specifications are presented in the appendix.

V. Results: Reaction Functions

My main hypothesis is that taking account of changes in Fed Chairmen in real-time will still help account for changes in the Fed's reaction function. Accordingly, I conduct Chow tests on equation (5) for three breaks during the 1970:Q1-2014:Q2 period corresponding to the terms of Chairmen Burns, Volcker, Greenspan, and Bernanke. I eliminate Miller from the analysis due to his short tenure (1979:Q3 – 1981:Q1), as do Judd and Rudebusch. The null hypothesis of the test is no structural change. Thus, a "large" critical F-value will result in rejection of the null and the conclusion that significant breaks exist in the data. The test rejects stability for the first two breaks (Burns/Volcker and Volcker/Greenspan) at the 95% and 99%, level of confidence respectively. However, the null is accepted for the third break (Greenspan/Bernanke). It is important to note, Judd and Rudebusch (1998) reject stability at the 0.00% level of significance for each of the two breaks they tested (their analysis ended before Bernanke's tenure). I additionally test for a break between the Burns/Greenspan period, the Burns/Bernanke period, and the Volcker/Bernanke period. The first two tests reject stability at the 99% and 90%, level of confidence respectively, while the third accepts the null. The critical F-values for each of the preceding tests as well as the values given changes in the measurement of the output gap are shown in Table 4. As Judd and Rudebusch (1998) note, finding significant breaks in the data is not necessarily strong evidence in favor of structural change at the Fed as Chairmen change, but the Chow tests are an initial step. With this understanding, I still estimate individual reaction functions for the Chairmen. To outline the remaining results, I present four exhibits for each of the four Fed Chairmen. In them, I estimate the reaction function (equation (5)) for each Chairman using OLS and then re-estimate each equation after eliminating the lagged observation of the funds rate and the lagged dependent variable. This eliminates the dynamics of adjustment from the equation and focuses exclusively on observations of the output and inflation gap. This function is represented by equation (3). I also display an analysis of plausible values for the equilibrium real funds rate and target inflation during each of the Chairmen's tenures. Before concluding, I also present an alternate reaction functions that describe the Greenspan/Bernanke period. My discussion here will first analyze each of the reaction functions estimated and then examine the respective calculations of r^* and π^*.

a. The Burns Period

In Regression A, the coefficient on the lagged actual funds rate of -0.03 has an interesting impact on the other independent variables. This coefficient is low enough to make the other coefficients significantly larger and estimates of target inflation and interest (which will be shown in the next section) vary widely. The only significant variable in this equation is the output gap, and the weight on the gap is more than double that on the inflation gap. This suggests the inflation gap was given relatively low consideration during the Burns period and is similar to Judd and Rudebusch's (1998) finding that the real funds rate appeared to not be adjusted on the basis of changes in inflation. The two also find the coefficient on inflation gap is negative, which corroborates my findings as well. This observation is most likely the result of Burns' decision to lower the funds rate and address the negative output gap, even as inflation was still increasing. The dynamic rule in general seems to be a poor representation of the Burns period given the coefficients estimated for the lagged funds rate and the lagged dependent variable. Both are statistically insignificant and less than 0.1, suggesting Burns did not focus monetary policy on changes in the rate.

Regression B, the stationary rule, does in fact describe the Burns period with more plausible estimates. Each of the economic variables is statistically significant in determining the actual funds rate. The weight on the output gap of -0.62 is still larger and now more than three times that on the inflation gap. Still, although both estimates are statistically significant, it appears that in real-time the output gap is given more consideration when determining both changes and levels of the funds rate.

Graph (1b) shows that the actual change in the funds rate follows the general movement that is predicted by Regression A, but the actual change is more volatile. For example, in the early 1970’s Burns made sharp adjustments to the rate that diverge from the more gradual transitions suggested by the rule. This is not surprising given the low magnitudes on the lagged variables in Regression A. Judd and Rudebusch (1998) do not find relatively low magnitudes for these coefficients in their analysis, thus this finding seems to be unique to the real-time data set. This could be the result of either Burns using forecast estimates of these variables that more closely resemble the ex-post data, which is very likely, or responding to other variables. Burns was vocal about supporting policy that the Fed should act to try and maintain an unemployment rate of around 4 percent.

Graph (1c) depicts the actual and rule predicted rates instead of the changes in the rate. Again, the actual rate follows the general movement of the predicted rate closely, however the predicted rate is noticeably lower from the early to mid 1970’s. Due to the 1973 oil crisis, gas prices and inflation rose quickly. As can be seen in the graph, average real-time inflation reached a peak of 12% in late 1974. Additionally, as inflation rose, the output gap became more negative. Thus, the graph shows the FOMC raised the federal funds rate through the first half of the 1970’s to combat quickly rising inflation, but sharply lowered rates (even before inflation exhibited a decline) in order to address the magnitude of the negative output gap. During this period, the federal funds rate both increased and decreased rapidly as information became available on the rising inflation rate and the declining output gap. This phenomenon has been described as “stopgo" monetary policy (Gavin and Cooke 2014) and was a reason for loss of credibility in the Fed pre-1980. When inflation rose, the FOMC reacted by raising the fed funds rate high enough to slow inflation, but when higher interest rates lowered aggregate spending and output, the FOMC lowered the fed funds rate sharply to stimulate growth. This narrative suggests Burns favored setting and achieving a target rate instead of changes in the rate, and that Regression B is a more accurate descriptor of policy during this period. Near the end of Burns term, the predicted rate was consistently above the actual. This alludes to Volcker's task as Chairman to keep funds targets high for long enough to control persistent inflation.

b. The Volcker Period

Regression results for the Volcker period are shown in Exhibit 2. In Regression A, all coefficients are significant except for that on the lagged dependent variable and that on the constant. The coefficients on the inflation gap and the output gap are 1.47 and 3.83 respectively. The coefficient on the output gap is more than double that on the inflation gap, suggesting more consideration is given to the output gap relative to the inflation gap in real-time. Although this observation is not consistent with Taylor's suggested weights ($\lambda_1= \lambda_2=0.5$), the regression does support the idea that both inflation and output are given consideration relative to a target. The coefficient on each of the gaps is highly significant, suggesting deviations of these variables from a target were important considerations in changing the funds rate target. In the Judd and Rudebusch (1998) analysis, the two find fairly similar magnitudes and differing signs for the coefficients estimated on the output gap and lagged output gap (2.40 and -2.04). Given this finding, the two note Volcker adjusted the federal funds rate based on the growth rate of real GDP instead of the level of real GDP. My analysis does not lead to the same conclusion. The respective coefficients are 3.83 and -2.68, which are not as similar in magnitude as those found by Judd and Rudebusch. Thus, my analysis so far supports the finding that while relationships between different variables (i.e., inflation and output) may be similar using real-time data, relationships between lagged observations of the same variable (i.e., the output gap and the lagged output gap) are not necessarily similar. This is an important first difference to note between analysis of historical policy using ex-post data and that using real-time data.

In Regression B, all coefficients, excluding the lagged output gap, are statistically significant. The coefficient on the inflation gap is 0.44 (virtually the same as Taylor's suggestion), but that on the output gap is 0.81, which is still about double that on the inflation gap. Although both regressions support differing weights on the inflation and output gap, the elimination of the lagged variables causes the weights on the gaps to become closer to Taylor's estimate. This finding is also observed in the Burns period. Thus, the analysis preliminary concludes that the non-dynamic Taylor rule results in findings more consistent with Taylor's original rule (1993) even when using real-time data. However, the question of whether a dynamic rule or stationary rule more accurately describes Fed behavior is still uncertain.

As seen in the Burns period, the actual change follows the general movement of the predicted change well in graph (2b). The changes prior to 1983 relative to those after 1983 are more abrupt. This is consistent with Volcker's decision to set the funds rate at nearly 20% in the early 1980s to lower persistent inflation. Due to the extended duration of high inflation and the loss of Fed credibility pre-1980, the FOMC needed to demonstrate commitment to controlling inflation, and that is seen in the abrupt and large increase in the rate in 1980. As inflation declined around the middle of 1983, it appears the Fed pursued more gradual changes in the rate. Due to the extreme inflation, it is likely the Fed would have deviated from any rules prescription if it thought the unique circumstance was not defined by a rule.

Graph (2c) again shows Volcker deviated from the rule's prescription in the early 1980s with a higher funds rate. The line representing four-quarter average inflation in real-time, shows Volcker lowered the fed funds rate only after inflation actually exhibited a decline. Judd and Rudebusch support this finding stating double-digit inflation was so far above any reasonable inflation target that policy did not need to be concerned with judgments about funds rate settings provided by a Taylor-type reaction function.

c. The Greenspan Period

Greenspan's reaction function is estimated with the most accuracy as measured by the R^2 and adjusted R^2. This may be the result of relatively more observations for the period (75 versus 33 at most for each of the other Chairmen), but it is also consistent with Judd and Rudebusch's (1998) analysis, which was conducted when the amount of available data for each Chairman was equal. In Regression A, the coefficient on the inflation gap of 0.75 is relatively low compared to those in Regression A from the Burns and Volcker period. While the estimate is relatively close to Taylor's (1993) prediction, the estimate on the output gap of 4.59 is not. Accordingly, Taylor's prediction of equal weights is disproven again. The real-time data suggest more than double the weight of the inflation gap is put on the output gap (in fact, more than 6 times here). The lagged dependent variable, the lagged funds rate, the output gap, and the lagged output gap are all highly significant. This suggests Greenspan closely monitored both data from the current and prior periods when setting a new target. The function suggests Greenspan not only attempted to correct "errors" from the prior target rate, but also considered the nature of rate transition- that is, the effect of changes from one period to the next. This finding may be the result of a perceived increase in the need to monitor changes due to the setting of unprecedented, low targets during Greenspan's tenure. Due to economic shocks resulting from both the dot com crash and the September 11 attacks, the FOMC reduced the funds rate to an all time low of 1.00% by 2004. Because the reaction of consumers and markets to these rates was somewhat unknown, it is likely the FOMC took increased care to ensure smooth rate transitions and monitor and correct any unanticipated effects.

Regression B seems to contradict Regression A because it predicts the weight on the inflation gap is higher than that on the output gap. Both coefficients are very close to one (1.08 and 0.97 respectively) and correspondingly close to one another. This is very different from the relationship of the two coefficients in Regression A, so whichever function seems to describe Fed behavior better during this period will allude to the true nature of the relationship. From Regression A, the significance of the lagged dependent variable suggests the Fed responded to changes in the funds rate, so it is likely the relationship between the weights is more similar to that found in the Regression A. To analyze this more, I examine the graphs for each equation.

In graph (3b) the actual change follows the predicted change very well, which makes intuitive sense given the accuracy of the equation. While there are periods during which the actual change appears sharper than the predicted change, the differences are marginal especially when compared to observations from the previous Chairmen's tenures. There also seems to be more changes in the rate during this period. The graph shows relatively more movement compared to that observed during the previous two Chairmen's terms. One possible reason for emphasis on incremental change is the low fed funds targets discussed previously. In graph (3c) Greenspan's response to economic shock is shown at the turn of the century, where the funds rate exhibits a sharp decline following the dot com crash. The output gap, also shown in graph (3c), also exhibited a sharp decline, but inflation remained steady in its fluctuations. These observations give support to Regression A for two reasons: 1) measures of economic variables, even in real-time, suggested changes in output were more pressing than changes in inflation, thus it would make sense to consider the slowing economy more than the barely changing inflation rate, and 2) the funds rate was lowered to unprecedented rates, and consumer as well as market reaction was unknown. It is likely the FOMC monitored the changes closely for any unanticipated effects. Thus far, it appears that in the period following the mid-1980s, also known as the Great Moderation, a dynamic Taylor rule is more descriptive of Federal Reserve behavior.

d. The Bernanke Period

In Regression A, the only significant term is the lagged dependent variable. Accordingly, Bernanke's reaction function is estimated with the least precision as measured by the R^2 and adjusted R^2. Judd and Rudebusch do not perform analysis for Bernanke, given the timing of their publication, so there are no findings from the pair to compare with my own. However, the finding of low accuracy is consistent with some of Bernanke’s comments. Bernanke has been vocal about his opinion on the Taylor rule, and in response to criticism of "overly easy" monetary policy in the decade since 2002, Bernanke referenced the Taylor rule in a speech at the Annual Meeting of the American Economic Association. At the meeting in January 2010, Bernanke lauded the use of the rule as a guideline but pointed out the rule is subject to a number of limitations. One of the most significant is the Taylor rule depends on contemporaneous values of inflation and output, while monetary policy works with a lag. As such, Bernanke emphasized the use of forecast values of the goal variables in policy decisions instead. Bernanke's apparent preference for using the rule only as a guideline is consistent with the low precision of the function. Additionally, the significance of the lagged depended variable implies Bernanke consistently considered previous observations of the funds rate when setting the rate for the current period and utilized the “momentum” from the change in the prior period. As seen in the

Volcker period, this too may be a function of the historically low federal funds targets during the Bernanke period. Following the financial crisis of 2007, the FOMC set the federal funds rate target to a range between 0.00% and 0.25%, and it has maintained this target since the first announcement at the end of 2008. Again it is likely the FOMC desires to maintain smooth transitions toward the unprecedented rate so that changes do not sharply impact consumers and/or markets.

In contrast to Regression A, Regression B is estimated with the most precision of the respective reaction functions for the other Chairmen. The coefficient on inflation of -0.52, although it is negative, is nearly equal to Taylor's estimate. However, the weight on the output gap is still almost double that on inflation. While Taylor has been vocal about Bernanke's use of discretion versus rules, it appears that in real-time Bernanke's policy decisions can be represented reasonably well by a Taylor-type rule. The function proves that analysis of ex-post data can result in misleading descriptions and evaluations of policy decisions.

Graph (4b) shows the predicted funds change and the actual change are very similar following 2010. The change also never exceeds 1% for either measure. This is consistent with Bernanke's tight target range between 0.00% and 0.25% that was in place for a slightly more than half his tenure. The range was decided upon in response to the financial crisis in 2007, and the immediate response of the Fed to the financial crisis can be seen in the sharp negative change in the funds rate following that year. Graph (4c) also depicts the actual decline in the funds rate following the 2007 financial crisis and the nearly zero rate that has persisted since 2010. I decide to show the quadratic estimate of the output gap in real-time as well as the output gap estimated by the CBO to address some possible reasons for keeping the funds rate low amid questions of the duration of the rate from some economists. The real-time estimate gives more support for the duration than does the actual gap estimate. While the actual estimate starts to become less negative at the end of 2009, the real-time estimate has remained relatively constant since it hit a low at the end of 2008. Therefore, the decision to keep the funds rate at its near zero level may be the result of a lack of information in real-time. This finding again supports the idea that ex-post data may depict misleading descriptions of historical policy.

e. The Greenspan/Bernanke Period

As mentioned at the beginning of this section, the null for structural change (no change) is accepted between the Greenspan and Bernanke period. As such, I perform additional tests for structural change between the Burns/Volcker period and the Greenspan/Bernanke period as well as between the Volcker period by itself and the Greenspan/Bernanke period. The null is rejected at the 99% level of confidence for each test (Exhibit 5, Table (5f)). Because of this finding, coupled with the finding of no structural change between the Greenspan and Bernanke period, I estimate an additional reaction function to describe the Greenspan/Bernanke period. The results from aggregating data in both periods are shown in Exhibit 5. Regression A's precision falls below that of the Greenspan function, but it is still above that of the Bernanke function. In fact, the accuracy is closer to the accuracy of Greenspan's than to that of Bernanke's. Again, this could be attributed to relatively more observations for the Greenspan period. Also similar to the Greenspan function is the significance of each variable except for the constant and the inflation gap. The coefficients on the output gap, the lagged output gap, and the lagged dependent variable are each significant at the 99% level of confidence. This reflects both the conclusion Greenspan monitored current and previous period data closely and Bernanke utilized the "momentum" from the prior period's rate change to guide smooth rate transitions. Using real-time data reveals a similarity between the two Chairmen in how they emphasized monitoring data from the prior period so that the target funds rate would be reached through gradual transition rather than abrupt change.

Regression B eliminates the lagged variables and each of the coefficients falls in magnitude. The coefficient on the output gap falls to 0.93, and the coefficient on the inflation gap falls to -0.66. Regression B also corrects the discrepancy found in Regression B from the Volcker period where the weight on the inflation gap became larger than that on the output gap. Analysis of combined data from the Greenspan and Bernanke period shows changes in Fed behavior may not be the result of different Chairmen, rather different "eras."

In graph (5b) it appears almost as if the Greenspan period graph and the Bernanke period graph are merged into one. The actual changes still follow the predicted changes closely, and there is no noticeable difference between the graphs previously examined. In graph (5c) the actual rate and the predicted rate are similar. Taylor (2012) described the period from 1985 to 2003 as "rules-based" and the period following 2003 as primarily "discretion based. Until 2003, the rate follows the rule in real-time closely as well. Following 2003, the same difference between the predicted rate and the actual rate that Taylor has drawn attention to is shown. Therefore, it appears this deviation from a policy rule could have been due to lack of information and not purely discretion as Taylor discerned. Regardless of the discrepancy, the overall depiction of behavior from the function for the Greenspan/Bernanke period appears more probable than the depiction of behavior from the individual periods. This again supports the conclusion that real-time data suggests changes in Fed behavior may be the result of changes in "eras" rather than Fed Chairmen. The Greenspan and Bernanke period were both characterized by stable inflation but sudden economic shocks (i.e., the dot com bubble or the subprime mortgage crisis). Thus, it may be more plausible that Taylor-type rules should evolve to define eras that are determined by similarity of economic events rather than a large sample of history or even an isolated sample such as individual Chairmen.

VI. Results: Estimates of r* and π*

In the remaining discussion of the results, I return to each of the 5 exhibits discussed in the previous section to analyze Table (5d) and Graph (5e). The two figures depict plausible estimates for the equilibrium real funds rate and the target inflation rate that correspond to the time periods described by each of the Exhibits. For each Exhibit, I follow the same method as Judd and Rudebsuch (1998) and calculate the average inflation rate and the average real funds rate during each Chairman's period as well as during the entire sample to use as estimates of r* and π*. Because r* and π* cannot be estimated simultaneously by the regression, I use either the average rate of r* or π* just described to calculate corresponding values for the undefined rate.

a. The Burns Period

As discussed in the previous results section, calculations for the equilibrium real funds rate are skewed by the large coefficients estimated for the constant and the weight on inflation in Regression A. The values calculated for the equilibrium funds rate range from -35.97% to -14.96%, which are inconsistent with Taylor's estimate, Judd and Rudebusch's findings (1998), and the findings in any other period in my own analysis. Because of this, I focus analysis of values for the equilibrium funds rate and the target inflation rate on Regression B. The full results are displayed in Figure (1e). Average inflation during the Burns period was 5.92%, while average inflation during the entire sample was 3.69%. In Regression B, those averages correspond to equilibrium real funds rate rates of 2.42% and 2.84% respectively, which are close to Taylor's estimates of 2 percent. Judd and Rudebusch (1998) estimate the equilibrium rate as

0.71%, but they drop the inflation gap and the output gap from their regression, which restricts r* to equal the constant.

The real funds rate during the Burns period and the total sample were 0.58% and 1.90% respectively. In Regression B, the inflation targets are calculated as 15.68% and 8.69%. These are clearly higher than Taylor's estimate of 2 percent, and even if r* is assumed to equal 2 percent, this rate corresponds to an inflation rate of about 6 percent. Most economists would agree 6 percent is not a reasonable estimate for a target either, but due to the persistent inflation during the Burns period, it is possible the rule considered this an implicit target. Also interesting to note is the inverse relationship between r* and π*. This relationship is seen in observations of average inflation and average interest rate over the Burns period. The average rate is very low at 0.58%, but the average inflation rate is 5.92%. High inflation accompanied by low growth seems to explain this finding, but it is clear estimating these variables in real-time is difficult.

b. The Volcker Period

Results for the Volcker period are shown in Figure (2e). During the Volcker period, the substitution rate between the equilibrium real funds rate and the target inflation rate is lower for Regression B than for Regression A. Average inflation during the Volcker period was 5.99% which corresponds to an equilibrium real funds rate of 7.15% in Regression A and 5.44% in Regression B. These are both considerably higher than Taylor's estimate of 2 percent, but this reflects higher than average inflation that persisted during the period. Judd and Rudebusch find a target rate of 3.80% given end of sample inflation equal to 3.07% and note the initial tightening of monetary policy could justify higher than expected targets. Given sample average inflation, estimates for r* range from 3.78% to 4.44%.

The average real funds rate during the Volcker period was 4.44%, which produces a range of target inflation estimates from 3.70% to 4.14%. Judd and Rudebusch find a range from -0.1% to 6.4%, and again note higher than expected targets can be justified by the tightening of policy. Alternatively, using the average real funds rate from the entire sample finds a range from -2.08% to 2.42%. This analysis still shows that calculations of these variables using a policy rule are skewed by events that occurred in the period of interest. This is not unique to the real-time data, but it does appear results using real-time data are more responsive to changes in the specification of the rule (i.e., dynamic versus stationary).

c. The Greenspan Period

During the Greenspan period, the relationship between target inflation and the equilibrium funds rate is less steep in Regression A than in Regression B. The relationship is displayed in Figure (3e). Average inflation during the Greenspan period was 2.43%, corresponding to equilibrium real funds rates of 0.61% in Regression A and 0.90% in Regression B. Total sample average inflation corresponds to a rate of 1.56% in Regression A and 2.27% in Regression B, which are closer to Taylor's estimates of 2 percent. Judd and Rudebusch find a range between 1.8% and 2.8%, which is also similar to the range calculated using sample average inflation. Thus, sample inflation seems to better estimate plausible values for the equilibrium funds rate during this period.

The average real funds rate during the Greenspan period was 2.33%, which corresponds to target inflation rates of 3.74% and 4.72% in Regression A and B respectively. This is not consistent with the average seen during the period or Taylor's 2 percent estimate. Instead, this result is caused by the relatively low coefficient on inflation from Regression A and the relatively high constant in Regression B. It appears the lack of volatility in inflation during the

Greenspan period skews calculations of the target rate. The real-time reaction function seems to interpret the lack of volatility as a lack of an explicit target. Judd and Rudebusch still find a range between 1.8% and 2.8% for target inflation, which suggests calculations of target inflation using the real-time rule, is skewed by some factor.

d. The Bernanke Period

During the Bernanke period, there is an inverse relationship between the equilibrium real funds rate and the target inflation rate, which is seen in the Burns period as well. However, Regression A displays a relationship that is less steep than that of Regression A from the Burns period. The relationship is shown in Figure (4e). Average inflation during the Bernanke period was 1.96%, corresponding to equilibrium funds rates of 0.63% in Regression A and 1.47% in Regression B. 1.47% is fairly close to Taylor's estimate, but 0.68% is closer to the average seen during the Bernanke period.

The average real funds rate was equal to -0.56%, corresponding to target inflation rates of 5.55% in Regression A and 5.87% in Regression B. This is inconsistent with the average from the Bernanke period as well as Taylor's estimate. It is also the result of relatively low estimates for the coefficient on the inflation gap in both regressions. This finding coupled with the same from the Greenspan period suggests that the low magnitude of the coefficient on the gap is in fact the result of low volatility in inflation. Additionally, this lack of volatility makes it difficult for a rule to predict a target in real-time. Furthermore, Bernanke has been vocal about an explicit target of 2 percent during his tenure, so the skewed calculations during the Bernanke and Greenspan period are most likely not the result of a lack of target. Calculations for target inflation using the sample average real funds rate correspond to -1.89% in Regression A and 1.12% in Regression B. These values are closer to Bernanke's target and suggest the Fed selects targets relative to long run economic performance rather than recent performance. This is not surprising given the Fed's emphasis on long-run economic stability over short-run gains.

e. The Greenspan/Bernanke Period

Finally, in the Greenspan/Bernanke period, Regression A is less steep than Regression B and is positive as during the Greenspan period. The relationship is shown in Figure (5e). The average real funds rate over this sample was 1.45%, which corresponds to a range of target inflation from 2.51% to 5.49%. This range is larger than those estimated during the individual periods, but the low end of the range reflects an estimate more in line with Taylor's estimate, Judd and Rudebusch's estimate, and Bernanke's verbal commitment.

Average inflation during the period was 2.28%, which corresponds to an equilibrium real funds rate of 0.76% in Regression A and 1.29% in Regression B. This is less than Taylor's estimate, but it is close to what was observed during the period. The equilibrium funds rate calculated from sample average inflation is even closer to the 2 percent estimate (1.06% in Regression A and 2.23% in Regression B). This again supports the idea the Fed chooses inflation targets based on long-run performance, and the targets remain relatively unchanged over time. Interesting to note, however, is that target inflation calculated using the average real funds rate from the entire sample of Chairmen is still higher than expected (3.20% in Regression A and 7.63% in Regression B). This in turn suggests the equilibrium real funds rate changes over time. This conclusion gives further support to the idea policy rules may define "eras" rather than an individual Chairman's tenure or even a long span of history. Rules that consider targets within a short period will be skewed by the events unique to that time.

VI. Conclusion

While the use of policy rules as a means to more effective monetary policy has been supported by many economists, it is apparent the lack of information available to a policymaker in real-time distorts the applicability of these rules. In the context of the Taylor rule, I conclude the rule does not describe Fed behavior in real-time nearly as well as it does using ex-post data, and as a result, analysis using the rule results in misleading descriptions of historical policy and suggestions of how monetary policy “should” have been conducted. My analysis finds that while relationships between different variables remain similar in real-time (i.e., the inflation gap and output gap), relationships between different observations of the same variable (i.e., the output gap and lagged output gap) differ. This difference results from the lack of accurate information available in real-time. It appears revisions in data are significant enough to impact these relationships and consequently recommendations in real-time versus those generated using ex-post data. Additionally, while Judd and Rudebsuch’s analysis finds that reaction functions differ significantly between Fed Chairmen, my analysis finds reaction functions differ between economic “eras” instead. It is clear that Fed action from the mid-1980s onward (during the period also known as the Great Moderation) is similar despite changes in Fed Chairman. Furthermore, Fed action before this era is found to be significantly different.

Lastly, do the rules estimated using real-time data have the power to predict Fed policy before it is enacted? Using those estimated from my analysis, no. There does not seem to be a strict pattern that the rules follow between eras. However, further analysis can be conducted to determine how an estimated Taylor rule changes as revisions of estimates are released. For example, further research can estimate a policy rule for a given date at each vintage date following the first release of the data. This will serve to determine how policy recommendations change as more accurate information becomes available. This analysis combined with that similar to my own will provide an even more accurate basis from which to describe, evaluate, and possibly predict Federal Reserve policy.

Appendix A: Supporting Tables, Figures, and Exhibits for Text

Table 1

	Number of Observations	Minimum	Maximum	Mean	Std. Deviation
Actual Federal Funds Rate	195	0.1%	17.8%	5.7%	3.7%
Growth Rate of Real GNP/GDP (Annual)	195	-3.5%	14.5%	2.3%	2.4%
Inflation Rate (Annual)	195	0.4%	11.8%	3.7%	2.4%

Figure 1

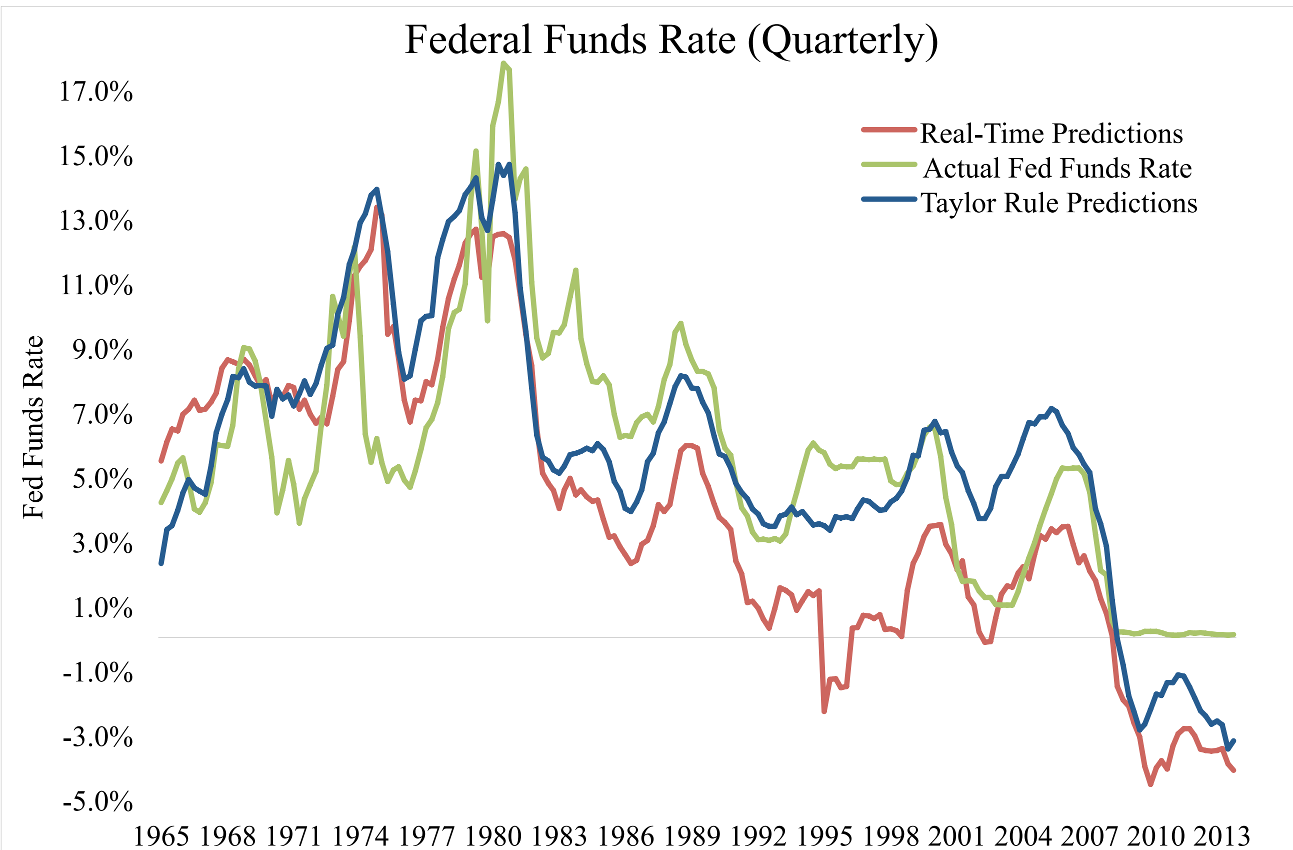


Table 2

Variable	Coefficient	
Constant	.010***	(.003)
Inflation Gap	.069	(.073)
Output Gap	.231***	(.037)

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

Figure 2

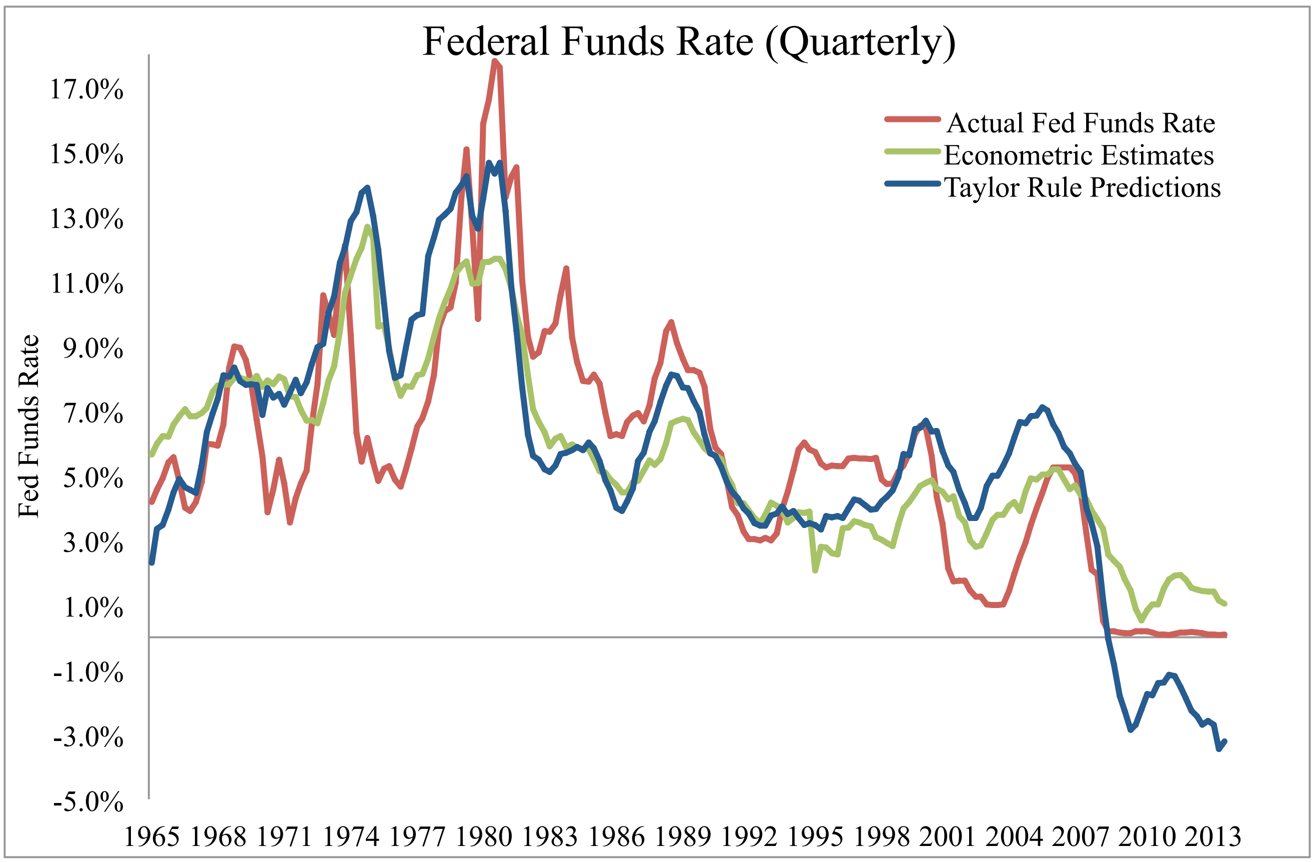


Table 3

	Long Sample (65:Q4-14:Q2)	Burns (70:Q1-78:Q1)	Volcker (79:Q3-87:Q2)	Greenspan (87:Q3-06:Q1)	Bernanke (06:Q2-14:Q2)
Average real interest rate	1.90%	0.58%	4.44%	2.33%	-0.56%
Average inflation	3.69%	5.92%	5.99%	2.43%	1.96%

Figure 3

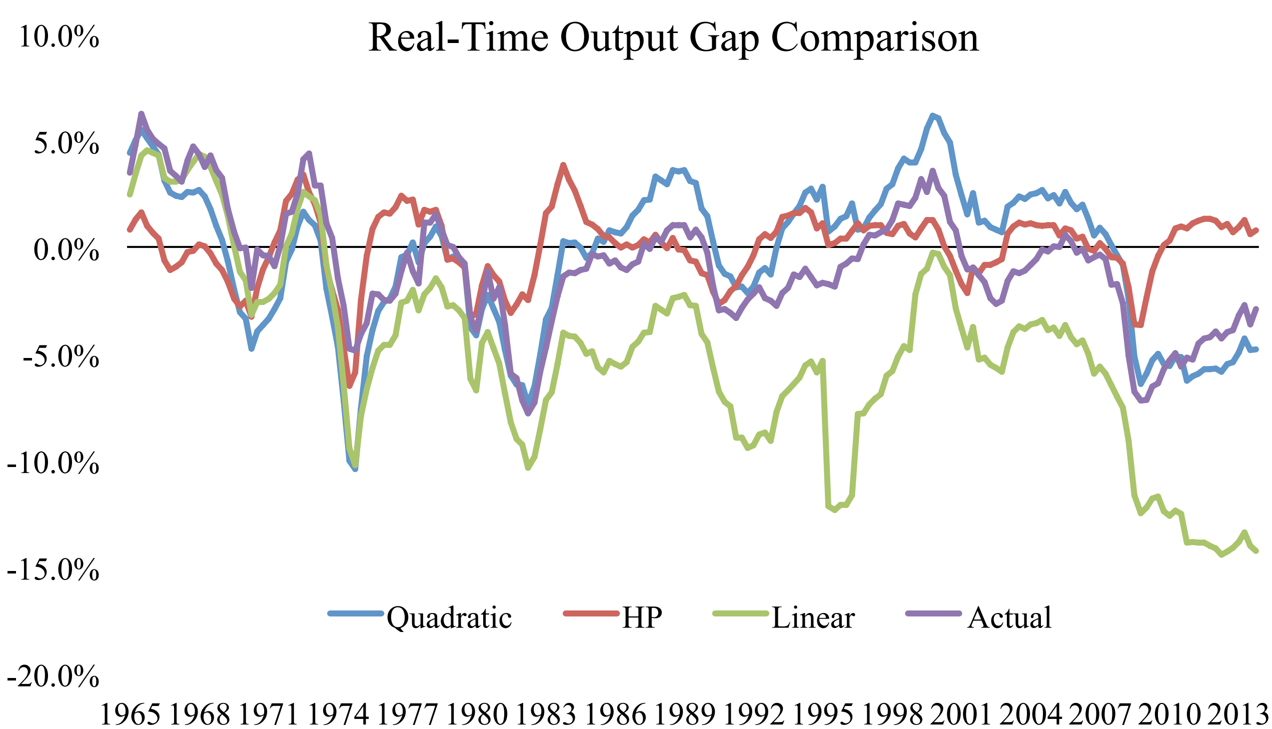


Table 4

Terms	Critical F-value
Consecutive	
Burns/Volcker	
Linear	4.38***
Quadratic	3.07**
HP Filter	5.17***
Volcker/Greenspan	
Linear	9.09***
Quadratic	5.56***
HP Filter	10.08***
Greenspan/Bernanke	
Linear	1.13
Quadratic	0.93
HP Filter	1.88*
Non-Consecutive	
Burns/Greenspan	
Linear	3.46***
Quadratic	4.03***
HP Filter	0.75
Burns/Bernanke	
Linear	1.57
Quadratic	1.96*
HP Filter	0.50
Volcker/Bernanke	
Linear	1.96*
Quadratic	1.82
HP Filter	3.79***

Significant at the ***99%, **95%, *90% level of confidence.

Exhibit 1

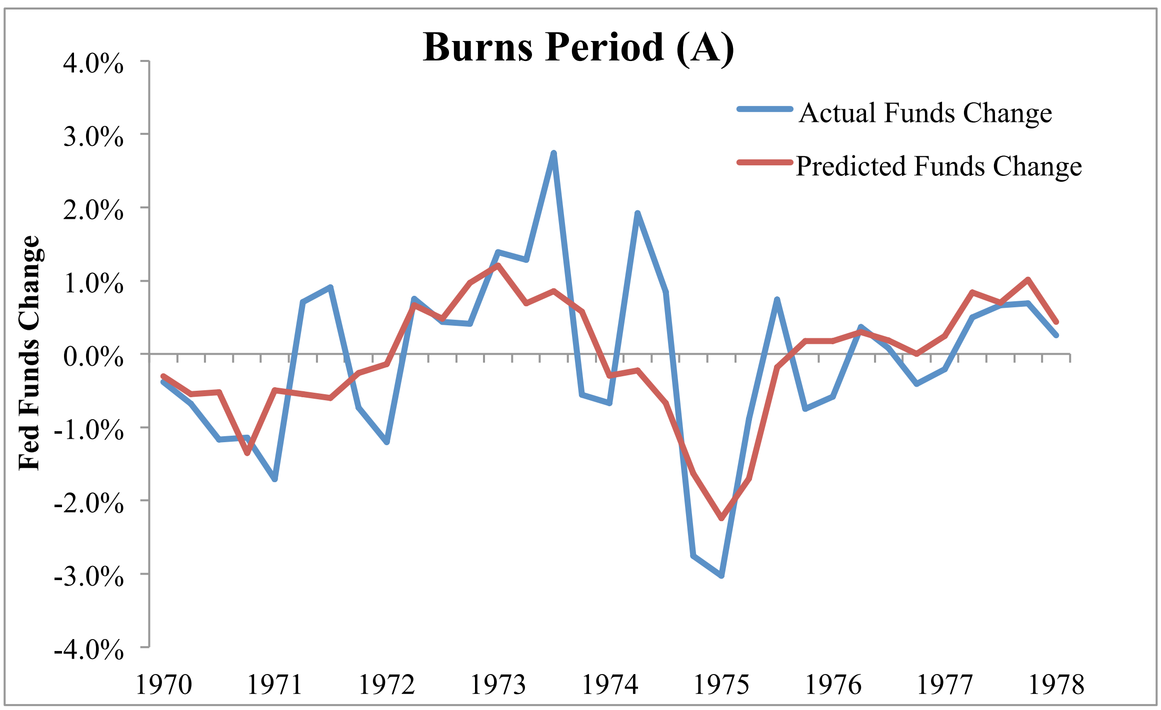
Regression Results for Burns Period,
1970:Q1-1978:Q1

(1a)

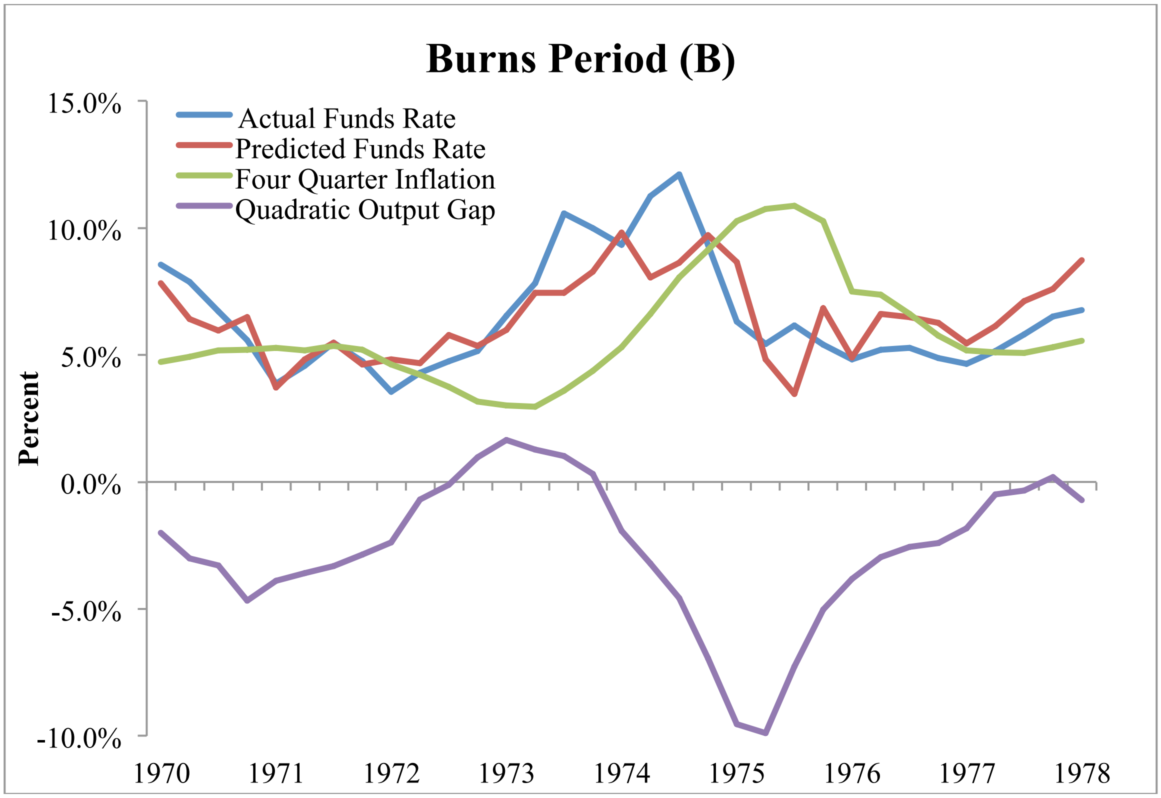
	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	19.89	-0.03	-9.43	-21.75**	7.77	-0.08	0.46	0.36
	(1.10)	(0.16)	(0.20)	(0.29)	(0.29)	(0.24)		
B	3.54***	-	-0.19***	-0.62**	1.44***	-	0.54	0.50
	(1.20)	-	(0.28)	(0.27)	(0.25)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

(1b)



(1c)



(1d)

Burns		**Variable Calculated**	**A**	**B**
Average π	5.92%	r*	-35.97%	2.42%
Average r	0.58%	π*	2.05%	15.68%
Total Sample		**Variable Calculated**	**A**	**B**
Average π	3.69%	r*	-14.96%	2.84%
Average r	1.90%	π*	1.91%	8.69%

(1e)

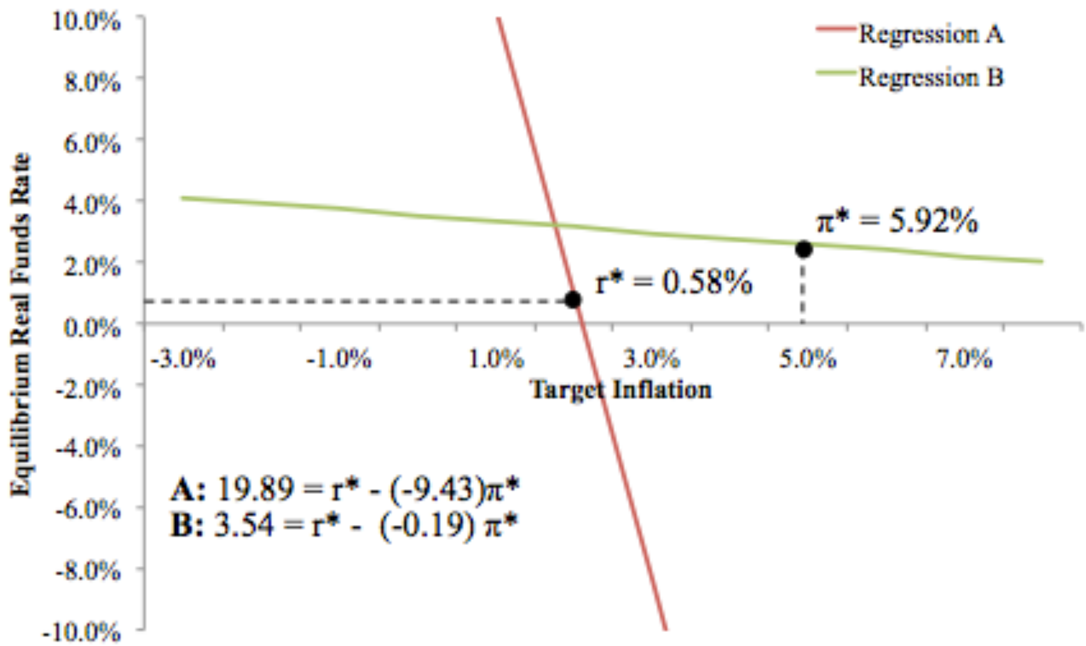

Regression A
Regression B
Equilibrium Real Funds Rate
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
-2.0%
-4.0%
-6.0%
-8.0%
-10.0%
-3.0%
-1.0%
1.0%
3.0%
5.0%
7.0%
Target Inflation
π* = 5.92%
r* = 0.58%
A: 19.89 = r* - (-9.43)π*
B: 3.54 = r* - (-0.19) π*

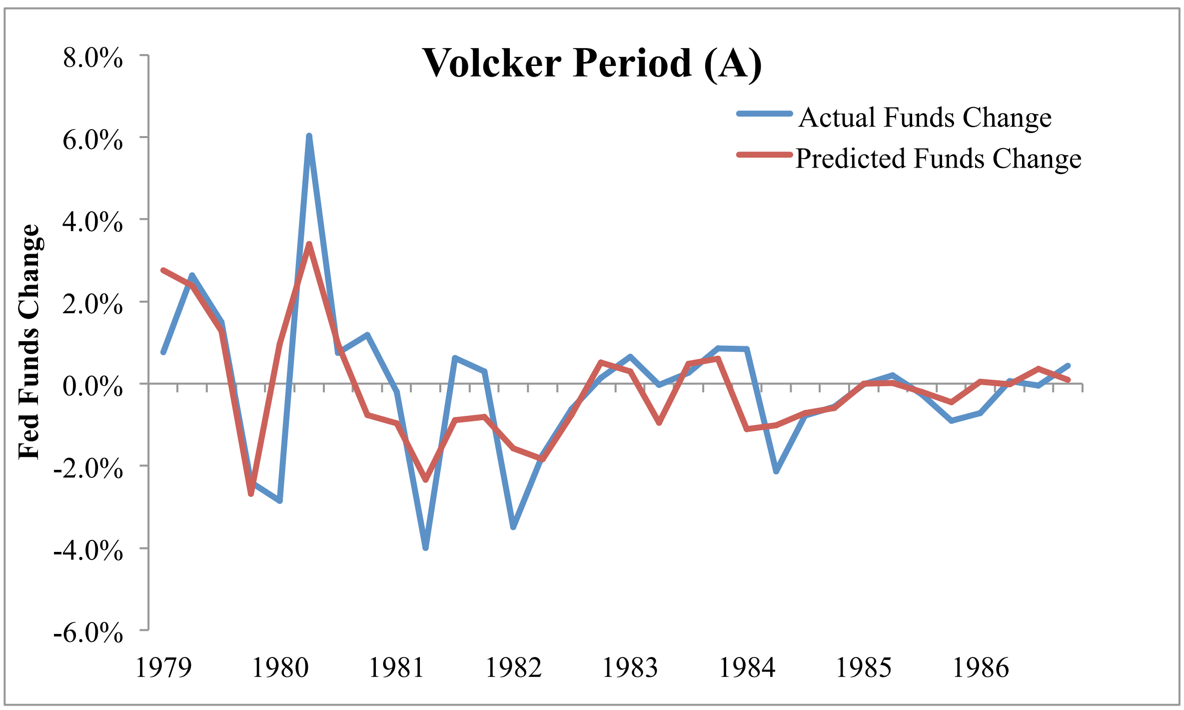
Exhibit 2
Regression Results for Volcker Period,
1979:Q3 – 1987:Q2

(2a)

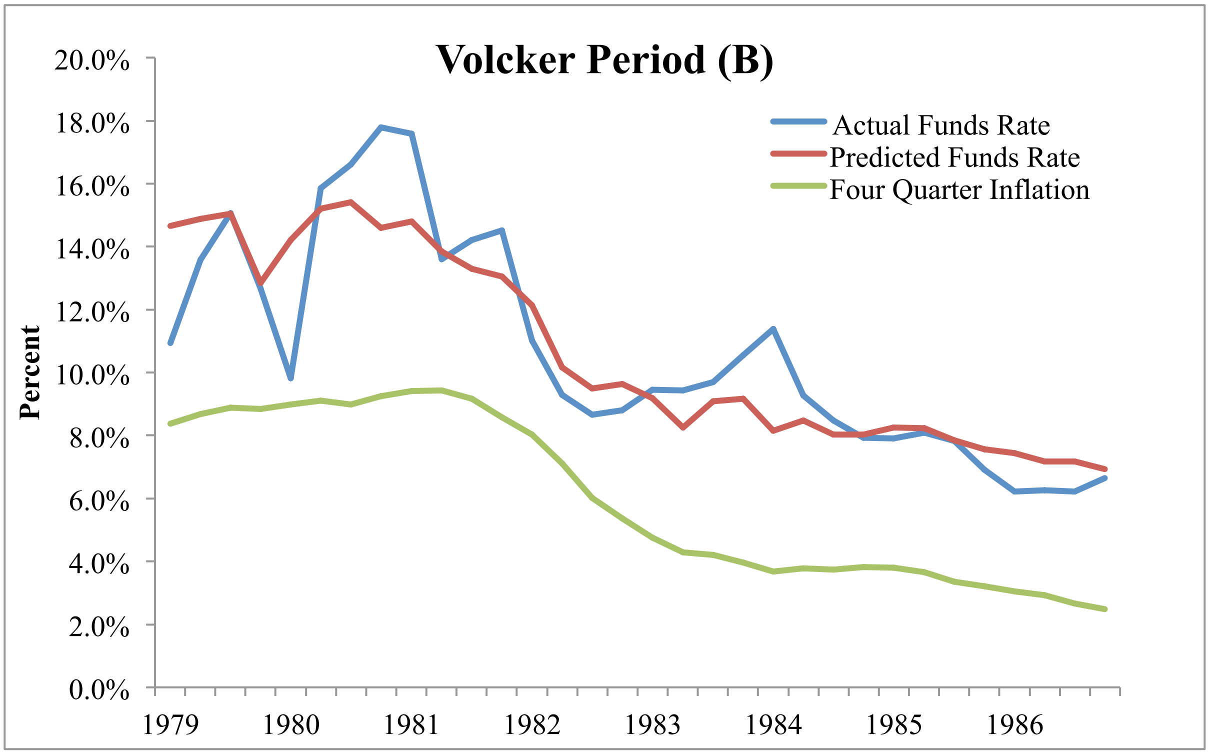
	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	-1.66	0.35*	1.47***	3.83***	-2.68**	-0.09	0.54	0.45
	(1.39)	(0.19)	(0.19)	(0.43)	(0.36)	(0.20)		
B	2.81***	-	0.44***	0.81**	-0.48	-	0.78	0.76
	(0.90)	-	(0.17)	(0.41)	(0.37)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

(2b)



(2c)



(2d)

Volcker		**Variable Calculated**	**A**	**B**
Average π	5.99%	r*	7.15%	5.44%
Average r	4.44%	π*	4.14%	3.70%

Total Sample		**Variable Calculated**	**A**	**B**
Average π	3.69%	r*	3.78%	4.44%
Average r	1.90%	π*	2.42%	-2.08%

(2e)

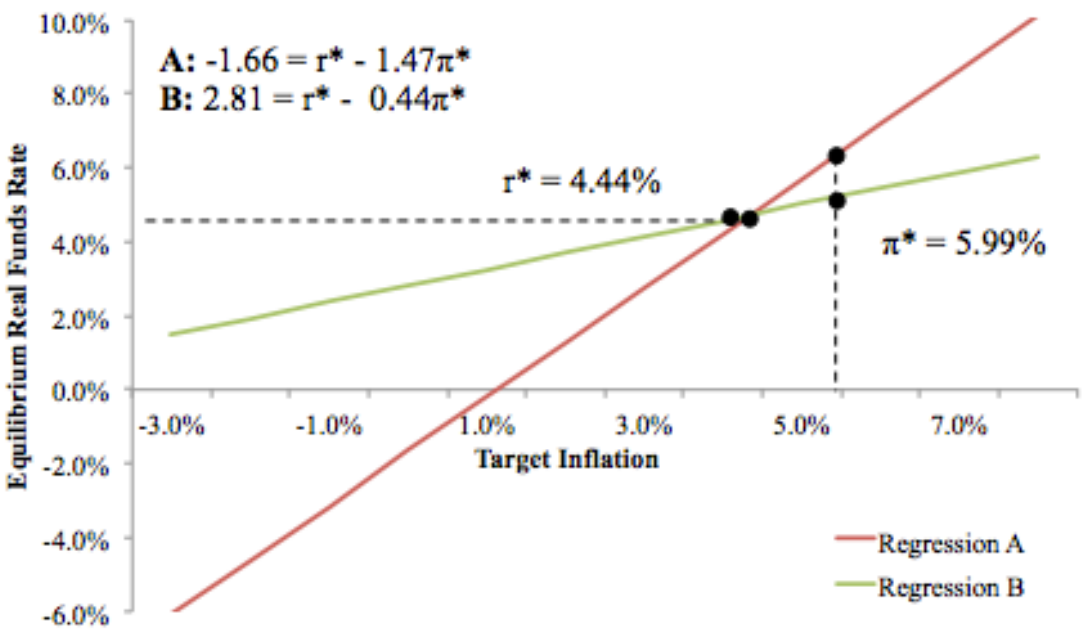

A: -1.66 = r* - 1.47π*
B: 2.81 = r* - 0.44π*
r* = 4.44%
π* = 5.99%
Equilibrium Real Funds Rate
Target Inflation
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
-2.0%
-4.0%
-6.0%
-3.0%
-1.0%
1.0%
3.0%
5.0%
7.0%
Regression A
Regression B

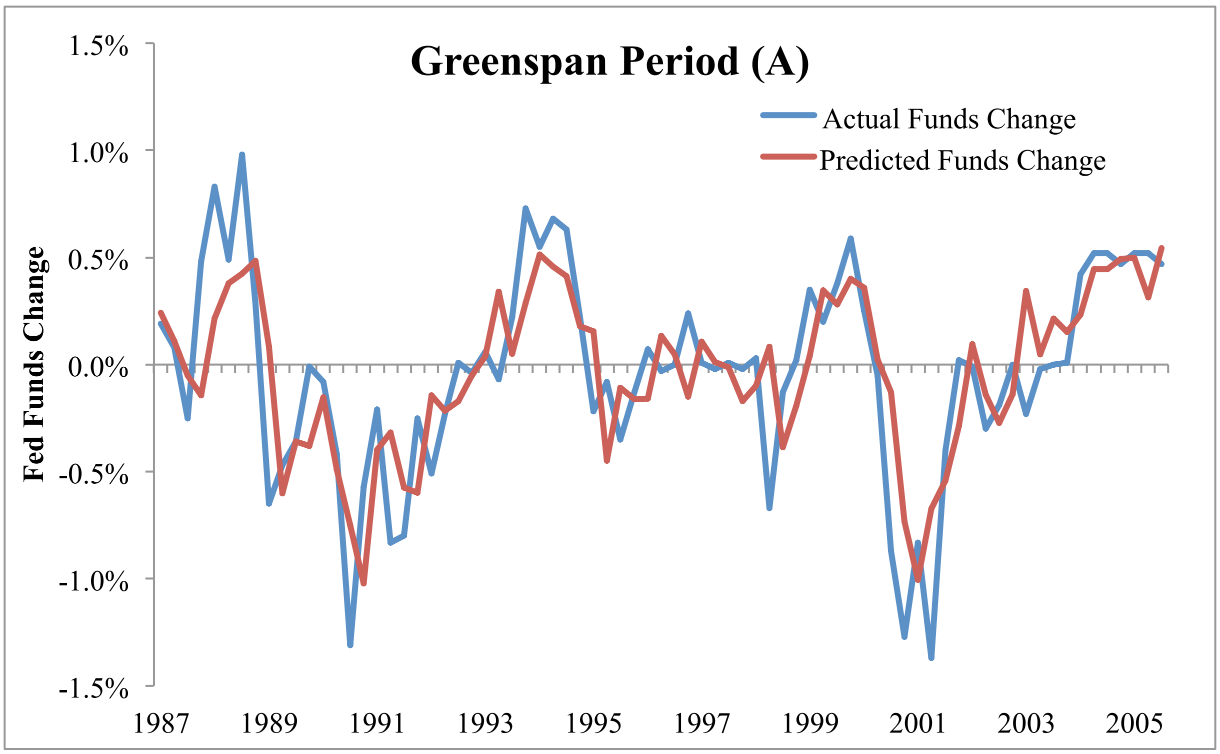
Exhibit 3
Regression Results for Greenspan Period,
1987:Q3 – 2006:Q1

(3a)

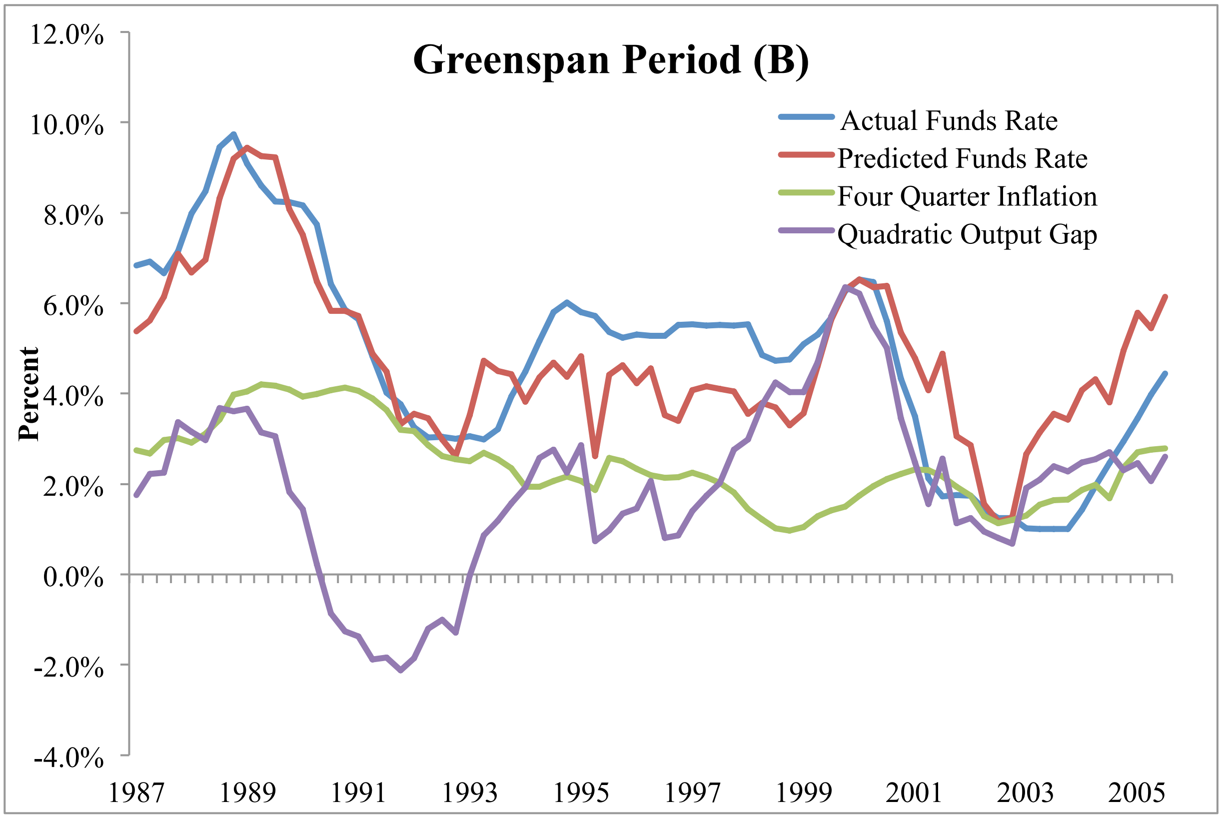
	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	-1.22	0.07**	0.75	4.59***	-4.05***	0.63***	0.59	0.56
	(0.15)	(0.03)	(0.07)	(0.09)	(0.09)	(0.09)		
B	-1.72***	-	1.08***	0.97**	-0.24	-	0.64	0.63
	(0.62)	-	(0.21)	(0.38)	(0.39)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

(3b)



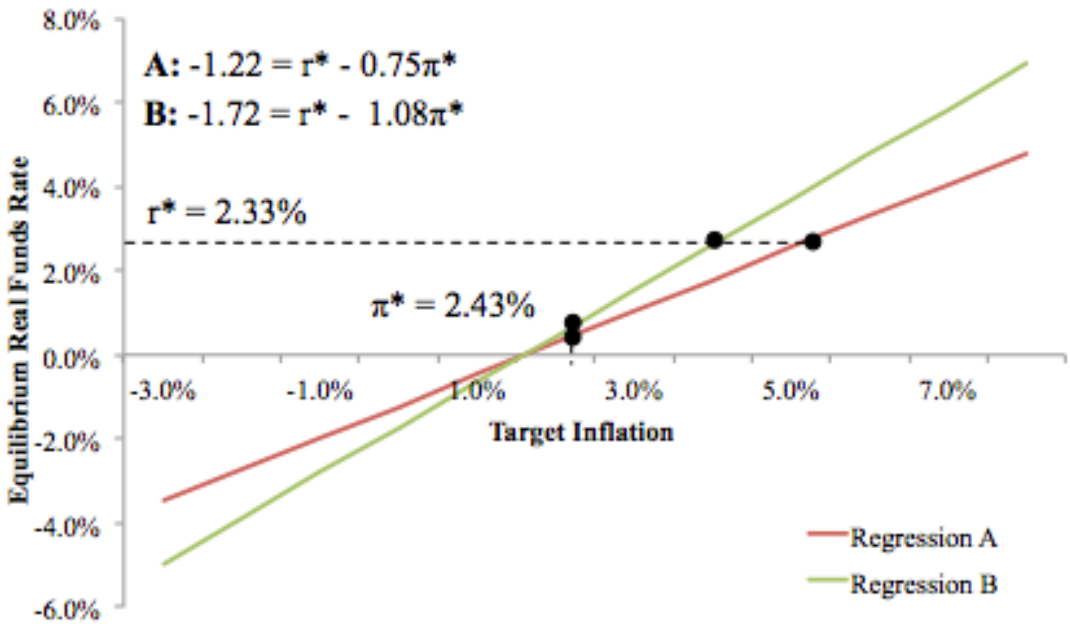
(3c)



(3d)

Greenspan		**Variable Calculated**	**A**	**B**
Average π	2.43%	r*	0.61%	0.90%
Average r	2.33%	π*	4.72%	3.74%
Total Sample		**Variable Calculated**	**A**	**B**
Average π	3.69%	r*	1.56%	2.27%
Average r	1.90%	π*	4.15%	3.35%

(3e)



A: -1.22 = r* - 0.75π*
B: -1.72 = r* - 1.08π*
r* = 2.33%
π* = 2.43%
8.0%
6.0%
4.0%
2.0%
0.0%
-2.0%
-4.0%
-6.0%
-3.0%
-1.0%
1.0%
3.0%
5.0%
7.0%
Target Inflation
Equilibrium Real Funds Rate
Regression A
Regression B

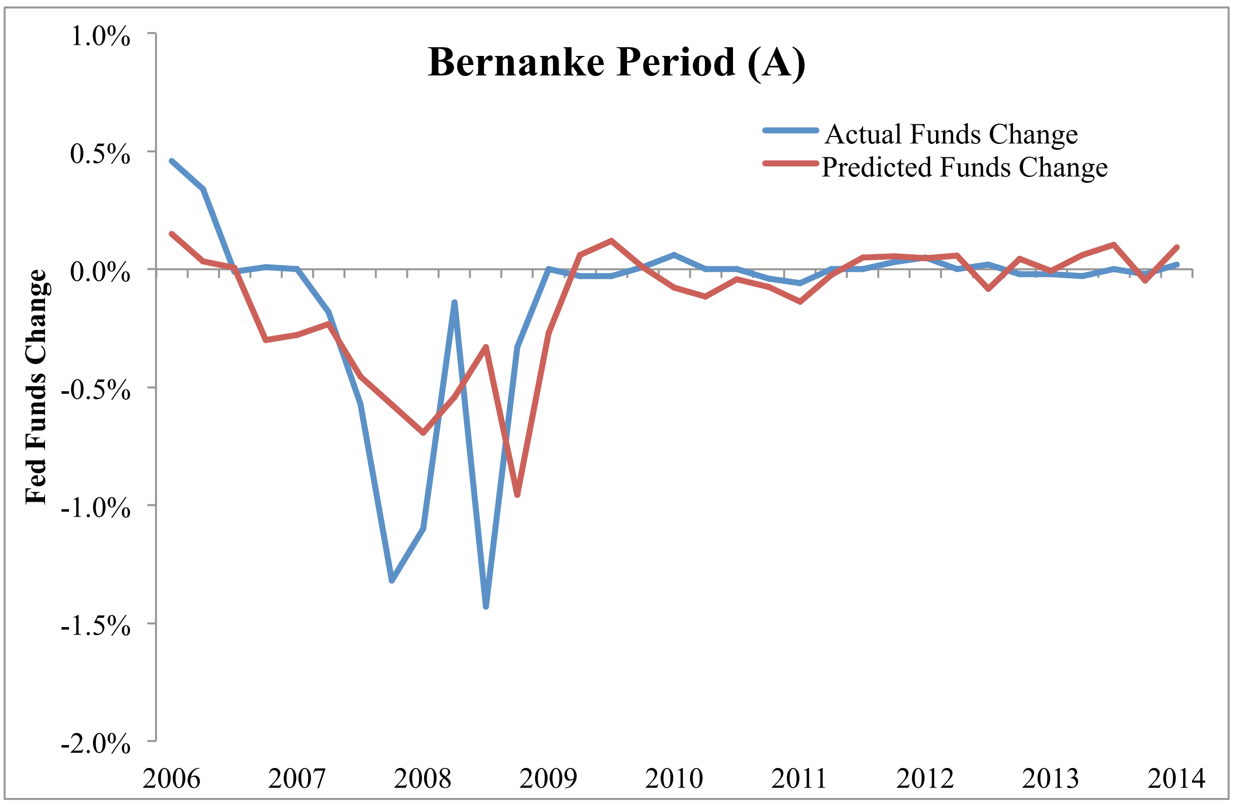
Exhibit 4
Regression Results for Bernanke Period,
2006:Q2 – 2014:Q2

(4a)

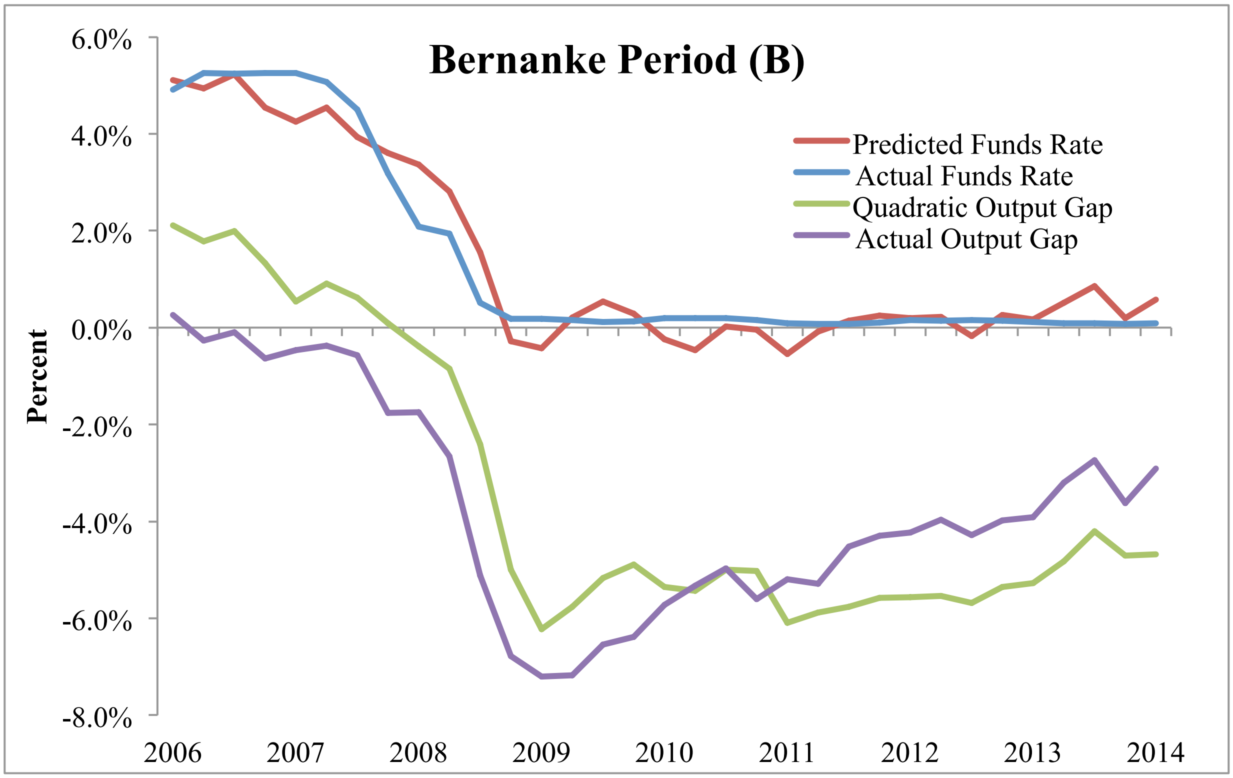
	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	1.27	0.17	-0.33	1.36	-0.94	0.45**	0.42	0.31
	(0.52)	(0.13)	(0.15)	(0.16)	(0.13)	(0.18)		
B	2.48***	-	-0.52**	1.00***	-0.41**	-	0.93	0.93
	(0.62)	-	(0.23)	(0.18)	(0.18)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

(4b)



(4c)

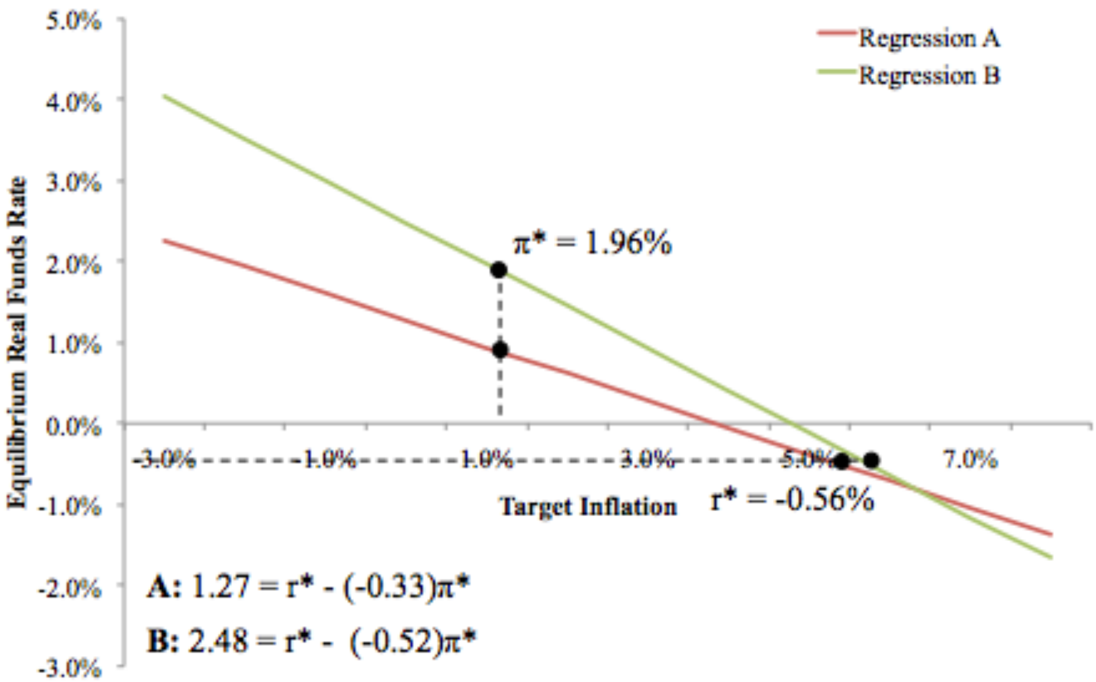


(4d)

Bernanke		**Variable Calculated**	**A**	**B**
Average π	1.96%	r*	0.63%	1.47%
Average r	-0.56%	π*	5.55%	5.87%

Total Sample		**Variable Calculated**	**A**	**B**
Average π	3.69%	r*	0.05%	0.57%
Average r	1.90%	π*	-1.89%	1.12%

(4e)



5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
-1.0%
-2.0%
-3.0%
Equilibrium Real Funds Rate
Regression A
Regression B
π* = 1.96%
-3.0%
-1.0%
1.0%
3.0%
5.0%
7.0%
Target Inflation
r* = -0.56%
A: 1.27 = r* - (-0.33)π*
B: 2.48 = r* - (-0.52)π*

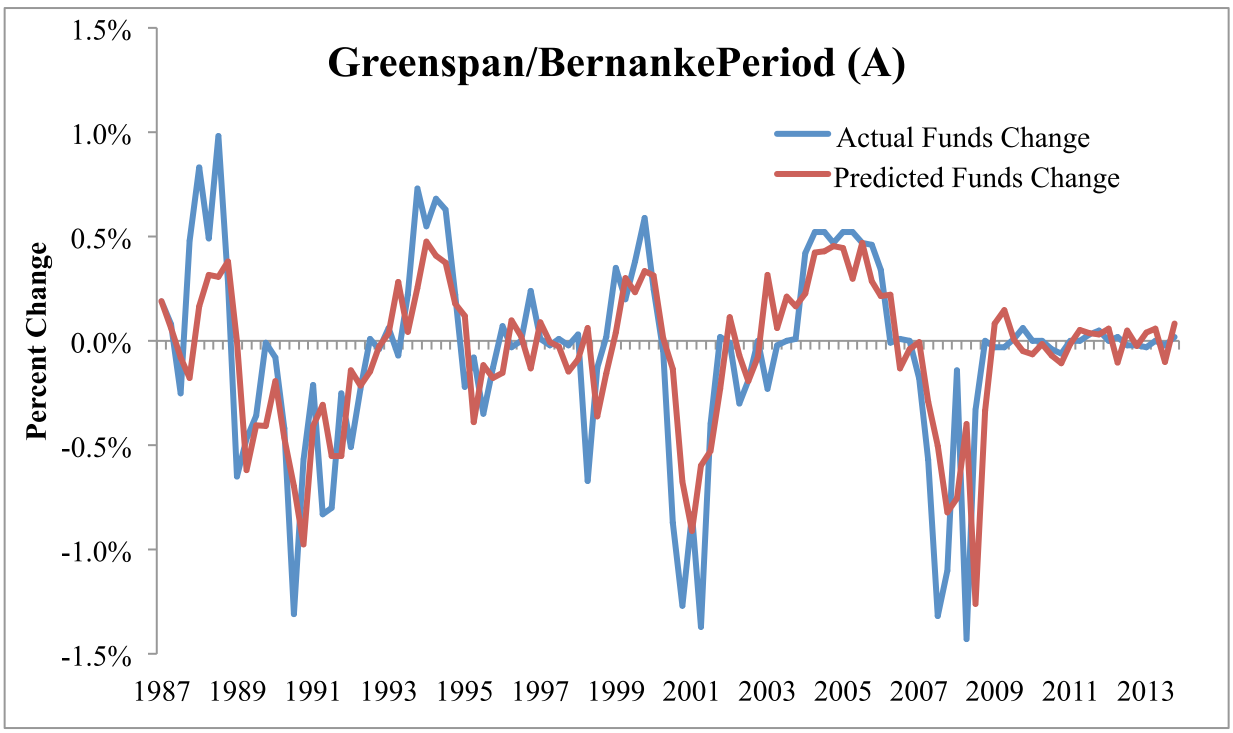
Exhibit 5
Regression Results for Greenspan/Bernanke Period, 1987:Q3 – 2014:Q2

(5a)

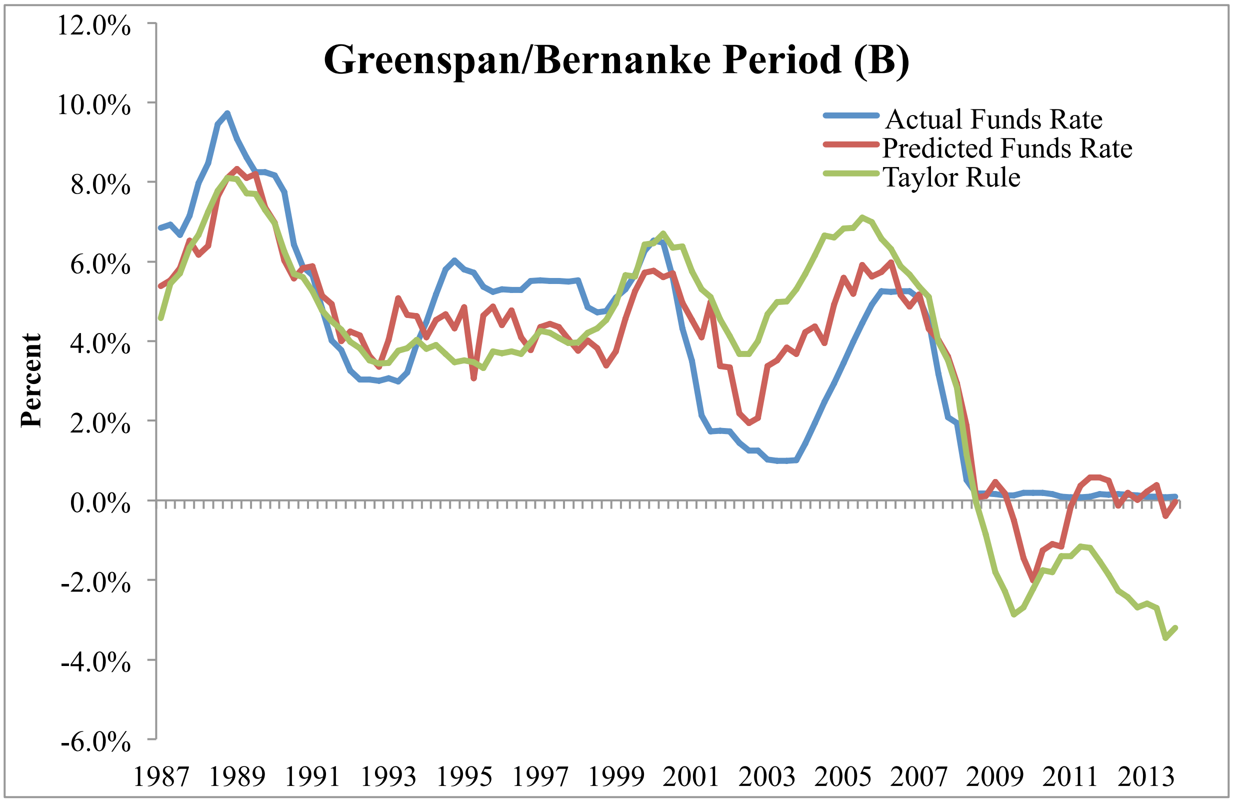
	α	ϒ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	0.27	0.06**	0.21	3.67***	-3.24***	0.59***	0.53	0.51
	(0.10)	(0.02)	(0.06)	(0.07)	(0.07)	(0.07)		
B	-0.22	-	0.66***	0.93***	-0.45**	-	0.78	0.77
	(0.38)	-	(0.16)	(0.26)	(0.27)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

(5b)



(5c)

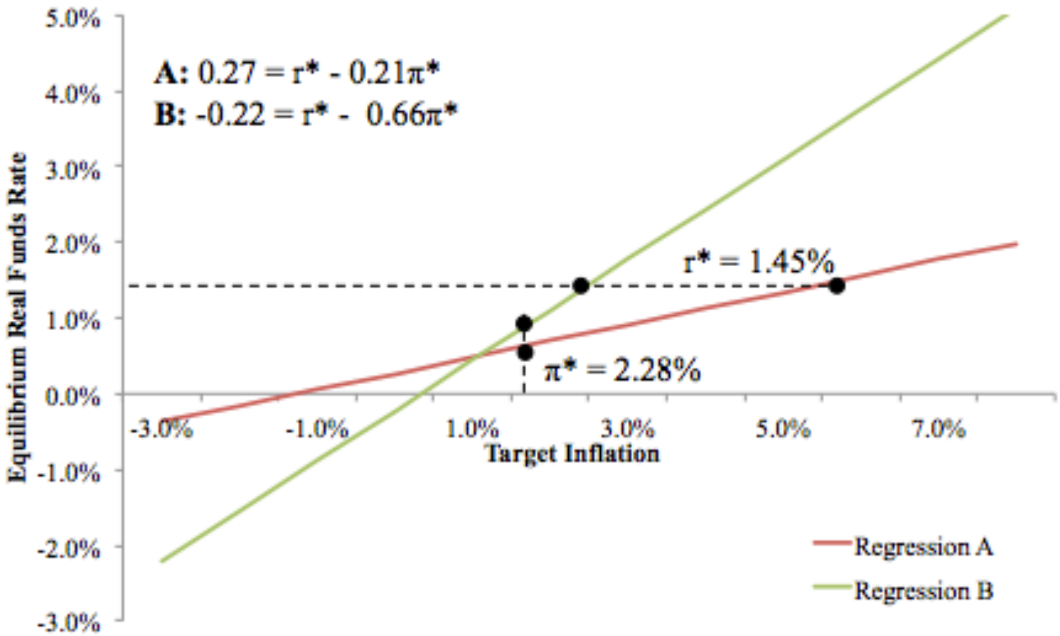


(5d)

Greenspan/Bernanke		Variable Calculated	A	B
Average π	2.28%	r*	0.76%	1.29%
Average r	1.45%	π*	5.49%	2.51%

Total Sample		Variable Calculated	A	B
Average π	3.69%	r*	1.06%	2.23%
Average r	1.90%	π*	7.63%	3.20%

(5e)



(5f)

Terms	Critical F-value
Burns-Volcker/Greenspan-Bernanke	8.04***
Volcker/Greenspan-Bernanke	9.66***

Significant at the ***99%, **95%, *90% level of confidence.

Appendix B: Alternate Reaction Functions

Linear Estimation of the Output Gap:

Burns Period

	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	-0.64	0.30	0.96**	1.62**	0.11	0.17	0.48	0.38
	(1.02)	(0.20)	(0.30)	(0.28)	(0.34)	(0.19)		
B	0.57	-	0.48***	0.14	1.05***	-	0.74	0.72
	(1.12)	-	(0.26)	(0.26)	(0.18)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

Volcker Period

	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	7.26**	0.39**	0.68***	3.22***	-2.17**	-0.08	0.57	0.49
	(1.15)	(0.17)	(0.18)	(0.38)	(0.34)	(0.19)		
B	5.67	-	0.24***	0.80***	-0.42**	-	0.80	0.78
	(1.13)	-	(0.13)	(0.38)	(0.37)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

Greenspan Period

	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	2.81	0.04**	0.46	7.84***	-7.67***	0.65***	0.59	0.56
	(0.14)	(0.02)	(0.06)	(0.10)	(0.10)	(0.09)		
B	2.11**	-	0.58**	0.75	-0.55	-	0.38	0.36
	(0.73)	-	(0.26)	(0.55)	(0.55)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

Bernanke Period

	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	3.52	0.18	-0.26	1.36	-1.04	0.48**	0.42	0.31
	(0.84)	(0.12)	(0.15)	(0.16)	(0.15)	(0.18)		
B	4.96***	-	-0.32***	1.11***	-0.68***	-	0.92	0.92
	(0.90)	-	(0.24)	(0.21)	(0.22)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

Greenspan/Bernanke Period

	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	3.82	0.04**	-0.02	6.06***	-5.81***	0.59***	0.52	0.50
	(0.13)	(0.02)	(0.05)	(0.08)	(0.08)	(0.07)		
B	2.34	-	0.67***	1.19***	-0.88**	-	0.65	0.64
	(0.62)	-	(0.20)	(0.36)	(0.37)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

HP Filter Estimation of the Output Gap:

Burns Period

	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	3.55	-0.10	-0.44	-4.68	2.60	0.06	0.37	0.26
	(1.49)	(0.21)	(0.12)	(0.32)	(0.29)	(0.27)		
B	6.22***	-	-0.94	-1.10***	1.30***	-	0.41	0.35
	(1.24)	-	(0.21)	(0.25)	(0.33)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

Volcker Period

	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	1.06	0.74***	0.63***	0.88***	0.00	0.18	0.53	0.44
	(1.13)	(0.17)	(0.26)	(0.29)	(0.34)	(0.16)		
B	1.08	-	0.63***	0.70**	0.23	-	0.84	0.82
	(0.93)	-	(0.15)	(0.29)	(0.33)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

Greenspan Period

	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	-3.58	0.03	1.85	7.10**	-1.31	0.48***	0.61	0.59
	(0.13)	(0.02)	(0.06)	(0.09)	(0.11)	(0.11)		
B	0.50**	-	0.73***	-1.00**	2.07***	-	0.47	0.45
	(0.67)	-	(0.26)	(0.44)	(0.52)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

Bernanke Period

	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	-3.26	0.07	0.78	2.19	-2.11	0.45**	0.40	0.29
	(0.27)	(0.05)	(0.16)	(0.13)	(0.13)	(0.19)		
B	-3.55***	-	1.51***	0.59	-0.41	-	0.67	0.64
	(0.71)	-	(0.34)	(0.39)	(0.44)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

Greenspan/Bernanke Period

	α	γ	λ_1	λ_2	λ_3	ρ	R^2	Adj. R^2
A	-3.20	0.02	0.84	11.79***	-6.81	0.53***	0.52	0.49
	(0.10)	(0.02)	(0.05)	(0.07)	(0.08)	(0.09)		
B	-1.29**	-	1.18***	-0.21	1.06**	-	0.48	0.46
	(0.60)	-	(0.25)	(0.40)	(0.45)	-		

Standard errors in parentheses.
Significant at the ***99%, **95%, *90% level of confidence.

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