THE TAYLOR RULE ERROR AND THE TERM STRUCTURE BEFORE AND AFTER THE GREAT RECESSION: THE ROLE OF QE, FORWARD GUIDANCE AND ZERO LOWER BOUND*

by

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Abstract

This paper investigates the impact of Taylor rule error in the pre-crisis period, and quantitative easing (QE) in the post-crisis period on the term structure. Using ordinary least squares (OLS) method, results showed that Taylor rule error negatively affects long-term Treasury yield before the Great Recession. Due to the zero lower bound, the Fed pursued three rounds of QE. Based on graphical analysis, only QE2 was effective in decreasing long-term Treasury yield.

In addition, this paper seeks to study the efficacy of forward guidance. Analysis showed that it serves its purpose of lowering the long-term Treasury yield through the channel of expectations for short-term rates. Using the estimates of the effect of longer-term yield on the Federal Funds Rate (FFR), my research predicts that there will be a gradual rate hike in 2016.

Before the Great Recession took place in 2008, the Federal Reserve mainly pursued conventional monetary policies to fulfill its dual mandate of maximizing employment and stabilizing prices. Due to the zero lower bound (ZLB) on the short-term nominal interest rate, the Fed had to use unconventional policies to stimulate the economy after the crisis.

The list of monetary policies used has been extensive (see Appendix). At the beginning, the Fed used time-dependent forward guidance to communicate future monetary policies with the market to drive market expectations. This policy was then accompanied by three rounds of quantitative easing (QE). Specifically, the goal of implementing QE1 is to lower the spread between mortgage-backed securities (MBS) and long-term Treasury bonds. QE2 and QE3 are aimed at affecting long-term interest rates directly via large purchases of long-term Treasury bonds. As time passed, forward guidance evolved into threshold-based guidance that depends on the state of the economy, such as unemployment rate and inflation.

In the pre-crisis era, the Fed had been using Taylor rule as a guide to adjust short-term nominal interest rate or FFR. This notion is backed by evidence presented in John Taylor's paper that describes how closely the actual rates are to the rates suggested by the rule (Taylor, 1993). The rule is not exact. There are still differences between actual rates and those predicted by the Taylor rule. These residuals are called the Taylor rule error in this paper.

The objective of this paper is to investigate the impact of the Taylor rule error, QE and forward guidance on the term structure before and after the Great Recession. How did the Taylor rule error affect the Treasury yield spread before the crisis? What is the role of zero lower bound? Did QE and forward guidance serve their purposes?

First, I determine the relationship between Taylor rule error and Treasury yield before the crisis. The purpose of this exercise is to be able to inform what yields would have been if interest rates could have been negative. Taylor rule error is positive when the actual FFR is higher than the predicted FFR, which is formed by using Taylor rule, and vice versa.[1] In other words, a positive error implies that the Fed is being tight. On the other hand, Treasury yield spread refers to the difference in yield between Treasuries, which consist of 1-year Treasury bills, 10-year Treasury notes and 30-year Treasury bonds. A decreasing spread means that the longer-term Treasury yield falls relative to the shorter-term Treasury yield. In this paper, I hypothesize that there is a negative relationship between Taylor rule error and Treasury yield spread before 2008, as a tighter Fed usually leads the public to lower its expectations of future inflation, which helps to bring down bond yield.

To examine Fed policy in the zero-lower-bound period, research focuses on unconventional monetary policy tools. For example, in Wu and Xia (2015), the paper concludes that these policies decrease the unemployment rate by 1%. Another work by Engen, Laubach and Reifschneider (2015) emphasizes on the positive effect brought by these tools on real activity and inflation starting from 2011. Unlike these two papers, this work focuses more on the relationship between short-term rates and long-term rates before and after the Great Recession. Perhaps, the paper that is closest to this work should be Krishnamurthy and Vissing-Jorgensen (2011). It finds empirical evidence that supports the notion that QE2 had a disproportionately large effect on long-term Treasury yield. Since QE2 is the only round that involves massive purchase of Treasuries, I hypothesize that only QE2 succeeds in lowering the long-term interest rates.

Furthermore, this paper seeks to determine the efficacy of forward guidance. Forward guidance was first adopted by the Fed in December 2008 to drive market expectations, as expectations and beliefs have always played huge roles in the market. Getting stuck at the

[1] Based on the Fischer equation, FFR is made up of two components, which are the rate of inflation and the real interest rate. A positive error emerges when either the inflation rate or the real interest rate is high. Since the inflation rate has not been moving much since the 1980s, a positive Taylor rule error can only be attributed to a high real short-term interest rate, which is associated with the implementation of contractionary monetary policy.

zero lower bound during the crisis, the Fed had to use this tool in hopes that the long-term Treasury yield could be lowered by the decrease in expectations for short-term interest rates, which are represented by the Federal Funds futures rates. In the post-crisis era, a co-movement between the predicted long-term yield based on Federal Funds futures rates and actual long-term yield implies that expected short-term rates have an effect on long-term yield. In other words, forward guidance is effective. Given that market always pays very close attention to the Fed's actions, any news regarding future monetary policies is going to alter market expectations. Thus, my hypothesis is that forward guidance succeeds in setting market expectations.

If short-term rates have some influence on long-term rates, it is important to determine if the causal effect works the other way round. To evaluate this hypothesis, this paper analyzes the impact of medium-term Treasury yield, which are represented by 1-year and 2-year Treasury yields, on FFR to learn more about market expectations and predict the movements of FFR in 2016. When the medium-term yield moves down, the fitted values of FFR should be in a negative trend because longer-term rates are an average of short-term rates. The downward pressure faced by the predicted FFR proves that forward guidance is effective in the sense that the market believes that the Fed will be accommodative for the next five to eight quarters.

The next section of this paper provides the models used for the regression analysis. Section II presents data sources. Section III discusses the results.

I. ANALYTIC FRAMEWORK

My analysis is divided into three parts. The first part is the construction of Taylor rule error. It is then followed by the analysis on the relationship between Taylor rule error and

Treasury yield spread. Together with graphical analysis, the last part seeks to determine the efficacies of QE and forward guidance by looking at the change in movements of the Treasury yield spread in the post-crisis era.

To construct Taylor rule error, I first use ordinary least squares method to estimate the unknown parameters using data from 1982-2007. I use two approaches to obtain predicted Federal Funds Rate, namely the static and the dynamic approach. Using these two approaches, I created two sets of predicted FFR. The residuals are then named Taylor rule error.

In the second part, I investigate the relationship between Taylor rule error and Treasury yield spread, such as the spread of 30-year and 10-year yield, the spread of 10-year and 1-year yield and the spread of 30-year and 1-year yield. Again, the analysis runs up till year 2008 using OLS method. A fitted Taylor rule is meaningless after the crisis because of the zero lower bound. Hence, I analyze the post-crisis results using graphs, and weave a narrative based on the movement of spread and the use of unconventional monetary policies, such as QE.

To further understand other factors that might be causing the movement in the yield curves, such as the use of forward guidance, I run a simple regression to study the relationship between short-term rates, namely the actual and expected FFR, and long-term rates, which are the Treasury yield spread ranging from 1-year notes to 30-year bonds. The yield spreads capture the effect of forward guidance on market expectations. The two models that I use measure the effect of the movements in Federal Funds futures on Treasury yield spread and the effect of 1-year and 2-year Treasury yield on FFR one year ahead.

A. The Construction of Taylor Rule Error

The model that I use in this part is based on John Taylor's economic model for monetary policy. John Taylor wanted to design a policy rule, which could serve as a general guide to the policymakers in the Fed when they set short-term nominal interest rate or Federal Funds Rate (FFR). This rule stipulates the Fed to determine FFR in response to the change in output and inflation. The original rule is shown in the form of

$$r_t = \pi_t + r_t^* + 0.5(\pi_t - \pi_t^*) + 0.5(Y_t - Y_t^*), \tag{1}$$

where r_t is the Federal Funds Rate,

π_t is the rate of inflation,

r_t^* is the assumed equilibrium real interest rate,

π_t^* is the targeted rate of inflation,

$(Y_t - Y_t^*)$ is the real output gap measured in percentage.

Note that r_t^* and π_t^* are typically assumed to be 2% (Federal Reserve Board, 2015). The coefficients 0.5 are the proposed setting in what is called the Taylor principle. Basically, this principle says that if the rate of inflation is higher than 2% or if the real GDP is higher than the trend real GDP, then the FFR should increase. Specifically, with all other variables being held constant, FFR should rise for 0.5 percentage points if the output gap is 1%, and FFR should increase for 1.5% if the rate of inflation is 1% higher than the targeted inflation rate. This principle is parallel to the Keynesian model, which advocates for the implementation of expansionary monetary policy in a recession and vice versa.

This paper modifies the original version of Taylor rule by adding an extra variable, which is the lagged short-term nominal interest rate (r_{t-1}) into equation (1). This addition of variable serves the purpose of smoothing interest rate because it allows the Fed to gradually change rates without introducing shocks to the economy. Such smoothing needs to be taken into account to track actual Fed policy. The constant in equation (1), which is the equilibrium real interest rate, is now the intercept of equation (2), which is as follows:

$$r_t = \beta_0 + \beta_1 (\pi_t - \pi_t^*) + \beta_2 (Y_t - Y_t^*) + \beta_3 r_{t-1} + \varepsilon_t, \tag{2}$$

where r_t is the Federal Funds Rate,

π_t is the rate of inflation,

π_t^* is the targeted rate of inflation,

$(Y_t - Y_t^*)$ is the real output gap (in percent),

r_{t-1} is one-quarter-lagged Federal Funds Rate,

β_0 is the intercept or equilibrium real interest rate,

β_1, β_2 and β_3 are the strength of reaction to their respective variables, and

ε_t is the error term.

After getting the estimated coefficients using OLS method for data from 1982 to 2007, I construct a set of predicted FFR ranging from 1982 to 2014. This approach is called the static approach.

Besides using the static approach to get the predicted FFR, I also use the dynamic approach to obtain another set of predicted FFR. Under this approach, the predicted FFR from year 1982 to year 2007 are calculated using equation (2). However, for the predicted FFR from year 2008 to year 2014, I use the equation below:

$$\hat{r}_t = \beta_0 + \beta_1 (\pi_t - \pi_t^*) + \beta_2 (Y_t - Y_t^*) + \beta_3 \hat{r}_{t-1} + \varepsilon_t, \quad (3)$$

where $\hat{r}_t$ is the predicted Federal Funds Rate,

π_t is the rate of inflation,

π_t^* is the targeted rate of inflation,

$(Y_t - Y_t^*)$ is the real output gap (in percent),

$\hat{r}_{t-1}$ is the lagged predicted Federal Funds Rate,

β_0 is the intercept or equilibrium real interest rate,

β_1, β_2 and β_3 are the strength of reaction of their respective variables, and

ε_t is the error term.

Basically, equation (3) replaces the actual lagged FFR in equation (2) with predicted lagged FFR. It is a dynamic approach because the FFR has been stuck at the zero level ever since the crisis hit in 2008. This approach leads to a less rapid convergence of Taylor rule error to zero compared to the static approach, as the static approach relies very heavily on lagged FFR, which became zero in the post-crisis era.

Finally, Taylor rule error, which is the residual, is constructed using both the static and dynamic approach. It is the difference between the actual FFR and the predicted FFR as shown below:

$$\varepsilon_t = r_t - \hat{r}_t. \tag{4}$$

Note: Static and dynamic errors depending on model

B. The Relationship Between Taylor Rule Error and Yield Spread

After the construction of Taylor rule error, I intend to find out if there is a significant relationship between the error and Treasury yield spread. So, I use the model

$$[R_t - r_t] = \alpha + \beta_0 \varepsilon_t + \mu_t, \tag{5}$$

where R_t is the longer-term Treasury yield (30-year and 10-year),

r_t is the shorter-term Treasury yield (1-year and 10-year),

α is the intercept,

β_0 is a measure of the strength of the relationship,

ε_t is the Taylor rule error, and

μ_t is the error term of regression.

There are three types of regression that I run using equation (5), each of which has a different responding variable. First, I use the spread of 1-year and 10-year Treasury yield. Next, I regress the spread of 1-year and 30-year Treasury yield on Taylor rule error. The last type is to use the spread between the 10-year and 30-year yield as the responding variable. Note that I only run these regressions for the pre-crisis period, specifically from 1982 to 2007, for the reason mentioned in the beginning of this section. The estimated coefficients of the regression should be able to tell us the impact of deviation from Taylor rule on long-term interest rate.

C. The Relationship Between Short-Term and Long-Term Rates

Putting graphical analysis aside, I regress long-term rates, namely the 1-year, 10-year and 30-year Treasury yield, on 30-day Federal Funds futures rates dated from 1989 to 2015 to find out the effectiveness of forward guidance. The model that I use is

$$R_t = \alpha + \beta_0 \, FFF_t + \mu_t, \tag{6}$$

where R_t is the long-term Treasury yield (1-year, 10-year and 30-year),

α is the intercept,

β_0 is a measure of the strength of the relationship,

FFF_t is the 30-day Federal Funds futures rates, and

μ_t is the error term of regression.

The futures rates (FFF_t) are obtained by taking the difference between 100 and the price of futures, as this is the way they are priced in the market. Like in the previous part, I regress different dependent variables, namely the 1-year, 10-year and 30-year Treasury yield, on the same futures rates in equation (6) three separate times. The estimated values for each long-term yield are constructed using the coefficients from the regression. I then plot the predicted long-term yield and actual long-term yield spread in the same figure. The ultimate goal is to determine if the movements of estimated long-term yield curves, which are constructed based on the movements of Fed Funds futures rates, resemble the movements of the actual Treasury yield spread curves. If the movements are similar in the post-crisis era, we can then say that expected FFR correlates with the long-term Treasury yield through the working of forward guidance.

In addition, to find out if longer-term Treasury yield affect the adjustment of Federal Funds Rate, I use this model

$$FFR_{Q5\text{-}Q8} = \alpha + \beta_0(2R_{Q1\text{-}Q8} - R_{Q1\text{-}Q4}) + \mu_t, \qquad (7)$$

where $FFR_{Q5\text{-}Q8}$ refers to the Federal Funds Rate one year ahead,

α is the intercept,

β_0 is a measure of the strength of the relationship,

$R_{Q1\text{-}Q8}$ is the 2-year Treasury yield,

$R_{Q1\text{-}Q4}$ is the 1-year Treasury yield, and

μ_t is the error term of regression.

Since long-term Treasury yield are an average of short-term rates, the 2-year Treasury yield refers to short-term rates 8 quarters ahead. Similarly, the 1-year yield refers to short-term rates 4 quarters ahead. Thus, the difference between them refers to quarters 5 to 8 ahead. The left-hand side of equation (7), which is the FFR one year ahead, should refer to those same 5 to 8 quarters ahead. Also, there is a coefficient of two for the 2-year yield because there is a square in the yield formula. A statistically significant regression result means that it is possible to use longer-term Treasury yield to forecast Fed Funds rate one year ahead. In other words, we can predict FFR a year from now using this model.

II. DATA

The first part of my analysis is mainly about the construction of Taylor rule error, which is constructed using equation (2). As we can see from this equation, I need to get data on Federal Funds Rate, inflation rate, targeted inflation rate, GDP and potential GDP. All of these variables are measured quarterly. They range from year 1982 to year 2014.

First of all, the data on the effective Federal Funds Rate and the lagged FFR are obtained from the Board of Governors of the Federal Reserve System (FRS). They are not seasonally adjusted and are aggregated by taking quarterly averages and expressing them as an annual rate (percent). For the rate of inflation, I use the implicit price deflator with an index of 2009=100 published by the U.S. Bureau of Economic Analysis. They are seasonally adjusted and their units are percentage change from year ago. The targeted inflation rate is assumed to be 2% because this is the rate that the Federal Open Market Committee (FOMC) has always been aiming for. The committee determines it to be the most consistent rate in the long run that fulfills the Fed's mandate of maximizing employment and stabilizing prices in the economy. The inflation difference is just the difference between the rate of inflation and the targeted inflation rate expressed in the unit of percentage.

In terms of real GDP or output, the data are seasonally adjusted annual rate from the U.S. Bureau of Economic Analysis. For potential output, I use data that are not seasonally adjusted from the U.S. Congressional Budget Office. To obtain the output gap, I take the percentage change between the real and potential output with real potential GDP as the denominator.

In the second part of my analysis, which centers on the idea of investigating the relationship between Taylor rule error and Treasury yield spread, I obtain the data for 1-year, 10-year, and 30-year Treasury yields from the Board of Governors of the Federal Reserve System (FRS). Even though they are daily rates, I use an aggregation method to get their average so that they can be converted into quarterly terms. All yields range from year 1982 to year 2007, except for the 30-year Treasury yield, as there is a discontinuity in the 30-year Treasury Constant Maturity Series from February 2002 to February 2006.[2] The spread is just the difference between any two yields. As a result, this paper considers the spread between 30-year and 1-year yield, 10-year and 1-year yield and 30-year and 10-year yield.

For the final part of my analysis, I extract Fed Funds futures data from Stevens Continuous Futures database because individual futures contracts have fixed trading-start and trading-end dates, short lifespans, and variable liquidity- all of which make them unsuitable for analyzing long-term trends in the data (Quandl, n.d.). The underlying future contracts are the 30-day Fed Funds futures contracts offered at the Chicago Mercantile Exchange.[3]

Besides using futures contracts with a 30-day expiration period, I also use 30-day futures contracts that expire six calendar months after the expiration date. It is called the 6-month mid curve option (CME Group, 2011). For instance, a 6-month mid-curve option that expires in January would refer to Federal funds futures contract that expires in July. The daily prices are obtained from the Bloomberg terminal.

All data on futures and options prices have daily frequencies. In order to standardize my analysis with the frequencies of Taylor rule error and Treasury yield spread, I take their average prices of three months so that their frequencies can be expressed quarterly.

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[2] The Treasury did not offer 30-year bonds in that period.

[3] Following a weighted-average process, called the calendar-weighted adjusted prices contracts, the price gap between consecutive contracts is smoothed in this set of data. The rolling date for the contracts is the first day of the delivery month of the expiring or front contract.

III. RESULTS

The paper will now present ordinary least squares (OLS) estimates of key parameters and then use the framework discussion in Section I to analyze Fed policy.

A. Pre-Crisis Period (1982-2007)

To construct predicted Federal Funds Rate, I run a regression using equation (2) to get the estimated coefficients of β_1, β_2 and β_3. According to Taylor rule, the coefficients determine how much the Fed should respond to their respective variables. For instance, if $\widehat{\beta_1}$ is 0.5 and the inflation difference is 5%, with other variables being zero, the Federal Funds Rate should be set at a level of 2.5%.

Table 1 shows the results of the regression. Based on the results, 0.91 is the coefficient of estimate for FFR in the previous period. This shows that the Fed took lagged FFR into account heavily while deciding nominal interest rate for current period. This is not surprising at all because the Fed prefers doing interest rate smoothing rather than introducing huge shocks to the economy. The estimated coefficient for the inflation gap, which is 0.16, is slightly higher than that of the output gap at 0.13, implying that the Fed takes inflation more seriously than output when adjusting FFR.

Plugging in the values from Table 1, the equation for predicted nominal interest rate under the static approach becomes

$$\widehat{r_t} = 0.46 + 0.16(\pi_t - \pi_t^*) + 0.13(Y_t - Y_t^*) + 0.91r_{t-1}. \tag{2a}$$

I then used equation (2a) to calculate predicted FFR from 1982 to 2015. As stated earlier, Taylor rule error is the difference between the actual and predicted FFR. Using equation (4), I constructed the error. Figure 1 plots the error over the entire sample.

Under the dynamic approach, from year 1982 to year 2007, I used equation (2a) to obtain the predicted FFR. However, for years from 2008 to 2015, I used the below equation

$$\widehat{r_t} = 0.46 + 0.16*(\pi_t - \pi_t*) + 0.13*(Y_t - Y_t*) + 0.91*\hat{r}_{t-1}, \tag{3a}$$

to obtain another set of predicted FFR. Again, equation (4) is used to compose the error. The graph of this data set is shown in Figure 2.

In Figure 2, there are a few interesting points that are worth analyzing. First, the fluctuations of error were quite steady from 1986 to 2007. If we observe closely, the error stayed at levels close to zero from 2002 to 2007. This observation refutes the common notion about the Fed being too loose on the interest rate in that period, as a zero error implies that the Fed followed Taylor rule in a very close manner. If the Fed had been too loose, the error would have been negative throughout that period, but the graph shows very small positive errors from 2004 to 2006 on the contrary. So, the Fed did not really deviate from Taylor rule.

Second, there was a huge drop in Taylor rule error from 2007 to 2009. To investigate the reason behind this phenomenon, I made Table 2, which effectively shows the decomposition of Taylor rule error, in that period. I included variables of interest that were regressed in the table, such as inflation gap, output gap, lagged FFR, and predicted FFR, as they are contributors to Taylor rule error.

As shown in Table 2, the inflation gap did not change as much as the output gap and the FFR did. Compared to the decrease of less than 2% in inflation gap, the output gap plummeted by approximately 7% and the FFR decreased by about 5% in the span of two years. Note that the estimated coefficients of output gap and inflation difference are about the same, which are 0.13 and 0.16 respectively. Since the coefficient of estimates for FFR is 0.91, I deduce that the negative error in the period from 2007 to 2009 stems mostly from the rapid decrease in Federal Funds Rate. The Fed had never adjusted the interest rate in such a big degree, but it intentionally lowered it to almost zero at the end of 2009. It suspended historical norms, mainly because the economy was changing faster at that point than it has historically.

Last but not least, we observe that by the end of 2009, Taylor rule error was back to zero, and has turned positive ever since. The reason behind this is that the Fed has not been able to adjust the FFR to below zero, so the interest rate has been restricted by the zero lower bound. The FFR though, should be adjusted to a negative level according to Taylor rule. So, a positive Taylor rule error was created. However, it has been gradually converging to zero because of the economic recovery.

In this paper, I opted to use Figure 2, which depicts Taylor rule error using the dynamic approach, for my analysis because of two reasons. First, the huge drop of error in Figure 2 from year 2007 to year 2009 is smoother than the inconsistent movement of the same period in Figure 1. This inconsistent movement in error occurred, as there was a large decrease in FFR from the last quarter in 2008 to the first quarter in 2009, and in inflation difference for the first three quarters in 2009 as shown in Table 2. Also, the error in Figure 2 does not converge to zero as rapidly as the error in Figure 1 after year 2009. The reason behind this is that the error composed in Figure 1 depends heavily on the actual FFR instead of the predicted FFR in Figure 2. The post-crisis actual lagged FFR was stuck at the zero bound, so the error converges to zero very soon under the static approach. It is more sensible to use Figure 2, as we want to investigate the effect of Taylor rule error on Treasury yield spread under normal circumstances.

After Taylor rule error is constructed, I investigated the relationship between the error and Treasury yield spreads for the period before the Great Recession. A positive Taylor rule error implies that the Fed is being tight and vice versa. An increase in yield spread suggests an increase in long-term interest rate and vice versa. I did a regression using equation (5) and the results are shown in Table 3.

From Table 3, we see that there exists a negative relationship between Taylor rule error and Treasury yield spread for all columns. This implies that when the Fed set actual FFR to be higher than predicted FFR using Taylor rule before the crisis, it managed to decrease long-term interest rate. This result fulfills the expectations of many because when the error is positive, people believe that the Fed sets the short-term nominal interest rate to be unexpectedly high, and thus lower their expectations for future inflation. Since market forces affect long-term interest rates or long-term bonds, a decrease in expectations of future inflation leads to an increase in the demand and price of long-term bonds, which then lowers their yield (Bernanke, 2013). So, a positive error leads to a decrease in long-term Treasury yield spread. Likewise, if the market believes that the short-term nominal interest rate is too low or there is a negative Taylor rule error, it increases its expected future rate of inflation and demands less long-term bonds. The equilibrium price of long-term bonds will decrease and cause an increase in Treasury yield spread.[4]

B. Post-Crisis Period (2008-2015)

After the crisis, the Fed had to use unconventional monetary policy tools to lower long-term interest rate due to the zero lower bound. The biggest operation carried by the Fed was to implement a few rounds of quantitative easing (QE), namely QE1, QE2 and QE3. In short, the Fed started QE1 in March 2009 by purchasing $1.25 trillion of mortgage-backed securities, $100 billion of agency debts and $300 billion of long-term Treasury securities. QE2, which began in November 2010, is an operation carried by the Fed that promised to purchase up to $600 billion of long-term Treasury securities (Ricketts, 2011). In September

[4] See Table 4 for data on Treasury spreads and Taylor rule error from 2008 to 2015.

2012, the Fed implemented QE3, which entails the purchasing of $40 billion of mortgage-backed securities per month and extending the maturity of its holdings of securities (U.S. Federal Reserve Board, 2012).

In this analysis, I used a different method compare to that of the analysis of pre-crisis for two reasons. First, a post-crisis positive Taylor rule error has a complete different meaning. It is derived from the zero-lower-bound of short-term nominal interest rate, but not from the adoption of contractionary monetary policy. It represents a constraint in policy rather than a policy surprise. Second, due to the big fluctuations in the output gap and the use of unconventional policy tools, such as quantitative easing, it is more appropriate to use graphical analysis (see Figure 3 and 4) rather than regression analysis.

Figures 3 shows the overview of the error and yield spread from 1982 to 2015 while Figure 4 focuses on the period between year 2006 and 2015. The vertical dotted lines are the timing at which each round of QE was implemented; starting from the left is QE1, followed by QE2, and subsequently QE3.

From these figures, we observe a decrease in 30-year minus 1-year yield spread and in 10-year minus 1-year yield spread after the implementation of QE2. This finding is particularly novel and interesting because of several reasons. First of all, the downward movement of spread after the implementation of QE2 justifies the main purpose of implementing QE2, which is to reduce long-term interest rates. Since Fed Funds Rate was stuck at the zero lower bound, the Fed believed that decreasing the long-term interest rate, which is also the yield, might be a better way to boost the economy. Both figures show that the spread did fall, so QE2 appears successful.

Furthermore, there is no apparent downward movement in both 30-year minus 1-year yield spread and 10-year minus 1-year yield spread after QE1 and QE3 were implemented.

This implies that QE1 and QE3 might not be as effective as QE2 in lowering long-term interest rates. This may not be surprising since QE1 is more about the purchase of mortgage-backed securities (MBS), which aims to lower the spread between MBS and Treasuries. Thus, QE1 did not create the same magnitude of effect on spreads as QE2 did. QE3 though, can be compared to QE2 because, like QE2, it focused on the purchase of only Treasuries. Based on the figure, we can say that its effect is less immediate than that of QE2.

In addition, we see a spike in yield spread in 2013 from Figure 3 and 4. The reason behind this escalation in spread is that the public's expected future inflation rose after Ben Bernanke, then Chairman of the Fed, mentioned the idea of tapering on May 22nd, 2013. The Fed announced to the public that it would start cutting down bond purchases later in the year if market conditions are conducive (Bernanke, 2013). This announcement effectively brings the curves of yield spread up, putting a halt to the downward pressure faced by the yield spread after QE2.

Furthermore, I plotted Figure 5 to study the relationship between quantitative easing and the 30-year minus 10-year yield spread, which solely represents the longer-term outlook of the market. Based on the figure, after QE1 was implemented, the 30-year and 10-year yield spread increased gradually. It stayed at a rather stable level after QE2 and QE3 were carried out. The reason behind this might be the fact that the public did not expect their effect to persist in the very long run. So, the implementation of QE does not have much impact on long-term Treasury yield.

To further understand the movement of yield spread post-crisis, I also created Table 4, which displays the values of 10-year minus 1-year, 30-year minus 1-year and 30-year minus 10-year yield spread in addition to the values of Taylor rule error. As we can see, all spreads, except for the 30-year minus 10-year yield spread, decreased after QE2, which was implemented after the end of quarter 4 in 2010. This is consistent with the graphical analysis. Thus, we can say that the public did not expect the effect of QE to be long-term.

C. The Relationship Between Short-Term and Long-Term Rates

Besides QE, the Fed also used forward guidance starting from December 2008 to alter market's expectations about future monetary policy. It wanted the market to believe that the Fed would continue to be accommodative in the future so that long-term Treasury yield could be lowered via the short-term rates expectation channel. First, the Fed lowered public's expectations on the FFR with phrases like "weak economic conditions are likely to warrant exceptionally low levels of federal funds rate for some time" (Board of Governors of the Federal Reserve System, 2008). Then, it switched to calendar-based forward guidance by adding specific dates in its announcement before changing it to threshold-based forward guidance that depends on the state of the economy.

Since forward guidance addresses future short-term rates, we can determine its effectiveness by looking at the effect of expected Federal Funds Rate on long-term Treasury yield. The prices of 30-day Federal Funds futures (FFF) can best represent expected FFR because investors buy and sell futures based on their expectations for movements in that rate. Since the prices of FFF are essentially the difference between 100 and the expected rates, the futures rates are then equivalent to expected FFR.

See Figure 6 for levels of futures rates and Treasury yield spread from 1989 to 2015. Based on the figure, the futures rates are negatively affecting the spread. The reason for that is that when expected FFR increases, it pushes up the shorter-term yield, which are the 1-year yield and 10-year yield, more than the first term of the spread, as shorter-term yield receive more influence from the changes in overnight rates. This increase causes the spread to become smaller, thereby creating a negative relationship between the futures rates and the spread.

To demonstrate the hypothesis empirically, I run a regression based on equation (6) and the results are displayed in Table 5. There is a strong positive correlation between futures rates and Treasury yields. Furthermore, we see a declining trend in the coefficients as the maturities of the Treasury securities increase from column (1) to (3). This observation is coherent with my hypothesis that shorter-term yields receive more impact from the changes in expected FFR.

Using the coefficients from Table 5, I found the fitted values of Treasury yield. The estimated yield curves, which are constructed based on futures rates, are plotted in the same graph (see Figure 7) with the yield spread to observe the relationship between expected short rates and long-term yield.

Before the crisis in 2008, the estimated yield curves were not moving in the same direction as the actual yield spread. However, starting from 2009, there appears to be a co-movement between these two sets of variables, especially between those spreads that involve the 1-year yield. As the estimated 1-year yield became relatively stable in that period, those spreads that involve the 1-year yield essentially depict the movements of the actual 30-year and 10-year yield. It can then be deduced that the movements of these estimated yields follow very closely to the movements of the actual yields, further testifying the notion that forward guidance, which evolved from time-based to calendar-based, was successful. This is because it lowers long-term Treasury yield through the channel of market's expectations about future short rates.

On a side note, it is interesting to observe the deep plunge in the estimated 1-year yield back in 2007. Falling from the 5% to slightly less than 2.5% within a year, this shows the market already foresaw deep Fed Funds Rate cuts before the crisis became huge. It turned out that the market was right about the bad outlook for the economy, but it probably expected it to only last for a short period of time in 2007, as the longer-term spreads were still growing at a high rate before they slowed down in 2009.

To further study market's expectations in the short term, I plotted a curve, which encapsulates the rates for Fed Funds futures six month ahead, on the same graph. Essentially, it is the market's expectation for FFR in six months from the time of purchase. The red dotted line is plotted at May 2013 because that is the period when the announcement of "tapering" was made. There is an upward shift in spreads and futures immediately after that date. This shows that the market predicted the FFR to increase in six months' time after the Fed announced that it was going to cut down on its purchases of bonds. After a period of months, when suspicions of taper were reduced, we see a downward shift in the yield curves and futures. This indicates that forward guidance was at work.

Now that we know expectations of short-term rates have an impact on long-term Treasury yield, it would be interesting to see if longer-term rates affect Federal Funds Rate. In other words, we want to know if FFR are shaped by longer-term Treasury yield. Here, I used the difference between 2-year and 1-year Treasury yield to forecast FFR one year ahead, as shown in equation (7). Since the zero lower bound prevented FFR to go beyond negative after the crisis in 2008, it only makes sense to run the regression up till 2007.

The results are displayed in Table 6. There is a strong positive relationship between these two variables. When the difference between the 2-year and 1-year Treasury yield, which refers to quarter 5 to 8 from time t, increases by one basis point, the predicted FFR one year ahead increases by 0.72 basis point. I then plotted the predicted values of the Federal

Funds Rate one year ahead and compare them with the movement of actual values in Figure 8. Figure 9 shows the forecasted values and Federal Fund futures rates from 2014 to 2016.

Based on Figure 8, we see the predicted FFR curve facing downward pressure from 2008 to mid-2014. Since the predicted FFR is one year ahead, this means that the market anticipated a decrease in FFR starting from 2007 to 2013. Only after the “taper tantrum” did the predicted FFR increase. This observation implies that the Fed successfully lowered the public’s expectations for short-term interest rates via forward guidance.

In Figure 9, we observe a big difference in level between the predicted FFR one-year-ahead curve and the Federal Funds futures curve. As the predicted FFR one-year-ahead curve is plotted based on medium-term Treasury yields before the Great Recession, it represents the market’s historical expectations on FFR. In other words, had the crisis not occur, the market would have expected the FFR to be identical to this curve. On the other hand, the FFF curve in Figure 9 represents the market’s expected FFR based on current available information. Thus, it is not surprising to observe its close resemblance to the actual FFR curve. The only thing that could have created the difference in the level of these two curves is the adoption of forward guidance in the post-crisis era. Therefore, we deduce that forward guidance is successful in lowering market’s expectations on FFR.[5]

Furthermore, we see a gradual increase in predicted FFR one year ahead starting from 2015. It signifies an increase in anticipation for a liftoff coming from the market in that period. The rate-hike in December 2015 helps to raise the slope of the predicted rate curve, especially the curve dated at the end of 2016. In other words, the market expects the Fed to raise FFR gradually until later in the year. It aligns with the message that the Fed attempted

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[5] See Appendix for a summary table of the Fed’s policy choices and their effects on Treasury yields

to convey to the market in the December FOMC meeting, which is to warrant only gradual increases in the FFR. [6]

V. CONCLUSION

There are several main findings in this work, which focuses on the impact of monetary policies on the term structure before and after the Great Recession. First, Taylor rule error is inversely related to Treasury yield spread before the crisis. This implies that when the Fed was tight, it successfully lowered the public's expectations of future inflation and thus decreased long-term yield spread. After the crisis, this relation breaks down because a Taylor rule error reflects the zero lower bound constraint but not a policy deviation.

After the crisis, the Fed adopted QE and forward guidance because of the zero lower bound. Graphical analysis shows that only QE2 is effective in bringing down long-term interest rates. Since QE1 was mostly just the purchase of mortgage-backed securities, it created no major impact on Treasury yields. QE3 appears to be less effective than QE2 because it had less immediate effect on long-term Treasury yield as compared to QE2.

Not only that, forward guidance plays a role in lowering Treasury yield as well. It came into effect by altering market's expectations for future short-term rates after the crisis. It is important to note that there was no co-movement between the spread and Fed Funds futures rates before the crisis. The co-movement between these two variables after the crisis implies that both calendar-based and threshold-based forms of forward guidance successfully brought down long-term Treasury yield via the channel of expected short-term rates.

[6] http://www.federalreserve.gov/newsevents/press/monetary/20151216a.htm

Moreover, this study finds that there exists a significant relationship between Federal Funds Rate one year ahead and medium-term Treasury notes. The difference in level between the Fed Funds futures curve and the FFR one year ahead curve implies that forward guidance is effective. Based on the strength of the relationship, findings predict that FFR is going to increase gradually in 2016.

In conclusion, this paper finds the Fed's policies to be effective because they fulfill their respective purposes, be it open market operations or unconventional monetary policies. Nevertheless, the individual effect of QE2 and forward guidance on long-term Treasury yield remains to be answered, as they are not focuses of this study. Further research on this topic needs to be done to ensure better policy-making in the future.

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Table 1: Estimates of Taylor Rule Coefficients

	(1) Federal Funds Rate
Inflation difference	0.16
	(0.06)
Output gap	0.13
	(0.04)
Lagged federal funds rate	0.91
	(0.03)
Constant	0.46
	(0.15)
Observations	104
R^2	0.96

Robust standard error in parentheses

Sample period: 1982:Q1 – 2007:Q4

Table 2: Decomposition of Taylor Rule Error (Dynamic Approach) from 2007 to 2009

Date	Inflation difference (%)	Output gap (%)	Lagged FFR (%)	Predicted FFR (%)	Taylor rule error (%)
2007:Q1	1.00	-0.53	5.25	5.31	-0.05
2007:Q2	0.80	-0.34	5.26	5.31	-0.06
2007:Q3	0.40	-0.23	5.25	5.26	-0.19
2007:Q4	0.50	-0.41	5.07	5.08	-0.58
2008:Q1	-0.10	-1.59	4.50	4.85	-1.67
2008:Q2	-0.10	-1.61	3.18	4.62	-2.53
2008:Q3	0.20	-2.57	2.09	4.34	-2.40
2008:Q4	-0.10	-5.07	1.94	3.70	-3.19
2009:Q1	-0.40	-6.79	0.51	2.84	-2.66
2009:Q2	-1.10	-7.26	0.18	1.90	-1.72
2009:Q3	-1.80	-7.27	0.18	0.92	-0.76
2009:Q4	-1.60	-6.67	0.16	0.15	-0.03

Table 3: Regression Before the Great Recession

	(1) 10-year – 1-year	(2) 30-year – 1-year	(3) 30-year – 10-year
Taylor rule error	-0.27	-0.26	-0.07
	(0.12)	(0.15)	(0.06)
Constant	1.26	1.33	0.20
	(0.10)	(0.12)	(0.03)
Observations	104	104	89
R^2	0.023	0.020	0.026

Robust standard errors in parentheses

Sample period: 1982:Q1 – 2007:Q4

Table 4: Treasury spreads and Taylor rule error from 2008-2015

Date	Spread(10-1year) (%)	Spread(30-1year) (%)	Spread (30-10year) (%)	Taylor rule error (%)
2008:Q1	1.56	2.30	0.74	-1.67
2008:Q2	1.81	2.50	0.69	-2.53
2008:Q3	1.73	2.32	0.59	-2.40
2008:Q4	2.24	2.67	0.43	-3.19
2009:Q1	2.17	2.89	0.72	-2.66
2009:Q2	2.80	3.65	0.85	-1.72
2009:Q3	3.07	3.87	0.80	-0.76
2009:Q4	3.11	3.99	0.88	-0.03
2010:Q1	3.36	4.26	0.90	0.65
2010:Q2	3.11	3.99	0.88	1.13
2010:Q3	2.51	3.59	1.08	1.39
2010:Q4	2.62	3.91	1.29	1.54
2011:Q1	3.19	4.29	1.10	1.73
2011:Q2	3.00	4.14	1.14	1.77
2011:Q3	2.28	3.56	1.28	1.85
2011:Q4	1.94	2.93	0.99	1.88
2012:Q1	1.88	2.98	1.10	1.90
2012:Q2	1.64	2.75	1.11	1.97
2012:Q3	1.46	2.56	1.10	2.02
2012:Q4	1.54	2.69	1.15	2.10
2013:Q1	1.80	2.98	1.18	2.14
2013:Q2	1.86	3.01	1.15	2.22
2013:Q3	2.59	3.59	1.00	2.23
2013:Q4	2.61	3.66	1.05	2.21
2014:Q1	2.65	3.56	0.91	2.24
2014:Q2	2.52	3.34	0.82	2.16
2014:Q3	2.39	3.16	0.77	2.00
2014:Q4	2.13	2.82	0.69	1.92
2015:Q1	1.74	2.32	0.58	1.93
2015:Q2	1.91	2.63	0.72	1.88
2015:Q3	1.87	2.61	0.74	1.72
2015:Q4	1.72	2.49	0.77	1.56

Notes: The shaded rows show the timing at which QEs were introduced.

Table 5: Regression of Treasury Yield on Federal Funds Futures

	(1) 1-year	(2) 10-year	(3) 30-year
Fed Funds Futures	0.95	0.64	0.54
	(0.01)	(0.03)	(0.03)
Constant	0.24	2.80	3.64
	(0.03)	(0.11)	(0.12)
Observations	108	108	93
R^2	0.98	0.78	0.70

Robust standard errors in parentheses

Sample period: 1989:Q1 – 2015:Q4

Table 6: Estimate of 2*2-year Treasury Yield Minus 1-year Treasury Yield

	(1)
	FFR one year ahead
2*2-year Treasury yield Minus	0.72
1-year Treasury yield	(0.06)
Constant	0.55
	(0.37)
Observations	104
R^2	0.67

Robust standard error in parentheses

Sample period: 1982:Q1 – 2007:Q4

Figure 1: Taylor Rule Error (Static Approach)

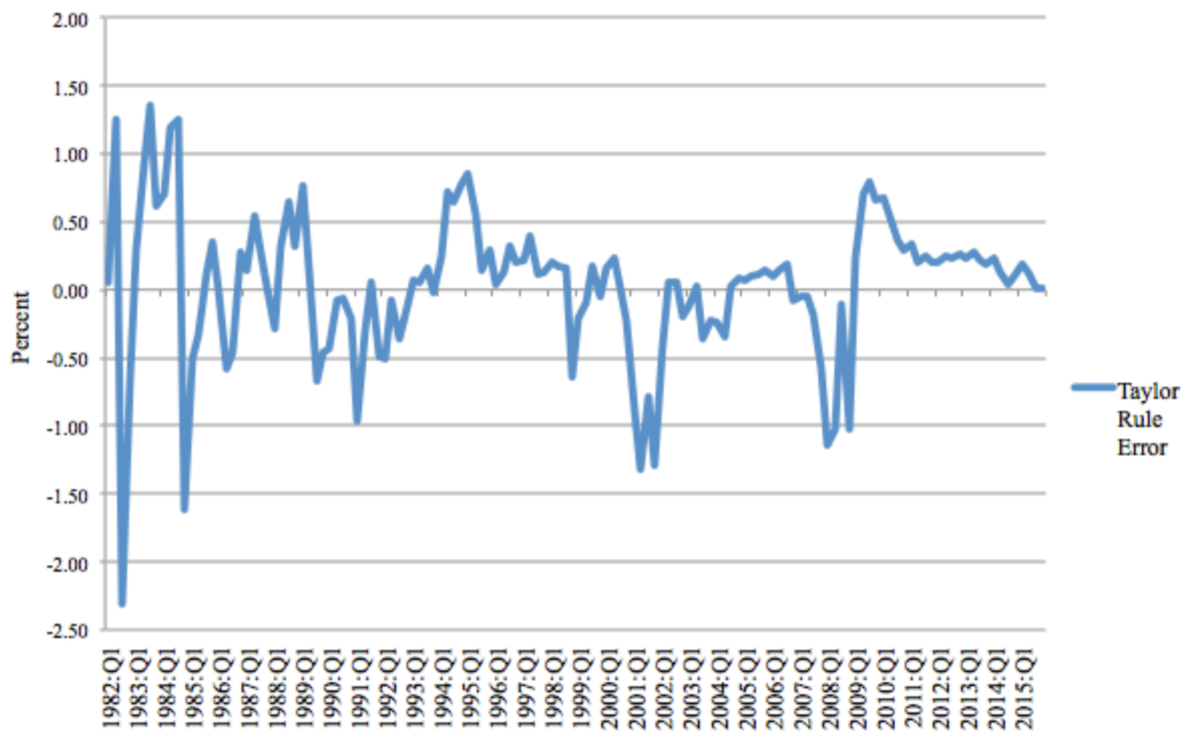


Figure 2: Taylor Rule Error (Dynamic Approach)

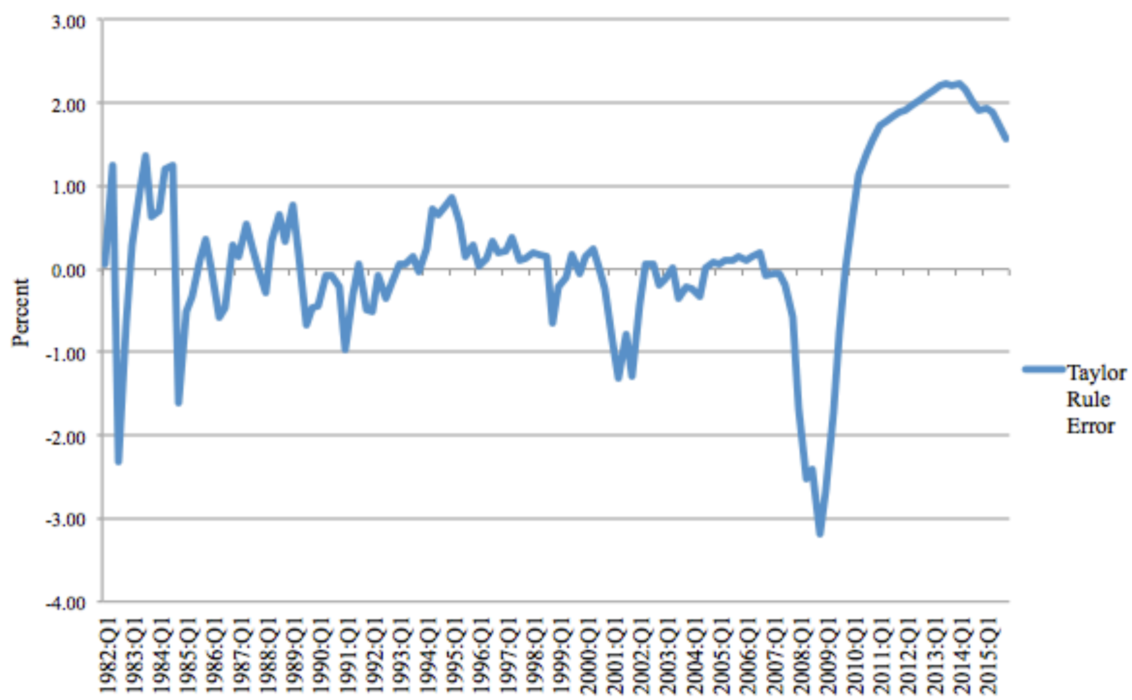


Figure 3: Taylor Rule Error and Treasury yield spread (1982-2015)

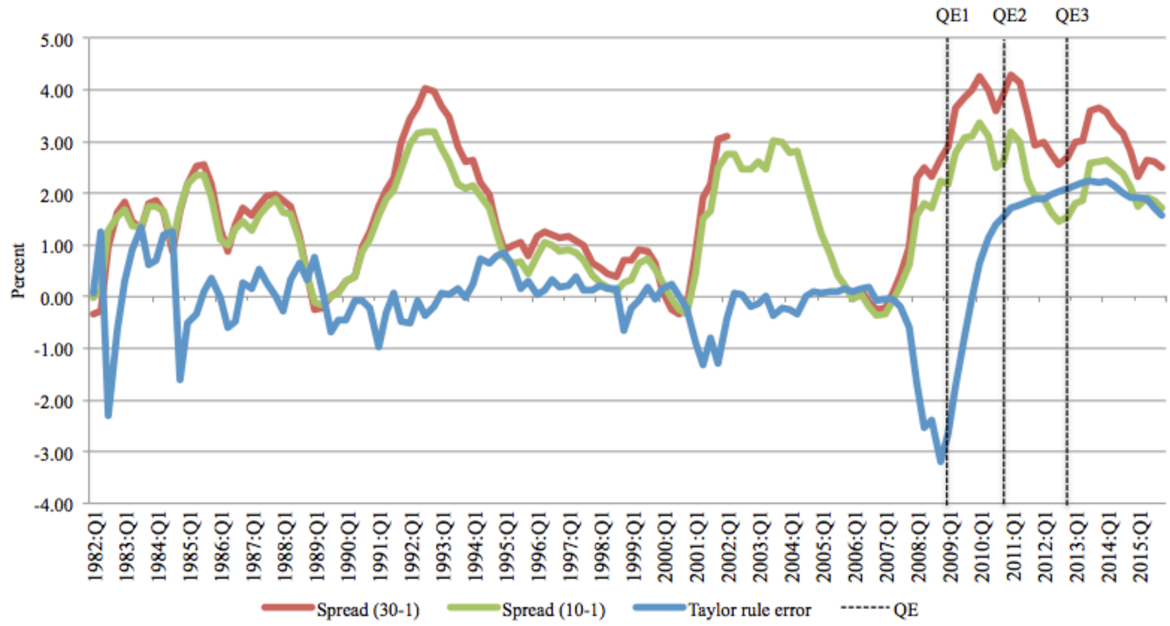


Figure 4: Taylor Rule Error and Treasury Yield Spread (2006-2015)

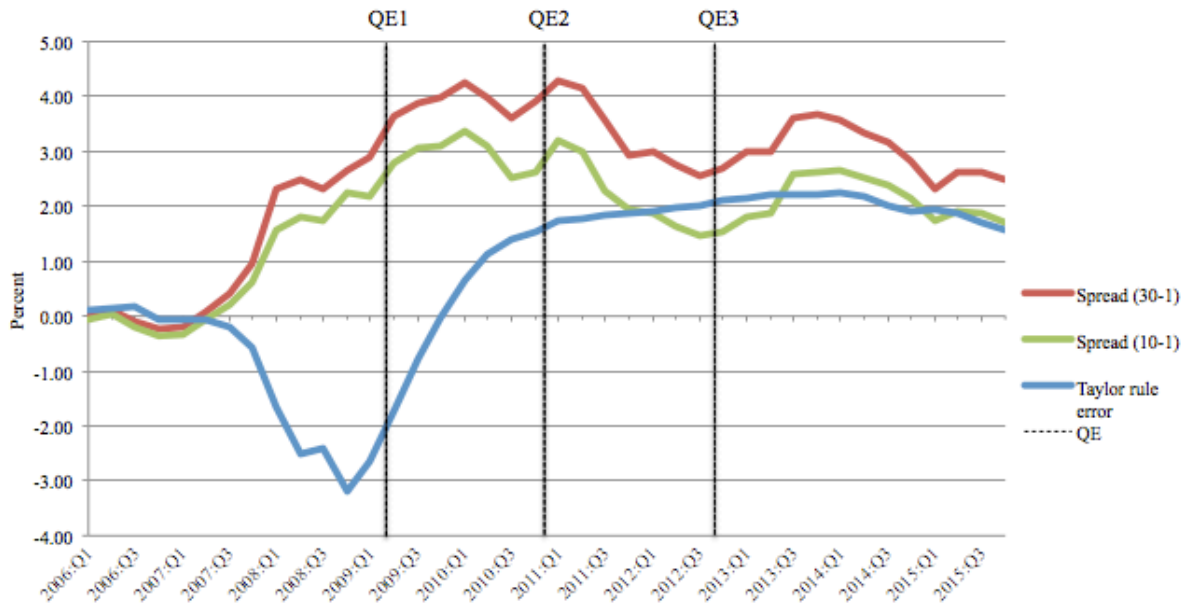


Figure 5: Taylor Rule Error and Treasury Yield Spread (30year -10year)

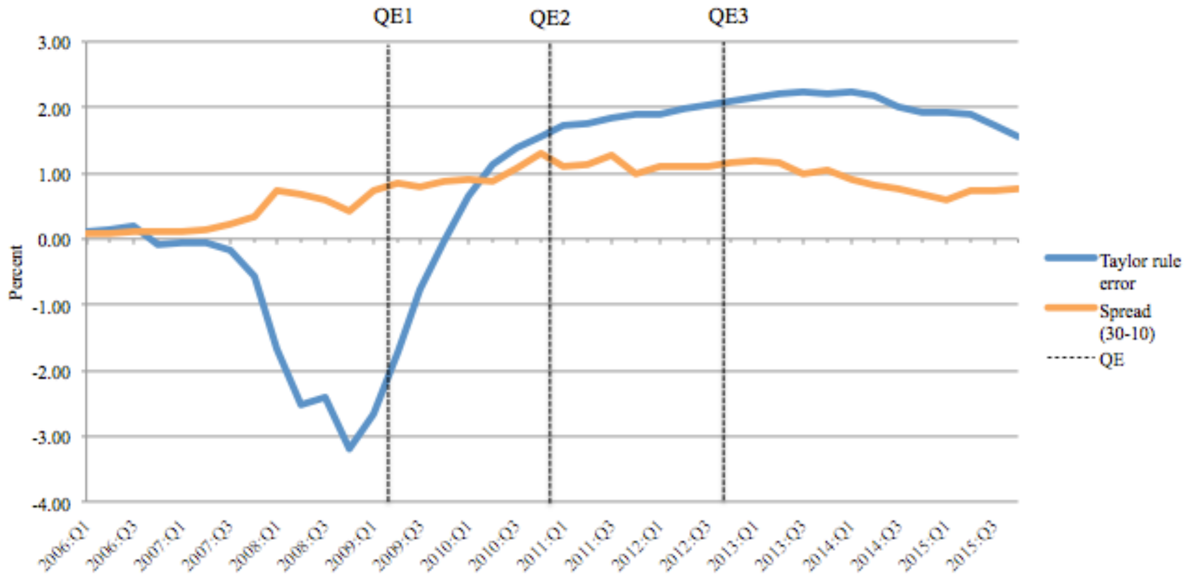


Figure 6: Futures Rate and Treasury Yield Spread

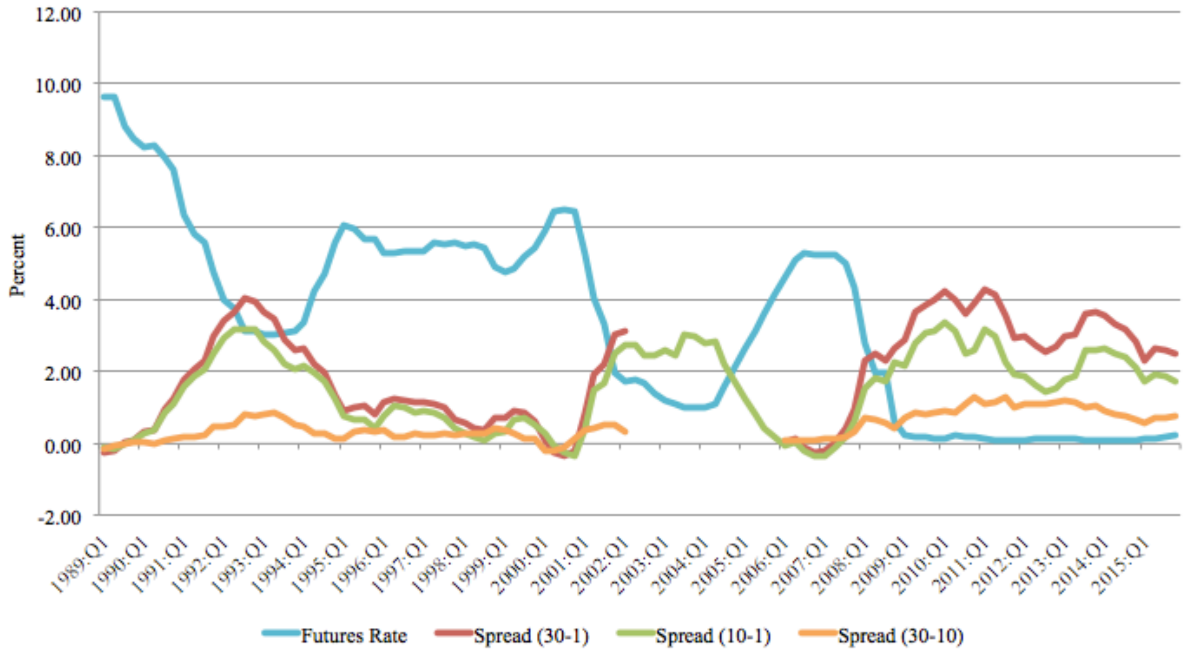


Figure 7: Estimated Treasury Yield Curves, Yield Spread and 6-Month Mid-curve Options

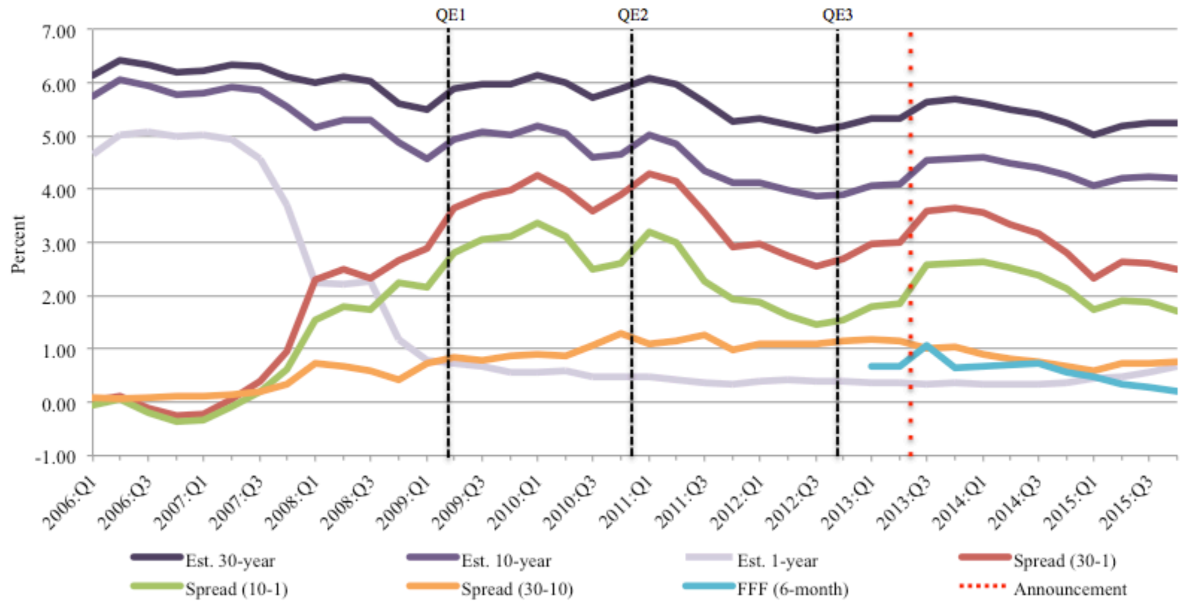


Figure 8: Predicted and Actual Federal Funds Rate One Year Ahead (1982-2016)

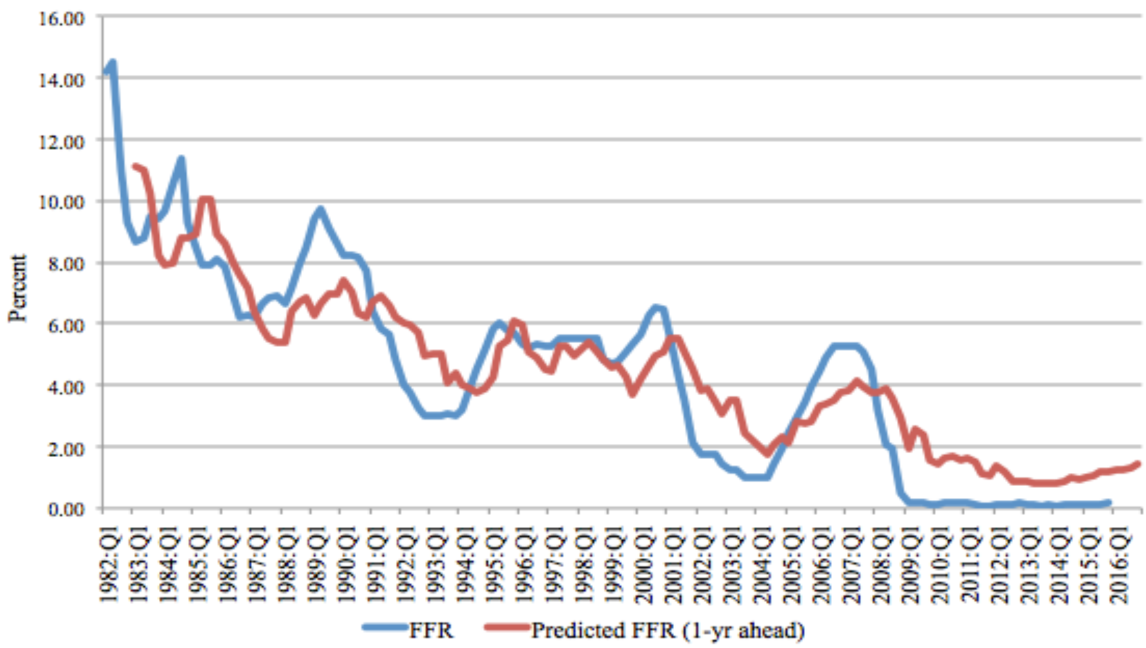
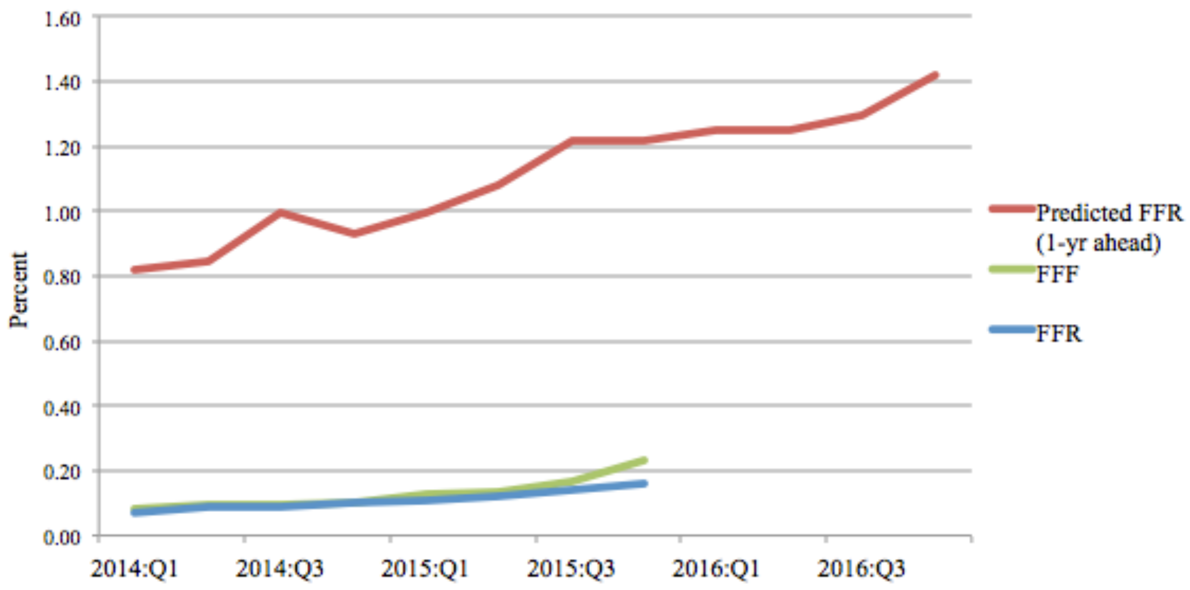


Figure 9: Fed Funds Futures, Predicted and Actual Federal Funds Rate One Year Ahead (2014-2016)



Appendix

A Summary Table of Policy Choices and Their Effect on Treasury Yields

Policy Choice	**Nature of Policy**	**Time**	**Effect on Treasury Yields**
Open Market Operations (OMO)	Buy or sell Treasury bills	Before the FFR hits the ZLB	Decreased or increased FFR
Forward Guidance	Time-dependent; Communicate likely future course of monetary policy with the public	Dec 2008	Decreased Treasury yields via the channel of expected FFR
QE1	Buy mostly mortgage-backed securities (MBS)	Mar 2009	Very little effect, as the goal is to lower the spread between MBS and Treasuries
QE2	Buy mostly longer-term Treasury bonds	Nov 2010	Decreased Treasury yields
QE3	Buy mostly longer-term Treasury bonds	Sept 2012	Less immediate effect
Forward Guidance	State-of-the-economy dependent; Communicate likely future course of monetary policy with the public	Dec 2012	Decreased Treasury yields via the channel of expected FFR