MEASURING THE CONSTRAINT OF THE ZERO LOWER BOUND ON MONETARY POLICY IN THE UNITED STATES

by

Samuel Hecksher

A thesis submitted to the faculty of
The University of North Carolina at Charlotte
in partial fulfillment of the requirements
for the degree of Master of Science in
Economics

Charlotte

2018

Approved by:

_____
Dr. Rob Roy McGregor

_____
Dr. Paul Gaggl

_____
Mr. Azhar Iqbal

ABSTRACT

SAMUEL HECKSHER. Measuring the constraint of the zero lower bound on monetary policy in the United States. (Under the direction of DR. ROB ROY MCGREGOR)

After the financial crisis in 2007-2008 the Federal Reserve lowered its target interest rate down to the zero lower bound (ZLB) forcing itself towards unconventional monetary policy. Attempting to mitigate the constraint that is the ZLB, the Fed enacted the use of forward guidance through official communications as well as large scale asset purchases. The purpose of this paper is to focus on the Fed's attempted policy action to shape market expectations through communication and interest rate targeting in three distinct periods: the pre-ZLB era, the ZLB era, and the post-ZLB era. By extracting the "surprise" element of both Fed communication and the fed funds rate during the three periods I quantify the effectiveness of the Fed's conventional and unconventional policy and thus determine how much of a constraint the ZLB actually is on monetary policy. I find that interest rate policy had a significant impact pre-ZLB and that FOMC intentions and market expectations have aligned post-ZLB leaving little to surprise. Fed communication, on the other hand, measured through surprise changes in tone, do not impact Treasury yields of various maturities.

ACKNOWLEDGEMENTS

First, I would like to thank my advisor, Dr. Rob Roy McGregor. His generosity with his time allowed for discussions that motivated my curiosity and educated me about the process of research.

Next, I would also like to thank the other members of my committee, Dr. Paul Gaggl and Mr. Azhar Iqbal.

Finally, I would like to thank the Economics Department of the Belk College of Business at UNC Charlotte for providing resources that made this work possible.

DEDICATION

For my family, Joe, Julie, Anna, and Sara who have supported and believed in me when I needed it most.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1: INTRODUCTION

The Federal Reserve, in pursuit of its dual mandate of stable prices and full employment, conducts monetary policy by taking actions to affect the level of interest rates and the amounts of money and credit available in the economy. There are several ways to accomplish this, but the Fed mainly uses a process called open market operations whereby it buys or sells U.S. Treasury bonds from banks and thereby increases or decreases their excess reserves. By doing so, the Fed is able to manipulate the interest rates throughout the economy in accordance with its policy objectives. The main target of the FOMC (Federal Open Market Committee), the monetary policy arm of the Federal Reserve System, is the fed funds rate or rather the rate at which banks lend to one another. Changes in the fed funds rate usually then trickle out to other interest rates and allow the Fed to ease credit conditions and spur the economy during tough times by encouraging lending and spending, while other changes in the fed funds rate target are aimed at having the opposite effect.

The Federal Reserve is made up of 3 key entities: the Federal Reserve Board of Governors, 12 district banks, and the Federal Open Market Committee (FOMC). The Board of Governors consists of seven members, led by the chairman, that must be nominated by the President and confirmed by the Senate allowing them to serve 14-year terms. The Board of Governors provides general guidance to each of the 12 districts and their respective reserve banks. Each district serves basic purposes such as providing financial support and supervising commercial banks, while some provide specialized functions. For example, the St. Louis District generates an economic database called FRED while the New York district conducts domestic and foreign market operations. Finally, we have the FOMC which is the monetary policy arm of

the central bank. The FOMC's decisions range from targeted levels of interest rates and the size of its asset holdings to crafting messages to convey to the public through official communication.

During normal times, the Fed continues to pursue its dual mandate in several ways. One recent change has been the FOMCs openness of targeting a 2% rate of inflation which it believes will allow for stable prices and low unemployment. Throughout various stages in the business cycle the FOMC will determine if stabilization policy is needed to help guide the economy back to potential. During a decline in demand perhaps resulting in a recession, the FOMC could decide to ease monetary policy with the goal of boosting demand back to a sustainable level. The opposite is true as well with the FOMC choosing to tighten monetary policy if members feel the economy is experiencing an expansionary gap. As discussed elsewhere throughout this paper, the FOMC performs these actions through manipulating the federal funds rate and through periodic communication. These two policy actions can work through various channels in overall financial conditions such as asset prices and exchange rates or by affecting the expectations of households and businesses.

The Fed has within its control the ability to set the rate of interest paid to banks on reserves. It is then illogical for a bank to lend at any rate lower than what is paid on its reserves held at the Fed. By adjusting the federal funds rate in accordance with its policy goals, the FOMC can manipulate the interest rates charged to households and businesses greatly impacting economic activity. While changes in the fed funds rate mainly work through short-term debt channels, communication can allow the FOMC to alter longer-term rates. Long-term rates take into account the current rate as well as the expected rate until maturity. Thus, by communicating intentions of future monetary policy and perhaps even future rate levels, the FOMC can manipulate long-term rates. This communication objective has become more pressing in recent years as central banks aim to align market expectations of monetary policy with their

own intentions as explained in Bernanke and Reinhart (2004).

The collapse of the housing market, and ultimately the start of the Great Recession in 2007-2008, led the Federal Reserve to lower its targeted fed funds rate from roughly 5.25% all the way down to the zero lower bound (ZLB) in an attempt to stop the U.S. economy from plummeting even more. However, with the recession worsening and the Fed unable to lower the interest rate any further, the country was at risk of entering the liquidity trap.

In a liquidity trap, a central bank's attempt to stimulate the economy by expanding the monetary base fails. At an interest rate near or at zero the demand for cash becomes essentially infinitely elastic thereby causing bonds and cash to become equivalent assets. The simple logic behind interest rates not being able to fall below zero (much) is that there is always the option of simply holding cash and earning 0%, instead of placing money into a negative interest rate bearing account that guarantees you will be poorer than where you started. This leaves the central bank in a bind, wanting to lower the interest rate further to stimulate lending and spending but unable to do so.

In response to this proposed constraint and worsening economic conditions, the Federal Reserve sought out two different forms of unconventional monetary policy. The first was quantitative easing (QE) in the form of large scale asset purchases (LSAP). Beginning in 2008, the Fed announced it would be purchasing $800 billion in assets including U.S. Treasuries, mortgage-backed securities, and other forms of debt from member banks. Over the next five years, the Federal Reserve would ultimately increase its balance sheet to over $4 trillion and replace its expiring Treasuries with new purchases to maintain the balance. Due to the fact that LSAP was not used as a policy tool before the ZLB, there is not an adequate way to compare its effectiveness in the two periods.

The second form of unconventional monetary policy, which will be the focus of this

paper, is the Fed's attempt to shape market expectations through forward guidance. Most central banks use their communication with the public as a way to inform them of the expected course of monetary policy in an attempt to influence their decisions on spending and lending. By providing a road map of future interest rates, the Fed can remove surprises that could disrupt markets and create economic uncertainty. The intent behind forward guidance during the ZLB period lies with the fact that although policymakers are not able to lower interest rates further, they are still able to signal that they will keep them low for extended periods of time. One important caveat to make is that forward guidance is only effective when the market deems it credible making it and QE a good policy combination as explained previously by Yellen (2006). Yellen conveys that the Fed can increase its credibility by focusing on implementing systematic and appropriate monetary policy in combination with improving transparency. Improved credibility in the eyes of the market will allow any attempted shaping of expectations to produce a stronger effect.

It is clear that the Fed used unconventional policy in an attempt to circumvent the constraint of the ZLB. As other papers have shown, extremely low interest rate periods have a high probability of occurring in the future and possibly become the new norm as shown by Kiley and Roberts (2017). In their paper Kiley and Roberts show that inflation targets, set by central banks, are below the past average level of inflation meaning that we are likely to experience lower interest rate levels than those seen in the past. Thus, it is imperative that we understand just how much of a constraint the ZLB truly is. If we believe that unconventional monetary policy is able to substitute for targeting interest rates, then it might not be a constraint at all.

Research has been conducted on monetary policy at the ZLB in the past, notably recently by Carvalho, Hsu, and Nechio (2016), who set out to compare a pre-ZLB and ZLB period and found that it was not as much of a constraint as previously thought; however, it did affect the Feds' ability to change short-term yields. These findings

are consistent with Swanson and Williams (2014) who again measured the sensitivity of yields during the two distinct periods. They found that longer-term maturities were still being affected by monetary policy showing that unconventional policy can be effective.

My empirical analysis will focus on U.S. Treasuries ranging from 6-month Treasury bills up to 20-year Treasury bonds. Impacts of FOMC policy can typically be studied through asset prices, in particular the bond market. Changes in interest rates have historically had a measurable impact on bond values. It is important to point out that notes, bills, and bonds have different relationships with interest rates set by the Federal Reserve. To start, Treasury bills (3- to 6-month maturities) typically respond in step with the fed funds rate. This is because they are competing short-term debt instruments and usually offer similar yields. Having longer maturities, Treasury notes and bonds move less closely with the fed funds rate as the longer maturities give a higher chance of large price swings. Uncertainty in rates and yields often causes investors who are more risk averse to accept lower yields in exchange for predictability. There is also an important distinction in the quantity in which bills, notes, and bonds are issued. Although bills are printed more frequently than notes and bonds (weekly vs. monthly or quarterly), there is greater uncertainty in the quantity that will be printed, thus causing bills to be more greatly influenced by supply and demand. All of this culminates into the fact that Treasury bills are essentially free of both credit and interest risk whereas notes and bonds possess interest risk. As a risk-free short-term asset, Treasury bills will always be purchased even with lower yields while notes and bonds have a mechanism that keeps the yields from dropping too low (investors stop purchasing them). Treasury yields will show us the effect that Federal Reserve interest rate target changes have on markets. If the Fed maintains the ability to change market yields and also the yield curve while the fed funds rate remains at zero, then the constraint of the ZLB is not as severe as we thought.

The rest of the thesis is organized as follows: Chapter 2 develops the methodology used in this paper and describes the data; Chapter 3 presents the results; and Chapter 4 provides the conclusion and discussion.

CHAPTER 2: DATA AND METHODOLOGY

Federal Reserve policy of roughly the past 20 years can be broken up into three distinct periods: the pre-ZLB period from January 1, 1999, up until December 15, 2008; the ZLB period from December 16, 2008, until December 17, 2015; and the post-ZLB period from December 18, 2015, to now. The beginning date of 1999 lends itself to the fact that in order to become more transparent the FOMC began releasing official statements following each meeting. Previous studies performed on this subject have left out the post-ZLB period, but now having experienced two full years of rates above the lower bound we have a large enough sample to test. The sample of communication events that will be used includes speeches by Fed chairs and members of the FOMC, as well as official Fed statements, minutes, and press releases. The total makeup of the data set yields 4,768 communication events with the breakdown shown in Table 2.1. These communication events are spread out unevenly through the three periods due to the relatively short amount of time after the ZLB period.

My analysis will focus on daily on-the-run U.S. Treasury yields of 3-month, 6-month, 1-year, 2-year, 5-year, and 10-year maturities. On-the-run Treasuries simply refer to the fact that they are the most recently issued; once a new batch of Treasuries with matching maturity is printed the older batch is considered off-the-run. The dependent variable will measure the change in a Treasury yield of given maturity from the close of the previous day to the close of the communication date. Bond prices and interest rates have an inverse relationship; rising interest rates lower bond prices in order for the yield to match the now higher interest rate (lowering interest rates raises bond prices). I assume that markets with perfect foresight of Fed action have already priced future monetary policy into asset prices. However, markets are

Table 2.1: Communication Events

Speaker	Communications	Pre-ZLB	ZLB	Post-ZLB
Official Press FRC	575	217	337	21
Ben S. Bernanke	287	136	151	0
James Bullard	235	15	186	34
Alan Greenspan	214	214	0	0
Eric Rosengren	182	17	140	25
Sandra Pianalto	176	77	99	0
Dennis P. Lockhart	174	25	139	10
Janet Yellen	171	59	77	35
FOMC Statement	165	85	63	17
Richard Fisher	156	66	90	0
Minutes FRC	152	80	56	16
William Dudley	150	0	109	41
Jeffrey Lacker	148	42	95	11
Discount Rate FRC	127	60	52	15
Charles Evans	125	17	84	24
Roger W. Ferguson, Jr.	118	118	0	0
Narayana Kocherlakota	113	0	113	0
Charles Plosser	105	21	84	0
John Williams	91	1	64	26
Donald Kohn	88	67	21	0
Susan S. Bies	82	82	0	0
Daniel Tarullo	77	0	72	5
Loretta Mester	70	13	31	26
Robert Parry	65	65	0	0
Edward M. Gramlich	58	58	0	0
Laurence H. Meyer	56	56	0	0
Jerome H. Powell	56	0	29	27
Mark W. Olson	54	54	0	0
Anthony Santomero	51	51	0	0
Randall S. Kroszner	50	50	0	0
Elizabeth A. Duke	49	1	48	0
Stanley Fischer	45	0	19	26
Timothy Geithner	44	44	0	0
Jack Guynn	42	42	0	0
Michael Moskow	40	40	0	0
Monetary Policy Report FRC	38	20	14	4
Gary Stern	36	28	8	0
Jeremy C. Stein	34	12	22	0
Lael Brainard	34	0	11	23
Frederic S. Mishkin	30	30	0	0
Patrick Harker	30	0	4	26
William J. McDonough	28	28	0	0
Esther George	24	0	11	13
J. Alfred Broaddus Jr.	23	23	0	0
Sarah Bloom Raskin	21	0	21	0
Neel Kashkari	20	0	0	20
Kevin M. Warsh	19	12	7	0
Robert Kaplan	13	0	1	12
Alice M. Rivlin	6	6	0	0
Edward W. Kelley, Jr.	6	6	0	0
Edward Boehne	6	6	0	0
Raphael Bostic	4	0	0	4
Manuel H. Johnson	3	1	2	0
Cathy Minehan	1	1	0	0
Susan M. Phillips	1	1	0	0

not perfect, and the Fed has the ability to "surprise" the market participants. I will measure these surprises in two distinct ways, first with interest rate surprises and then with communication surprises.

Following Kuttner (2001), I construct interest rate surprises by using daily fed funds futures contracts. A fed funds futures contract is a financial instrument originally traded on the Chicago Mercantile Exchange (CME) that shows us the market's opinion on the fed funds rate on the expiration date of the contract, giving us a proxy of monetary policy expectations. The spot futures rate is defined as 100 minus the fed funds futures price, so a contract priced at 95 would imply a spot futures rate of 5%. Naturally, when the Federal Reserve raises its target fed funds rate, market rates rise as well, in turn causing a fall in bond prices. If bond markets are forward looking, changes in fed funds futures contract prices would already be priced in ahead of the communication event along the lines of the efficient market hypothesis. If, however, there is a swing in the contract prices surrounding the date of a communication event, it would imply there was new information made available to the market. Thus, in order to extract a "surprise" measure, I follow the method laid out by Kuttner (2001) by calculating the unexpected change in the Fed's target rate following a communication event. A spot futures rate can be thought of as the average of actual rates previous to the communication date and the expected rate for the rest of the month. If the market expects the Fed to hold steady and leave the fed funds rate unchanged, then the implied rate from the futures contract the day prior to and the day of the communication date would be relatively unchanged. However, if the market does not possess perfect foresight, then we can measure the "surprise" as the difference in effective fed funds rates implied by the spot futures before and after the communication date.

It is important to note that the price is based on the average of the month's fed funds rates so that the implied spot rate depends on which day of the month it is

calculated. In order to unwind the time-averaging, I use the adjustment proposed by Kuttner (2001) and scale the spot rate by the inverse of the number of days left in the month. Just like with the Treasury yield, I will look at the change in the implied spot rate from the close of the previous day to the close of the communication date and apply the time-adjustment as shown below:

$$\Delta r_t = \frac{m_s}{m_s - t} \left(f_{s,t} - f_{s,t-1} \right),$$

where t is the date of the communication event, m_s is the number of days in the month, s, of the communication event, and $f_{s,t}$ is the implied spot futures rate on day t of month s.

While the federal funds rate is not resting at the ZLB, targeting interest rates is a readily available tool for policy. During the ZLB period, the federal funds rate was at or near zero and could not be lowered any further. Enter unconventional monetary policy and the use of communication as a tool.

For measuring FOMC communication as it pertains to monetary policy implications, I turn to Prattle Analytics LLC, which creates a news article score index. Prattle makes use of sentiment analysis focused on treating central bank communications as financial data rather than the classical applications of interpreting text. By combining automated interpretation technology with domain expertise, Prattle produces its Central Bank Analytics aimed at quantitatively scoring central bank communications based on linking specific words, phrases, and sentences to corresponding market reactions. Each communication event, ranging from official FOMC statements to speeches by members of the Board of Governors, is scored in terms of hawkishness or dovishness towards the economy. For each communication event, the Prattle raw score is the level of hawkishness or dovishness compared to the average of the past communication events. From Prattle's product data sheet, the raw scores

are normalized around zero and range mostly between -2 and +2, negative numbers indicating dovishness and positive numbers indicating hawkishness. Thus, if a communication is given a raw score of -1, this indicates that the message is more dovish than the past average. Furthermore, Prattle provides a speaker residual score that takes the difference of the communication raw score and that of an average of the past 12 months for the given communication type. Therefore this speaker residual score can give us insight into the change in tone in the given communication from that which was expected.

Since we only want to take into consideration those communication events that were deemed a "surprise", I now make a clear distinction. We can view communication events with speaker residuals surrounding zero as neutral, or rather expected, in that they did not deviate from the Fed's past tone. In order to make a cutoff on both sides of zero for communication events that can be considered surprises, I look at the distribution of speaker residuals.

Table 2.2: Summary Statistics - Full Sample

Variable	Obs	Mean	Std. Dev.	Min	Max
Raw Score	4768	-.078	1.058	-5.125	3.83
Speaker Residual	4768	-.009	.594	-3.609	2.635
Interest Rate Surprises	4768	-.233	4.703	-102.018	37.5
Unemployment Rate	4768	6.361	1.825	3.8	10
Inflation Rate	4768	1.943	.443	.611	2.931
Δ 3-month yield	4768	-.117	5.292	-52	76
Δ 6-month yield	4768	-.12	4.637	-48	75
Δ 1-Year yield	4768	-.095	4.515	-50	52
Δ 2-Year yield	4768	-.052	5.769	-54	38
Δ 5-Year yield	4768	-.07	6.664	-46	34
Δ 10-Year yield	4768	-.012	6.235	-51	25

The data provided by Prattle includes 4,768 different communication events that have a mean speaker residual of -0.0092064. In this analysis we only care about the surprise communications, so I create a threshold of one standard deviation to either side of the mean in order for a communication to qualify as a surprise. When

summarizing the data, this equates to any score below -0.6031968 being a dovish surprise and any score above 0.584784 being a hawkish surprise. A speaker residual that is in between these two values is considered to be neutral and surrounding zero and thus is not a surprise. Using this method to sort the communications into three baskets gives us 674 Hawkish communications, 654 Dovish communications, and 3,440 Neutral communications over the full sample.

The descriptive statistics for each variable in the sample are shown in Table 2.2. For ease of interpretation, yield changes and interest rate surprises are measured in basis points.

The purpose of this paper is to estimate the effectiveness of Fed communication as a form of monetary policy and to determine if the communication's impact changes surrounding the ZLB. First I will estimate the average effects of Fed communication on Treasury yields throughout the entire sample, following that I will re-estimate the regression for each distinct period. My baseline regression model is as follows:

$$\Delta y_c^m = \alpha^m + \beta_1^m Dovish_c + \beta_2^m Hawkish_c + \gamma^m IS_c + \epsilon_c^m,$$

where communication surprises, measured by the speaker residual scores, are transformed into dummy variables. For the model, β_1 captures the effect of Fed communication that is deemed a dovish surprise, and β_2 captures the effect of Fed communication that is deemed a hawkish surprise. These two dummy variables are compared against a neutral Fed communication event which is captured by the constant term α. The effect of interest rate surprises as obtained through fed funds futures contracts is found in γ. I run the regression model for each Treasury yield maturity, where m indicates the given maturity and c indicates the given communication event.

In order to control for market and economic conditions I perform a robustness check by including the unemployment rate and inflation rate during the month that the

communication event occurred. It is important to infer how the initial coefficient estimates behave while adding new explanatory variables. The robustness check model is shown below:

$$\Delta y_c^m = \alpha^m + \beta_1^m Dovish_c + \beta_2^m Hawkish_c + \gamma^m IS_c + \eta^m UR + \mu^m IR + \epsilon_c^m.$$

Including the unemployment rate (UR) and the inflation rate (IR), measured as the Consumer Price Index - All Urban Consumers, help control for policymakers' responses to changing economic conditions.

CHAPTER 3: RESULTS

I begin the empirical analysis with the baseline model for the full sample ranging from 1999-2017 with the results presented in Table 3.1. The table shows the effects of both communication and interest rate surprises on six different Treasury yields ranging from 3-month to 10-year maturities.

Table 3.1: Full Sample - Baseline Regression

Variables	Δ3-month Yield	Δ6-month Yield	Δ1-year Yield	Δ2-year Yield	Δ5-year Yield	Δ10-year Yield
Dovish	-0.212	-0.359	-0.259	-0.118	-0.129	0.00240
	(0.281)	(0.243)	(0.218)	(0.275)	(0.311)	(0.287)
Hawkish	0.132	0.154	0.206	0.293	0.133	0.136
	(0.178)	(0.170)	(0.173)	(0.231)	(0.267)	(0.258)
IS	0.310***	0.218***	0.245***	0.260***	0.202***	0.148***
	(0.0636)	(0.0507)	(0.0432)	(0.0406)	(0.0399)	(0.0329)
Constant	-0.0344	-0.0422	-0.0315	-0.0165	-0.0240	0.00297
	(0.0822)	(0.0732)	(0.0715)	(0.0927)	(0.110)	(0.103)
Observations	4,768	4,768	4,768	4,768	4,768	4,768
R-squared	0.077	0.050	0.066	0.045	0.020	0.012

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The coefficients for interest rate surprises, γ, are statistically significant, which fits with prior logic that market expectations of the fed funds rate affect asset prices and in particular U.S. Treasuries. Looking at the magnitude of the coefficient for all maturities shows that surprise changes in the fed funds rate impact Treasuries with short and medium-term maturities more than those with longer maturities. The fed funds rate is an overnight rate, so its effects would be stronger at shorter maturities than longer maturities. The FOMC also usually votes to adjust the target rate at

least eight times a year, so Treasuries with shorter maturities will face a greater impact. This is consistent with other evidence in the literature. Kuttner (2001) showed that the one day response of interest rates to Fed funds surprises is stronger for maturities between 3-months and 2-years than it is for longer-term Treasuries. These results are also shown by Cook and Hahn (1989) who regress changes in Treasury yields on changes in the Fed target rate and find that the impact of rate changes on market interest rates diminishes as the maturity increases. Determining the economic significance of the interest rate surprises requires more attention. The coefficient of 0.310 associated with 3-month Treasuries implies that, roughly, a three basis point interest rate surprise shown in fed funds futures contracts causes a one basis point increase in the 3-month Treasury yield. Assuming that markets have already priced expected Fed action into asset prices, or at least a majority of it, then a small surprise would have a negligible effect on Treasury yields. However, if the Fed decided to take action that was unforeseen or the opposite of what was expected (raising the target rate when no change was predicted) then these interest rate surprises could have an economically meaningful effect. For instance, an increase of the target rate by 50 basis points when markets expected no change or perhaps only a 25 basis point increase and priced assets accordingly, would increase the 3-month Treasury yield by 15.5 or 7.75 basis points respectively.

Turning to communication surprises, the coefficients for all Treasuries with given maturities are neither statistically nor economically significant over the full sample. The signs, with dovish surprises having a negative coefficient except the 10-year Treasury and hawkish surprises having a positive coefficient, do fit with logic. A communication that is deemed a hawkish surprise and increases the chance of the target rate rising should be expected to raise yields as interest rates and yields have a positive relationship. The opposite is true with dovish surprises and lowering rates. The constant term can be thought of as a neutral communication which should not

have an impact on Treasury yields as no new information is expressed. Looking at the coefficient for the constant term on all maturities I find that it is close enough to zero to be thought of as irrelevant and it is always statistically insignificant. For example, on the 2-year Treasury, the constant coefficient of -0.0165 implies that a communication event that is deemed neutral is expected to reduce Treasury yields by 0.0165 basis points which is essentially noise.

Following the baseline model using the full sample, I analyze each period separately with results shown in Table 3.2. For the pre-ZLB period ranging from 1999 up until December 2008, the results show that interest rate surprises still have a statistically significant impact on Treasury yields of all maturities, although the magnitudes are smaller compared to the full sample model.

Looking at the effect that Fed communication has on Treasury yields through our measure of speaker residual, I find that the results are again mostly neither statistically nor economically significant. The coefficient for dovish communication surprises on the 6-month Treasury is significant at the 10% level. One aspect to note is that dovish surprises have a stronger impact on Treasury yields than hawkish surprises for shorter-term maturities. Perhaps during the pre-ZLB period market participants saw the Fed as being more predictable when it came to raising rates than when it was lowering them. There could be more uncertainty surrounding easing of Fed policy during an economic crisis, two of which occurred during the pre-ZLB period. The Fed eased aggressively in response to the bursting of the Dot-com bubble during 2000-2001, and there was an extended period when the fed funds rate target was at 1.00%. These results do not match with the results shown by Carvalho, Hsu, and Nechio (2016) who use news sentiment rather than Fed communication sentiment. Their measure of communication surprises are statistically significant for the majority of maturities and the impact grows as the maturity increases.

For the ZLB period, the Fed's target rate, the fed funds rate, was at a historic low

Table 3.2: Subperiods of Full Sample - Baseline Regression

Variables	Δ3-month Yield	Δ6-month Yield	Δ1-year Yield	Δ2-year Yield	Δ5-year Yield	Δ10-year Yield
Pre-ZLB Period (2,047 Observations)						
Dovish	-0.551	-0.924*	-0.495	-0.260	-0.0872	0.0808
	(0.608)	(0.516)	(0.467)	(0.551)	(0.545)	(0.467)
Hawkish	0.117	0.203	0.318	0.496	0.206	0.00518
	(0.432)	(0.412)	(0.418)	(0.515)	(0.532)	(0.481)
IS	0.262***	0.175***	0.192***	0.186***	0.147***	0.108***
	(0.0877)	(0.0653)	(0.0670)	(0.0678)	(0.0487)	(0.0343)
Constant	-0.119	-0.0775	-0.108	-0.106	-0.155	-0.0783
	(0.187)	(0.165)	(0.160)	(0.191)	(0.196)	(0.172)
R-squared	0.070	0.044	0.055	0.036	0.022	0.015
ZLB Period (2,260 Observations)						
Dovish	0.0434	0.160	-0.0288	-0.0812	-0.233	-0.0462
	(0.0891)	(0.105)	(0.0934)	(0.236)	(0.391)	(0.404)
Hawkish	0.0689	0.0512	0.125	0.0527	-0.0166	0.220
	(0.0724)	(0.0785)	(0.0917)	(0.204)	(0.308)	(0.327)
IS	-0.00975	0.131***	0.178***	0.471***	0.639***	0.611***
	(0.0370)	(0.0497)	(0.0379)	(0.0626)	(0.101)	(0.104)
Constant	-0.00743	-0.0259	-0.00393	0.0743	0.119	0.0868
	(0.0302)	(0.0313)	(0.0387)	(0.0854)	(0.144)	(0.147)
R-squared	0.001	0.016	0.021	0.028	0.020	0.017
Post-ZLB Period (461 Observations)						
Dovish	0.0222	-0.324	-0.542**	-0.0186	-0.186	-0.495
	(0.247)	(0.259)	(0.268)	(0.397)	(0.560)	(0.555)
Hawkish	0.316	0.355	-0.0429	0.445	0.373	0.0190
	(0.326)	(0.255)	(0.212)	(0.378)	(0.483)	(0.510)
IS	0.145*	0.0699	-0.00623	0.0334	-0.162	-0.140
	(0.0810)	(0.0612)	(0.0533)	(0.0789)	(0.100)	(0.101)
Constant	0.0758	0.0228	0.183	0.0981	0.188	0.277
	(0.121)	(0.110)	(0.113)	(0.184)	(0.228)	(0.219)
R-squared	0.014	0.011	0.007	0.002	0.005	0.004

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

ranging between 0 and 0.25 and was left unchanged. Looking at the coefficients for interest rate surprises I see that those for all but the 3-month Treasury are statistically significant. I consider these results to be economically insignificant due to the fact that the fed funds rate was unable to be lowered and was not at risk to be raised save for a small portion towards the end of the period when the market was unsure when the Fed was going to lift from the ZLB. In past literature, Carvalho, Hsu, and Nechio (2016) produce like results and form the same conclusion. Since market expectations of the fed funds rate during this period did not change, variance in the one-month fed funds futures prices must have had an alternative cause. Looking again to communication surprises, I find that surprise Fed communications did not have an impact on Treasury yields and were statistically insignificant. It is interesting to note that while all coefficients for the hawkish variable remain positive, the coefficients for dovish communications on 3-month and 6-month Treasuries are positive. I view these as economically insignificant as shorter term maturities would not be the target of dovish communication during this period. Dovish communication surprises during the ZLB period would have the intent of informing market participants that low rates will continue to persist and thus are aimed at longer-term maturities. Again these results for the communication surprise measure go against those found by Carvalho, Hsu, and Nechio (2016) and also go against Swanson and Williams (2014). Swanson and Williams, using rolling windows during the ZLB period, find that longer-term yields still respond to macroeconomic news.

One addition that this paper makes to previous literature is the analysis of the post-ZLB period ranging from December 16, 2015, through the end of year 2017. With economic activity returning to "normal" and inflation hawks growing louder, the Fed was able to begin using its main policy tool of targeting interest rates once again. This, however, is not consistent with the results of the regression and the coefficients for interest rate surprises. None of the coefficients is statistically significant at the 5%

level (only the 3-month Treasury is statistically significant at the 10% level). Looking at the communication surprises I see that again dovish and hawkish surprises in communication have no impact and are almost all statistically insignificant. The coefficient for dovish communication surprises on 1-year Treasuries is statistically significant but corresponds to only a half basis point decrease in yields which I view as economically insignificant. Predictions of Fed action have become increasingly popular, with several leading news outlets and corporations issuing their own crystal ball leading up to FOMC meetings. This, along with a concerted effort by the Fed itself to be more transparent, could mean that the Fed has little left to surprise markets with and has adopted the goal of aligning market expectations with FOMC intentions on a timely basis.

Following the estimation of the baseline regression model I include two additional regressors, the monthly unemployment rate and the monthly inflation rate, to control for economic conditions at the time of each communication event. Again using the full sample of 4,768 communication events I run the robustness check regression for the full sample period and then for each of the three specific periods. The results shown in Table 3.3 show that when controlling for the unemployment and inflation rates the impact of interest rate surprises on Treasury yields is quantitatively unchanged. Next, looking at both dovish and hawkish communication surprises I find that the results are qualitatively similar with the baseline regression. Unlike the baseline model, the coefficients on the constant term representing a neutral communication are now no longer at zero. Except for the 3-month Treasury which has a value of roughly zero, the impacts of a neutral communication all imply increases in yields however the results are statistically insignificant. Examining the additional regressors, the results associated with the inflation rate's impact on Treasury yields is perplexing. The inflation rate has the same relationship with bond yields as interest rates have: when the inflation rate rises bond yields also rise. Looking at the coefficients for all

Table 3.3: Full Sample - Robustness Check

Variables	Δ3-month Yield	Δ6-month Yield	Δ1-year Yield	Δ2-year Yield	Δ5-year Yield	Δ10-year Yield
Dovish	-0.213	-0.357	-0.257	-0.113	-0.123	0.00656
	(0.280)	(0.242)	(0.217)	(0.274)	(0.310)	(0.287)
Hawkish	0.116	0.137	0.193	0.282	0.121	0.126
	(0.177)	(0.169)	(0.173)	(0.231)	(0.267)	(0.258)
IS	0.310***	0.217***	0.244***	0.259***	0.200***	0.147***
	(0.0638)	(0.0509)	(0.0432)	(0.0405)	(0.0398)	(0.0329)
UR	0.0465	0.0188	0.000631	-0.0255	-0.0385	-0.0247
	(0.0349)	(0.0300)	(0.0303)	(0.0449)	(0.0596)	(0.0609)
IR	-0.137	-0.280	-0.279	-0.317	-0.414	-0.310
	(0.208)	(0.190)	(0.182)	(0.239)	(0.272)	(0.253)
Constant	-0.0624	0.385	0.509	0.763	1.027	0.762
	(0.549)	(0.491)	(0.475)	(0.658)	(0.797)	(0.773)
Observations	4,768	4,768	4,768	4,768	4,768	4,768
R-squared	0.077	0.051	0.067	0.046	0.021	0.013

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

maturities shows the opposite of this, an increase in the inflation rate is associated with a decrease in bond yields, but again the results are statistically insignificant.

Moving on the the pre-ZLB sub-period, I find that controlling for economic conditions leaves the effects of interest rate surprises quantitatively unchanged and still statistically significant. The effects of communication surprises are also left roughly unchanged from the baseline model and still statistically insignificant except for 6-month Treasuries. Matching the results from the robustness check on the full sample period, the coefficients for the inflation rate are again negative and are now significant for the 1-year, 2-year, and 5-year maturities. The results shown in the ZLB period are also left roughly unchanged from the baseline model with interest rate surprises still having a statistically significant yet economically insignificant impact on Treasury yields. One difference from the pre-ZLB to ZLB periods is that the inflation rate coefficients for short and medium-term Treasuries is positive which is the expected

Table 3.4: Subperiods of Full Sample - Robustness Check

Variables	Δ3-month Yield	Δ6-month Yield	Δ1-year Yield	Δ2-year Yield	Δ5-year Yield	Δ10-year Yield
Pre-ZLB Period (2,047 Observations)						
Dovish	-0.618	-0.975*	-0.507	-0.234	-0.0259	0.145
	(0.598)	(0.509)	(0.462)	(0.547)	(0.541)	(0.463)
Hawkish	0.122	0.201	0.308	0.479	0.184	-0.00981
	(0.434)	(0.412)	(0.419)	(0.516)	(0.533)	(0.480)
IS	0.265***	0.177***	0.191***	0.182***	0.141***	0.103***
	(0.0894)	(0.0662)	(0.0673)	(0.0676)	(0.0479)	(0.0338)
UR	0.612*	0.486	0.143	-0.183	-0.503	-0.552*
	(0.369)	(0.343)	(0.288)	(0.302)	(0.327)	(0.300)
IR	-0.0104	-0.385	-0.767*	-1.032*	-1.110**	-0.685
	(0.544)	(0.481)	(0.451)	(0.550)	(0.544)	(0.456)
Constant	-3.203	-1.697	0.862	3.103	4.850*	4.238*
	(2.913)	(2.612)	(2.233)	(2.435)	(2.500)	(2.188)
R-squared	0.074	0.048	0.057	0.038	0.024	0.018
ZLB Period (2,260 Observations)						
Dovish	0.0451	0.161	-0.0269	-0.0804	-0.237	-0.0540
	(0.0890)	(0.105)	(0.0933)	(0.236)	(0.391)	(0.404)
Hawkish	0.0736	0.0549	0.130	0.0550	-0.0278	0.198
	(0.0726)	(0.0786)	(0.0919)	(0.205)	(0.308)	(0.326)
IS	-0.0120	0.130***	0.176***	0.470***	0.644***	0.621***
	(0.0373)	(0.0502)	(0.0382)	(0.0628)	(0.100)	(0.103)
UR	-0.0267	-0.0151	0.0183	0.0374	0.0498	0.0735
	(0.0199)	(0.0223)	(0.0274)	(0.0567)	(0.0862)	(0.0888)
IR	0.0758	0.0689	0.173**	0.131	-0.208	-0.442
	(0.0617)	(0.0635)	(0.0820)	(0.191)	(0.328)	(0.353)
Constant	0.0735	-0.0240	-0.440	-0.441	0.0806	0.259
	(0.220)	(0.236)	(0.296)	(0.637)	(1.024)	(1.076)
R-squared	0.003	0.017	0.023	0.028	0.020	0.019
Post-ZLB Period (461 Observations)						
Dovish	0.0738	-0.193	-0.476*	0.0444	-0.202	-0.554
	(0.253)	(0.252)	(0.264)	(0.399)	(0.562)	(0.556)
Hawkish	0.312	0.346	-0.0629	0.442	0.350	0.000340
	(0.328)	(0.261)	(0.221)	(0.385)	(0.484)	(0.510)
IS	0.141*	0.0588	-0.0107	0.0279	-0.159	-0.134
	(0.0786)	(0.0573)	(0.0550)	(0.0790)	(0.101)	(0.102)
UR	-1.171	-2.958***	-1.771***	-1.395	-0.0464	0.927
	(0.767)	(0.662)	(0.647)	(1.112)	(1.323)	(1.248)
IR	1.154	2.893***	2.077**	1.329	0.579	-0.388
	(0.957)	(0.797)	(0.907)	(1.499)	(1.860)	(1.790)
Constant	3.134*	7.789***	4.133***	3.830	-0.771	-3.210
	(1.895)	(1.736)	(1.544)	(2.624)	(3.074)	(2.967)
R-squared	0.020	0.061	0.022	0.007	0.006	0.007

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

relationship but only the 1-year maturity is statistically significant at the 5% level.

Finally the post-ZLB robustness check model is qualitatively unchanged from the baseline regression, with the exception of neutral communications. Looking specifically at 3-month to 1-year Treasuries, a neutral communication is associated with a statistically significant and economically meaningful positive impact on yields. In the post-ZLB period there was only one direction for interest rates to go, up. If market participants and past Fed communications expressed raising interest rates was the predicted action, then raising interest rates would not be a surprise and yields would go up hand in hand. If the FOMC was already expected to increase the rate, then an increasingly hawkish tone would still produce the same target rate increase with the only policy action appearing more hawkish being increasing rates by more than expected. The only remaining chance for there to be dovish policy action would be to leave the rates unchanged. Thus, a period of two years in which interest rates could only go up leaves us in a situation where determining the true impact of Fed communication is difficult.

In theory, interest rate policy and Fed communication go hand in hand as a means to influence markets. In general, forward guidance sets a road map for future interest rate policy. During the ZLB period, the FOMC maintained that interest rates would stay low for a longer period of time than market participants previously thought. In order to test the hypothesis that the relationship between interest rate surprises and Treasury yields was different for Dovish and Hawkish communications I include interaction terms.

After running auxiliary regressions for the full sample and 3 sub-periods, the effects of the interaction term are particularly significant in the Post-ZLB period as shown in Table 3.5. The coefficients for the interaction between Dovish communication surprises and interest rate surprises is statistically significant for all but the 3-month Treasury. On the other end of the communication spectrum, the interaction term

Table 3.5: Post-ZLB - Auxilliary Regression

Variables	Δ3-month Yield	Δ6-month Yield	Δ1-year Yield	Δ2-year Yield	Δ5-year Yield	Δ10-year Yield
Dovish	0.0223	-0.353	-0.573**	-0.0614	-0.243	-0.539
	(0.247)	(0.242)	(0.240)	(0.356)	(0.511)	(0.524)
Hawkish	0.286	0.346	-0.00193	0.520	0.451	0.0675
	(0.344)	(0.268)	(0.214)	(0.379)	(0.486)	(0.521)
IS	0.127	0.0530	0.00626	0.0621	-0.138	-0.129
	(0.0850)	(0.0669)	(0.0572)	(0.0768)	(0.102)	(0.110)
Dovish*IS	-0.253	1.816***	2.347**	3.407**	4.335**	3.278**
	(0.297)	(0.275)	(0.954)	(1.417)	(1.745)	(1.613)
Hawkish*IS	0.116	0.0358	-0.156**	-0.288***	-0.298**	-0.183
	(0.258)	(0.144)	(0.0642)	(0.105)	(0.141)	(0.181)
Constant	0.0794	0.0262	0.180	0.0924	0.183	0.275
	(0.122)	(0.110)	(0.114)	(0.184)	(0.229)	(0.220)
Observations	461	461	461	461	461	461
R-squared	0.015	0.023	0.030	0.022	0.024	0.015

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

between Hawkish communication surprises and interest rate surprises is statistically significant for 1-year, 2-year, and 5-year Treasuries. Dovish communications would imply easing Fed policy by leaving rates steady in the post-ZLB period contradicting a positive interest rate surprise. So changes in market participants expectations of the Fed funds rate on a day when a Dovish communication took place impact Treasury yields for maturities between 6-months and 10-years by roughly 1 to 4 basis points. For example, during the post-ZLB period the results tell us that a 1 point interest rate surprise on a day that a Dovish communication surprise occurred is associated with a almost 2 basis point increase in a 1-year Treasury yield.

The coefficients associated with the interaction term between Hawkish communication surprises and interest rate surprises, specifically for 1-year, 2-year, and 5-year Treasuries, imply that interest rate surprises that occur on days with a Hawkish communication surprise do not impact Treasury yields by an economically significant amount. Hawkish communications are associated with raising interest rates and thus

would coincide with raising the fed funds rate which shows up in the interest rate surprises.

The auxiliary regression for the post-ZLB period shows that by including interaction terms, interest rate surprises can still impact Treasury yields when they occur on days that a Dovish communication surprise occurred.

CHAPTER 4: CONCLUSION

The ZLB is an interesting complication on monetary policy set by the Federal Reserve. The inability of interest rates to fall below zero left policymakers in an uncomfortable and unfamiliar situation following the financial crisis. With recent literature suggesting that we might be looking forward to a continued low interest rate environment, it is imperative that the Fed become increasingly familiar with the ZLB and its possible constraints. Forward guidance has been thought of to be an aid to interest rate policy giving warning of possible changes to smooth market expectations and reduce uncertainty. In the absence of interest rate policy, the ability of communication to affect markets is crucial to the Fed's pursuit of low unemployment and stable prices.

Interest rate policy, as measured in surprise changes implied from fed funds futures, showed that in the pre-ZLB period interest rate policy had a meaningful impact on Treasury yields. While not at the ZLB, the FOMC is able to manipulate its targeted rate to ease or tighten as they see fit. These results were not shown in the baseline regression for the post-ZLB period. When including interaction terms between communication surprises and interest rate surprises I found that interest rate policy still has meaningful impacts on Treasury yields when paired with Dovish communication surprises. Since rising from the ZLB, the Fed has been very methodical and predictable in its policy action leaving very little to guesswork. Forward looking markets anticipate future Fed action and price the action in accordingly, which would render the surprise measure meaningless unless it contradicted with Fed communication.

The results appear to suggest that Fed communication, as measured in surprise changes in tone of the communication, are not a suitable replacement for interest rate

policy. None of the three periods shows a meaningful impact of dovish or hawkish surprises on Treasury yields. If Fed communication truly has no impact on markets, then the ZLB indeed places a constraint on the Federal Reserve and its ability to perform stabilization policy.

There has been a great amount of research performed on monetary policy at extremely low interest rates, and future projections of continued low interest rate economies necessitate the continued investigation. Communication was not the only unconventional policy exercised surrounding the Fed's time at the ZLB. Quantitative easing offers central banks another option to fighting this constraint. Perhaps further research into the combination of communication alongside QE during low interest rate periods will provide a better picture of the Fed's ability to maneuver during unfamiliar times.

As used in past literature, news sentiment could offer a better surprise measure through changes in tone in news articles rather than Fed communication. It is uncertain to what extent official Fed communication actually conveys what FOMC members are thinking so we are unable to determine whether the communication matches their thoughts. In the end, it is the expectations and actions of market participants that move markets and not the Fed itself (QE aside) and news sentiment would offer an insight into market expectations.

REFERENCES

[1] R. G. Anderson, C. S. Gascon, and Y. Liu, "Doubling your monetary base and surviving: Some international experience," *Review. Federal Reserve Bank of St. Louis*, vol. 92, pp. 481–505, November 2010.

[2] B. S. Bernanke and V. R. Reinhart, "Conducting monetary policy at very low short-term interest rates," *American Economic Review*, vol. 94(2), pp. 85–90, May 2004.

[3] C. Carvalho, E. Hsu, and F. Nechio, "Measuring the effect of the zero lower bound on monetary policy," December 2016.

[4] T. Cook and T. Hahn, "The effect of changes in the federal funds rate target on market interest rates in the 1970s," *Journal of Monetary Economics*, vol. 24(3), pp. 331–351, 1989.

[5] M. T. Kiley and J. M. Roberts, "Monetary policy in a low interest rate world," *Brookings Papers on Economic Activity*, vol. 2017, pp. 317–396, March 2017.

[6] K. Kuttner, "Monetary policy surprises and interest rates: Evidence from the fed funds futures market," *Journal of Monetary Economics*, vol. 47(3), pp. 523–544, June 2001.

[7] D. Lucca and F. Trebbi, "Measuring central bank communication: An automated approach with application to fomc statements," March 2011.

[8] E. T. Swanson and J. C. Williams, "Measuring the effect of the zero lower bound on medium- and longer-term interest rates," *American Economic Review*, vol. 104(10), pp. 3154–3185, October 2014.

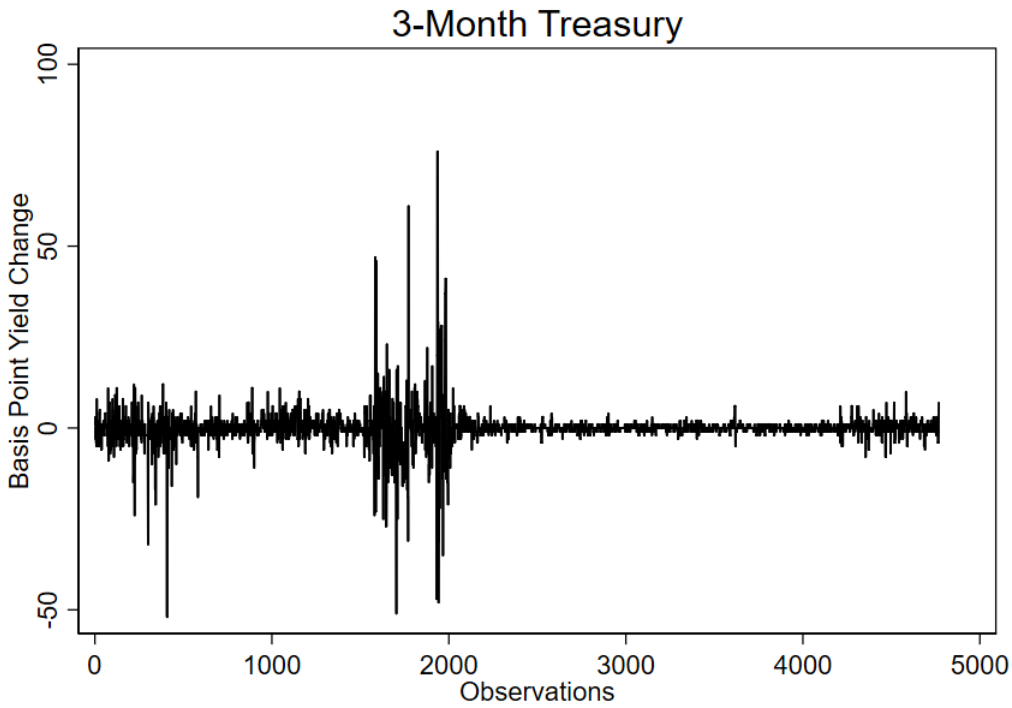
[9] J. L. Yellen, "Enhancing Fed credibility," *Business Economics*, vol. 41(2), pp. 7–13, April 2006.

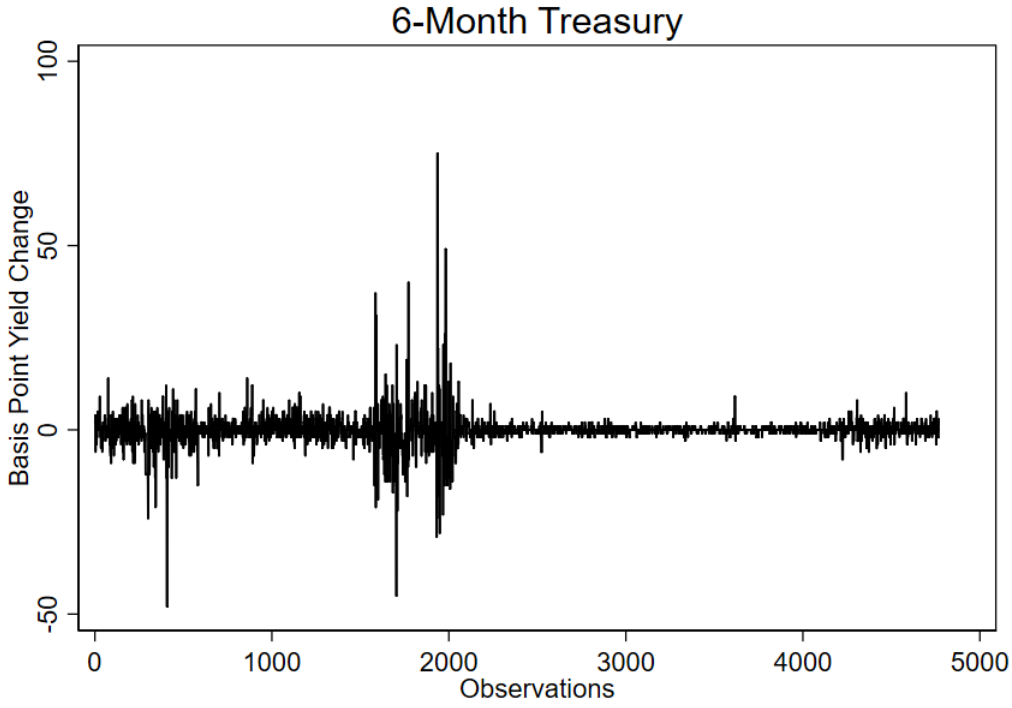
APPENDIX A: Additional Summary Statistics

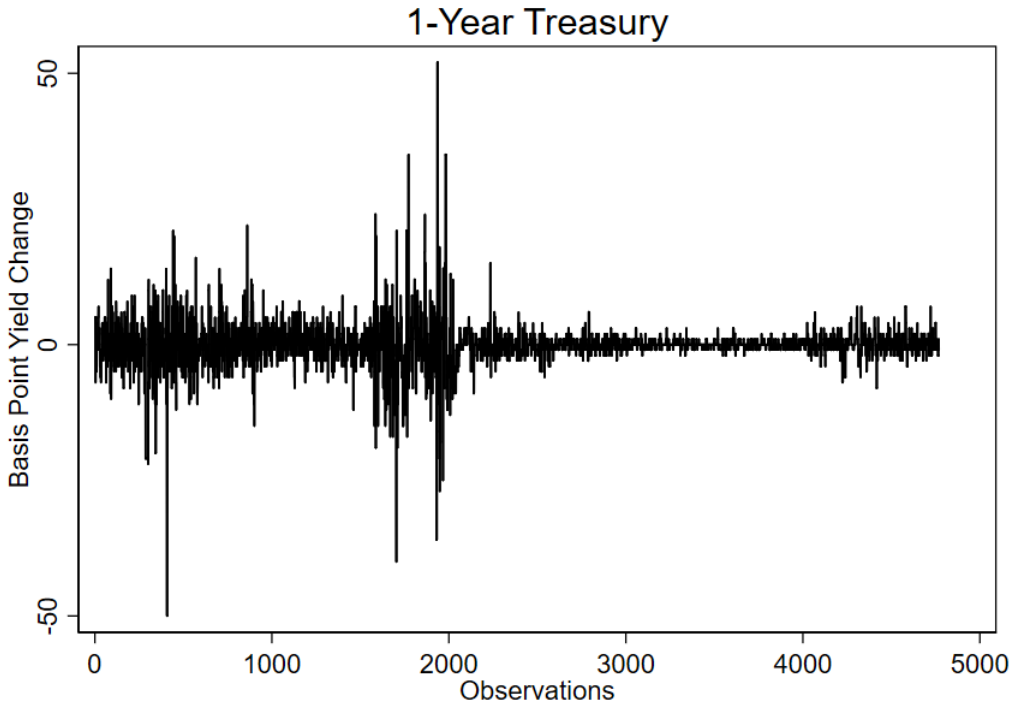
Table A.1: Summary Statistics - Subperiods

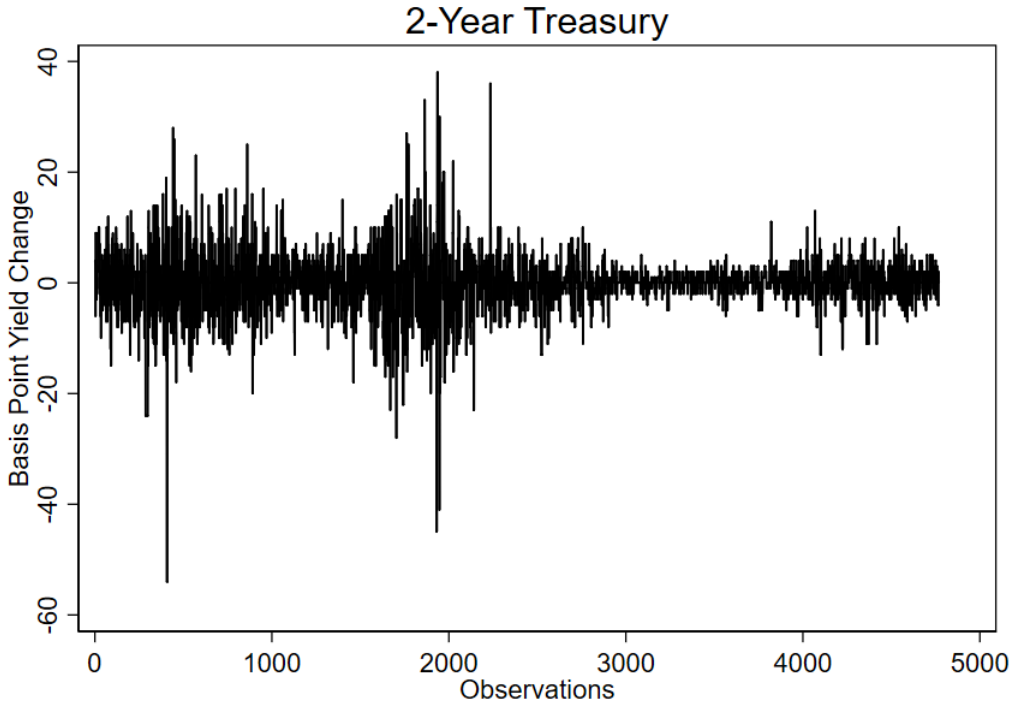
Pre-ZLB					
Variable	Obs	Mean	Std. Dev.	Min	Max
Raw Score	2047	-.152	1.059	-3.636	3.659
Speaker Residual	2047	-.042	.584	-3.609	2.318
Interest Rate Surprises	2047	-.455	7.009	-102.018	37.5
Unemployment Rate	2047	5.098	.732	3.8	7.3
Inflation Rate	2047	2.208	.371	1.095	2.931
Δ 3-month yield	2047	-.317	7.897	-52	76
Δ 6-month yield	2047	-.277	6.864	-48	75
Δ 1-year yield	2047	-.237	6.621	-50	52
Δ 2-year yield	2047	-.174	7.83	-54	38
Δ 5-year yield	2047	-.215	7.93	-38	34
Δ 10-year yield	2047	-.12	6.922	-28	25
ZLB					
Variable	Obs	Mean	Std. Dev.	Min	Max
Raw Score	2260	-.05	1.068	-5.125	3.83
Speaker Residual	2260	.019	.615	-2.259	2.635
Interest Rate Surprises	2260	-.119	1.261	-15.5	10.369
Unemployment Rate	2260	7.86	1.487	5	10
Inflation Rate	2260	1.684	.381	.611	2.314
Δ 3-month yield	2260	.01	1.261	-6	6
Δ 6-month yield	2260	-.012	1.374	-8	13
Δ 1-year yield	2260	-.009	1.572	-9	15
Δ 2-year yield	2260	.016	3.546	-23	36
Δ 5-year yield	2260	.01	5.775	-46	29
Δ 10-year yield	2260	.042	5.95	-51	24
Post-ZLB					
Variable	Obs	Mean	Std. Dev.	Min	Max
Raw Score	461	.109	.972	-2.738	3.648
Speaker Residual	461	-.003	.523	-2.191	1.939
Interest Rate Surprises	461	.189	1.572	-4.167	13.179
Unemployment Rate	461	4.62	.316	4.1	5
Inflation Rate	461	2.035	.23	1.684	2.331
Δ 3-month yield	461	.145	2.159	-8	10
Δ 6-month yield	461	.046	1.952	-6	10
Δ 1-year yield	461	.117	1.99	-8	7
Δ 2-year yield	461	.158	3.205	-11	10
Δ 5-year yield	461	.184	4.064	-13	12
Δ 10-year yield	461	.2	3.968	-11	11

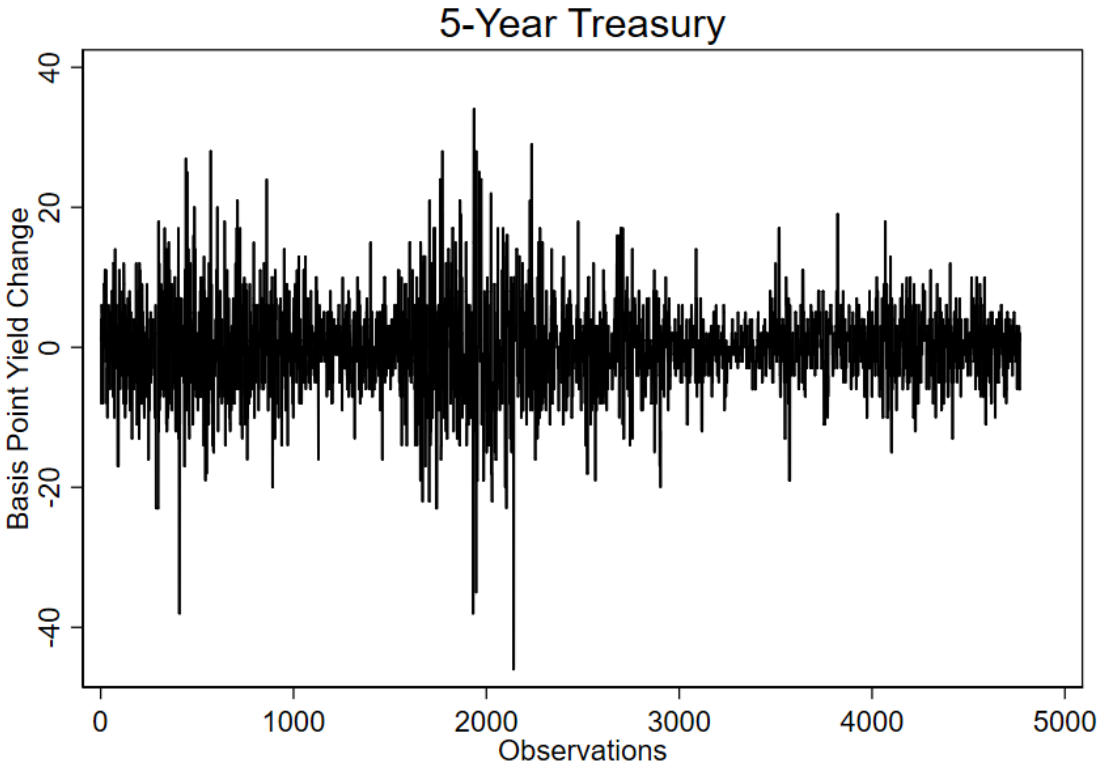
APPENDIX B: Variables

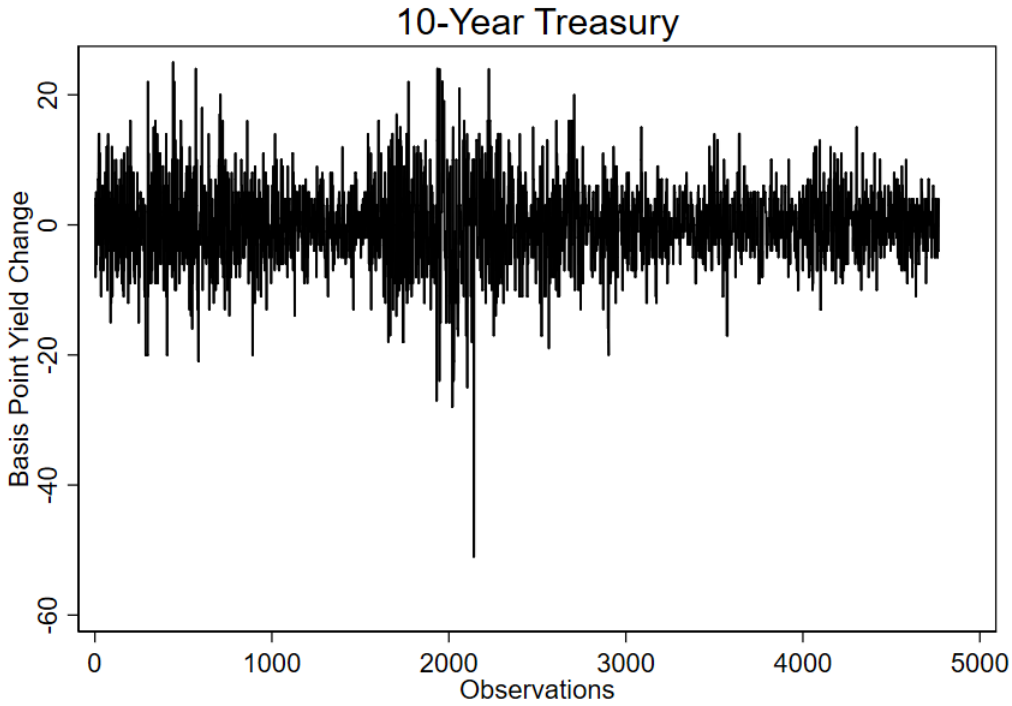


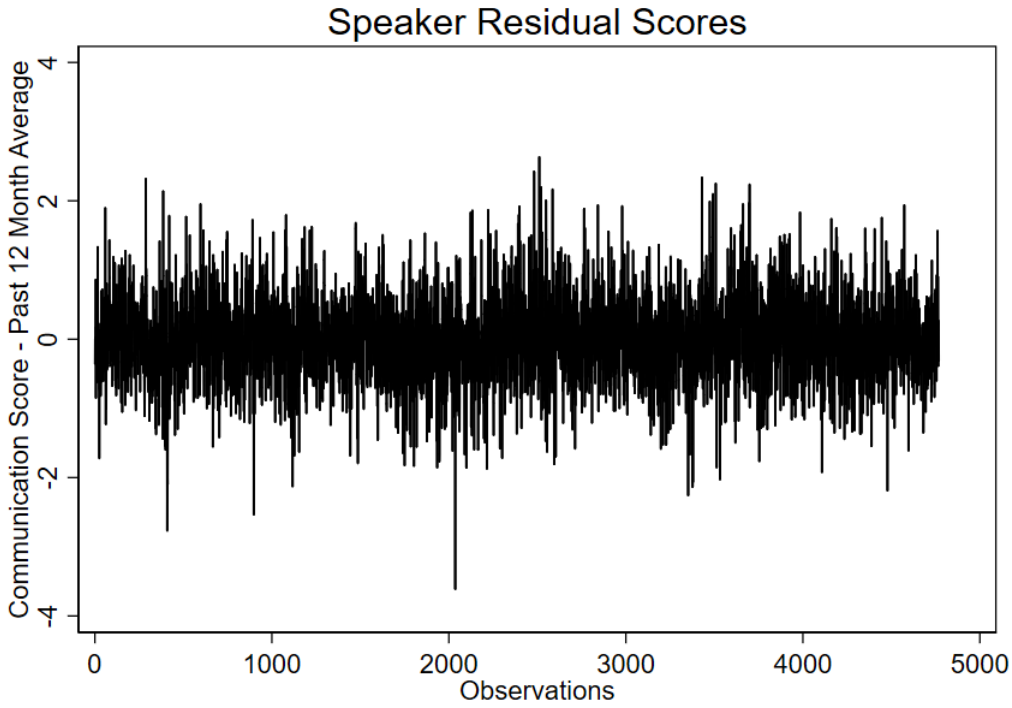


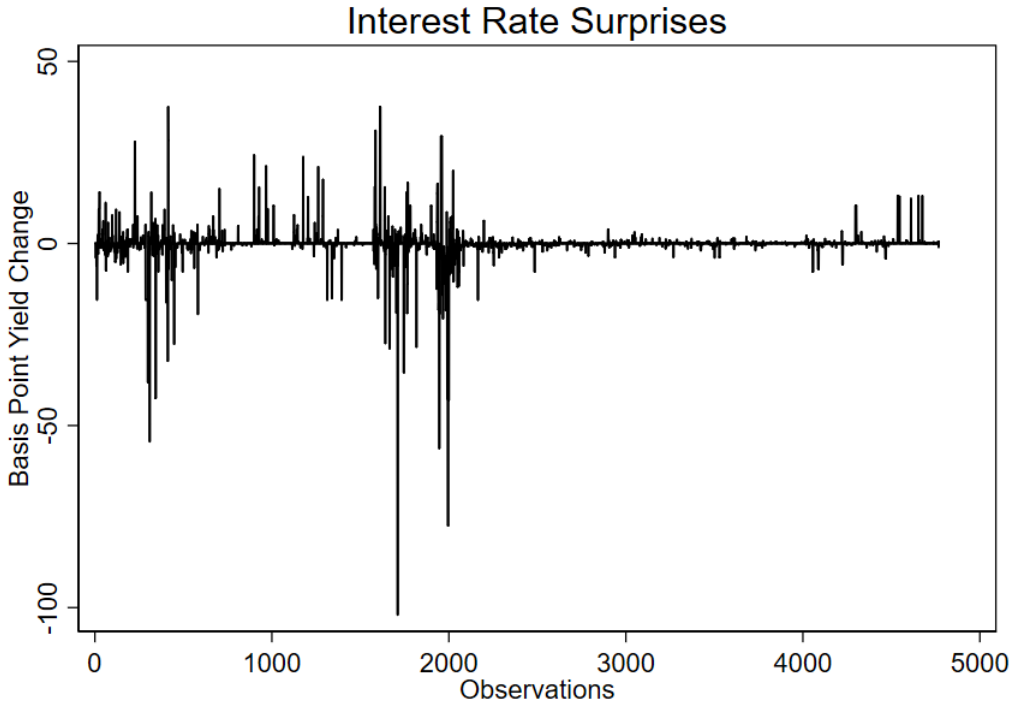

1-Year Treasury
Basis Point Yield Change
50
0
-50
0
1000
2000
3000
4000
5000
Observations


2-Year Treasury
Basis Point Yield Change
40
20
0
-20
-40
-60
0
1000
2000
3000
4000
5000
Observations


5-Year Treasury
Basis Point Yield Change
40
20
0
-20
-40
0
1000
2000
3000
4000
5000
Observations


10-Year Treasury
Basis Point Yield Change
20
0
-20
-40
-60
0
1000
2000
3000
4000
5000
Observations


Speaker Residual Scores
Communication Score - Past 12 Month Average
4
2
0
-2
-4
0
1000
2000
3000
4000
5000
Observations


Interest Rate Surprises
Basis Point Yield Change
50
0
-50
-100
0
1000
2000
3000
4000
5000
Observations