The Fed and the Secular Decline in Interest Rates*

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Abstract

This paper documents a striking fact: a narrow window around Fed meetings captures the secular decline in U.S. Treasury yields since 1980. Yield movements outside this window are transitory and wash out over time. This is surprising because the forces behind the secular decline are thought to be independent of monetary policy. However, Fed announcements might provide guidance about the long-run path of interest rates. In direct support of such "Long-run Fed Guidance", the Fed's expectations for the long-run level of the federal funds rate – released through the "dot plot" – strongly impact long-term bond yields.

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1 Introduction

The Fed's ability to affect real rates of return, especially longer-term real rates, is transitory and limited. Except in the short run, real interest rates are determined by a wide range of economic factors, including prospects for economic growth – not by the Fed.

Ben Bernanke in "Why are interest rates so low?"

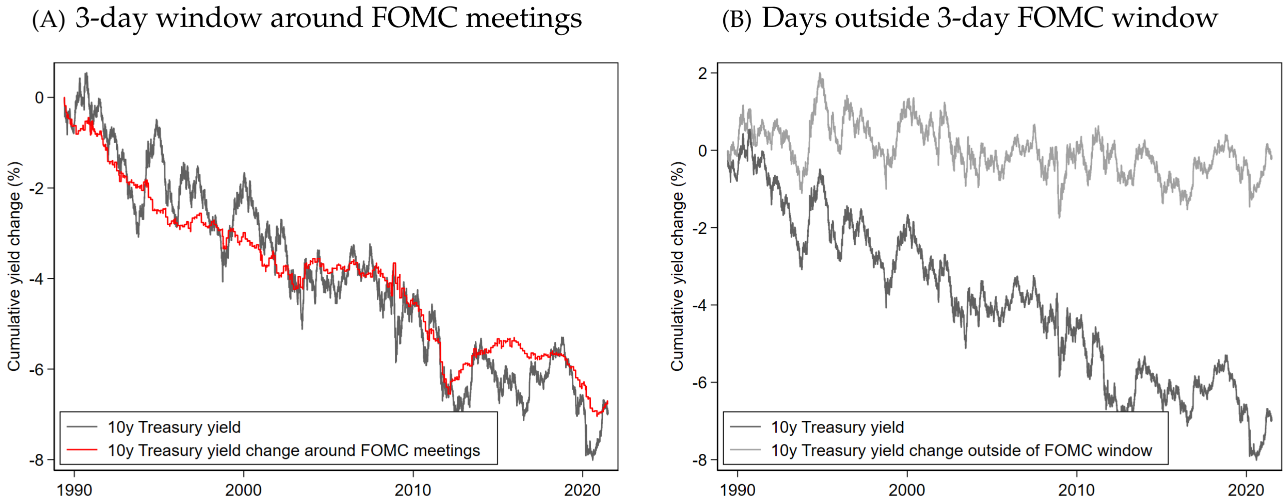
One of the most important macroeconomic trends over the last several decades has been the secular decline in nominal and real interest rates. While the Federal Reserve has the ability to control interest rates in the short run, economists believe that the Fed has limited ability to affect real interest rates in the longer run. Accordingly, other economic forces are seen as the more likely driver of the decline in interest rates. Indeed, the most prominent explanations for the secular decline are – together with a decline in inflation expectations (Bauer and Rudebusch, 2020) – a global savings glut (Bernanke, 2005), a lack of capital investment opportunities (Summers, 2014), and a slowdown in productivity growth (Gordon, 2017). What is common among these latter forces is that they are slow-moving and supposedly lie outside the control of monetary policy.

This paper documents a surprising fact in light of these theories: a narrow time window around monetary policy meetings of the Federal Reserve captures the entire secular decline in long-term interest rates over the last decades. As Panel A of Figure 1 shows, changes in the 10-year U.S. Treasury yield that occurred within this window not only add up to the entire cumulative yield change since 1989, but also capture the low-frequency movements of the 10-year yield strikingly well. To put this finding differently, yield changes outside this window were transitory and offset over time. This is exactly what Panel B shows.

The puzzling nature of this fact remains when we look at how other bond yields changed around Federal Open Market Committee (FOMC) meetings. The empirical pattern holds for both the 5-year Treasury yield as well as the 5-year/5-year Treasury forward rate. That is, even the decline in longer-term forward rates – which are supposedly less affected by the monetary policy stance – is fully captured by a narrow window around Fed meetings. Additionally, we can decompose nominal yields into real yields and risk-adjusted inflation expectations, so-called breakeven inflation, which is possible since the introduction of Treasury inflation-protected securities (TIPS) in 1997. Consistent with the notion that inflation expectations have been relatively stable over the last two decades, the decline in long-term nominal yields comes entirely from a decline in real yields. This reinforces the puzzling nature of the observed pattern: while most economists believe that the Fed can influence long-term inflation expectations, they are less likely to believe that the Fed can impact long-term real interest rates. The main fact is robust. For example, it holds when we expand the size of the window around FOMC meetings from 3 days to more days or when we use yields derived from transaction prices of on-the-run securities.

What could explain the fact that a narrow window around FOMC meetings captures the entire secular decline in short-term as well long-term rates? I distinguish potential explanations based on whether they work through investors' expectations or the risk premium that investors demand for holding onto bonds. I examine three potential risk-based explanations. First, the risk premium on long-term bonds

Figure 1: The Decline in Interest Rates around FOMC Meetings



Note: The figure documents that a 3-day window around FOMC meetings captures the secular decline of the 10-year U.S. Treasury yield. This 3-day window includes, for every FOMC meeting, the day prior to the meeting, the day of the meeting and the day after the meeting. The dark gray line (both panels) shows the actual evolution of the 10-year U.S. Treasury yield. The red line in Panel A shows a hypothetical time series that is constructed by taking into account only the yield changes that were realized in the 3-day window around FOMC meetings; the yield changes that occurred on all days outside of this window are set to zero. The light gray line in Panel B shows a hypothetical time series that is constructed by taking into account only the yield changes that occurred on days outside of the 3-day window around FOMC meetings. The 10-year U.S. Treasury yield is obtained from Gürkaynak et al. (2007). The analysis includes all FOMC meetings from June 1989 to June 2021.

might change around monetary policy dates, because investors might reach for yield (Hanson and Stein, 2015) or because investors might demand a larger premium for holding onto less liquid assets (Drechsler et al., 2020). While these theories can account for the high sensitivity of long-term rates to short-term rates, they, on their own, cannot explain why short rate movements have been persistently negative at FOMC meetings. They can also not explain why the decline in long-term rates continued when the federal funds rate was at the zero lower bound (ZLB). A second possibility is that investors demand a risk premium for being exposed to announcement news (Savor and Wilson, 2013; Ai and Bansal, 2018). While this could explain why bond returns are high on meeting days (and equivalently why bond yield changes are negative on these days), this explanation struggles to explain why the FOMC window captures the low-frequency movement of yields. That is, even when yields stayed flat or increased for a sustained period of time, the FOMC windows captures this trend. Third, it is possible that the Fed, by eliminating tail risk from financial markets (through the so-called "Fed put"), has lowered the risk premium on long-term assets (Cieslak et al., 2019; Cieslak and Vissing-Jorgensen, 2021). This explanation faces the challenge that the bond beta has changed over time and has been negative in a substantial part of my sample (Campbell et al., 2017, 2020) thus predicting an increase in long-term yields. In addition, negative stock returns have no predictive power for the movement of long-term yields around FOMC meetings. To conclude, while risk-based explanations might have contributed to the observed pattern (Cieslak and Pang, 2021), they are unlikely to explain the majority of the decline in yields around FOMC meetings.

Alternative mechanisms work mostly through the information that investors acquire on their own or extract from the Fed around FOMC meetings. For example, the Fed might provide valuable information about the near-term economic outlook (Romer and Romer, 2000; Campbell et al., 2012; Nakamura and Steinsson, 2018) or its response to such news (Bauer and Swanson, 2022). However, while near-term economic news have a strong direct effect on short-term rate expectations, their impact on long-term rate expectations is likely measured (unless investors extrapolate short rates). Thus, a complementary explanation might be that investors extrapolate the current short rate when forming expectation about the long-run level of interest rates (Hanson et al., 2021). Contrary to this explanation, I find that variables, which explain the Fed's response to news channel, have low predictive power for the movements of long-term yields around FOMC meetings.

An alternative interpretation of the fact is that investors have learned about the secular decline in nominal and real rates around FOMC meetings. This might be due to the fact that FOMC meetings play a coordinating role in financial markets and investors collect or trade on their information preferably around FOMC meetings. Or it might be because the market learns important information about the long-run level of rates from the Fed. I call this idea "Long-run Fed Guidance", reflecting the notion that the Fed's actions and communications can provide guidance to markets about the long-run level of *nominal* interest rates. It seems quite natural that the market learns from the Fed about the long-run path of inflation, since the Fed supposedly controls inflation over the longer run. Thus, if the Fed lowers its inflation target and this ultimately feeds into lower long-run inflation, then this information is valuable for investors. But the Fed might also provide guidance about the long-run level of *real* interest rates. Even if the natural rate (or the "long-run real rate") rate lies outside the Fed's control (as the Fed itself believes), its position as the monetary authority might give it superior information about the natural rate. The natural rate is defined as the rate at which monetary policy is neither expansionary nor contractionary. To estimate its level, most models therefore rely on observing the effects of monetary policy (e.g., Laubach and Williams, 2003). Thus, the Fed, by closely tracking the effect of rates on the economy, obtains an estimate for the natural rate.[1] And as the natural rate is the key input for monetary policy, the Fed spends great efforts to understand how monetary policy impacts the economy and where the natural rate is at a given point in time. This might give the Fed an advantage over many market participants who might not have the same resources nor sufficient incentives to "compete" with the Fed.[2] But this does not rule out that some information is learned by investors themselves. In fact, if the Fed has some private information about long-run rates, then FOMC meetings might play a coordinating role for financial markets. Informed investors might then want to trade more aggressively in the run-ups to FOMC meetings at which prices become more informative.

The daily pattern supports this interpretation. A substantial part of the yield decline is realized on days prior to FOMC meetings. This might be due to trading by informed investors. The majority of the yield decline occurs thereafter on the meeting day and the following day. This might reflect the information coming out of the Fed which leads investors to revise down their expectations for future

[1] If monetary policy has a stimulative effect on the economy, then current rates are likely above the natural rate and if monetary policy has a contractionary effect, then current rates are likely below the natural rate.

[2] An alternative interpretation is that the Fed has substantial flexibility in setting real rates or that the Fed itself affects the natural rate (Rungcharoenkitkul and Winkler, 2021; McKay and Wieland, 2021). If this were true, then the Fed's information advantage arises naturally. Consistent with this interpretation, Bianchi et al. (2022) find that a large amount of the downward trend in the real short rate can be attributed a shift in the Fed's policy.

rates. For the period after 1994, we can get an even finer decomposition of the pattern on a 5-minute frequency using intraday data on on-the-run 10-year U.S. Treasury Notes. In line with the daily pattern, I find that yields started to drift downward on days prior to FOMC meetings and continued their decline during the next day until they dropped sharply at the meetings. This pattern is consistent with the presence of Long-run Fed Guidance.

To provide direct evidence for Long-run Fed Guidance, I make use of the Fed's "dot plot". The dot plot, released since 2012 in the Statement of Economic Projection at FOMC meetings, shows FOMC members' forecasts for the federal funds rate over the next three years as well as their forecasts for the federal funds rate over the "longer run". Over the past decade, this long-run forecast has declined by more than 180 bps, driven by the Fed's view that the natural rate of interest has declined substantially. Under the hypothesis of Long-run Fed Guidance, the release of the Fed's long-run forecast should have a strong influence the market's expectation for the long-run level of interest rates. To test this prediction, I regress the change in long-term *real* yields on the meeting day (i.e., when the dot plots are released) on the change in the Fed's long-run forecast relative to the prior meeting. The results are stark. They show that a 100 bps decrease in the Fed's forecast for the long-run level of (real) interest rates leads to a more than 70 bps decrease in long-term *real* yields. Thus, the results directly imply that the release of the dot plots has lowered real bond yields by around 130 bps over the last decade. It is important to keep in mind that this likely reflects only the causal impact of the information release, and not the causal impact of monetary policy itself. That is, long-term yields might have declined by the same amount without the Fed communication (but potentially at a different date).

What about the period before the dot plot when the Fed's main policy tool was the federal funds rate and short rates were not at the ZLB? Consistent with the idea that the Fed can also provide guidance through the federal funds rate, I find that the yield decline is almost entirely concentrated at meetings where the Fed changed the target for the federal funds rate. Alternatively, we can split the sample of FOMC meetings based on whether the monetary policy was unexpectedly hawkish or dovish using the current month's federal funds futures contract (Kuttner, 2001). This split reveals that the yield decline solely occurred at meetings at which the new target of the fed funds rate was set below the market's expected target. Together, these results suggest that the nature of Long-run Fed Guidance might have changed over time: while the market might have learned previously from short rate decisions, it, nowadays, might learn from the Fed's explicit long-run guidance released through the dot plot.

Lastly, I formalize the idea of Long-run Fed Guidance. More concretely, I develop a Bayesian learning model in which the bond market and the Fed, in addition to processing their own information about the economy, learn from each other: the Fed learns from the yield curve, and the market learns from the Fed's short rate action (the model can be extended to include the Fed's dot plot). In the model, the Fed controls the short rate, while longer-term bonds are priced by the market. Firstly, the model formalizes why the Fed's short rate decisions can lead to updates in investors' expectations about the long-run level of interest rates (and therefore to changes in long-term bond yields). If the Fed sets the short rate according to a standard Taylor rule (e.g., Taylor, 1993), then, by setting the level of the short rate, the Fed reveals – albeit imperfectly in the real world – its inflation target as well as its expectation about the natural rate. The theoretical analysis provides several additional insights: first, the fraction of long-run changes in bond yield occurring at FOMC meetings is about as large as the dot plot coefficient, i.e., the coefficient when regressing the yield change on the meeting day on the meeting-to-meeting change in the Fed's long-run dot plot. Based on the empirical estimates, this suggests that Long-run Fed Guidance might explains more than 60% of the decline around FOMC meetings (which is consistent with the observed daily pattern). Second, the importance of Long-run Fed Guidance is increasing in two factors: (a) how good the Fed is (relative to the market) at collecting information about the nominal long-run rate and (b) how uncertain the agents are about the true level of the long-run rate. The intuition behind the importance of the latter factor is the following: if new information comes out all the time and it is easy to make an accurate forecast, then the market does not wait until the FOMC meeting to incorporate this information into prices. Finally, I use a macro-finance term structure model (Ang and Piazzesi, 2003, e.g.) to quantify these two factors. The calibration suggests that the uncertainty about the level of the nominal long-run rate must be high and that the Fed must possess a substantial advantage in estimating this level.

Contribution to the literature. This paper relates to several research strands. First, it relates to the literature on the secular decline in interest rates. A large literature has examined the decline in trend inflation that occurred after the Great Inflation (Clarida et al., 1999; Drechsler et al., 2020, e.g.) as well as the decline in real interest rates.[3] My paper documents that the secular decline in interest rates occurred in a narrow window around monetary policy meetings.

Second, this paper argues that one potential explanation for this pattern might be "Long-run Fed Guidance", namely that the Fed's short rate decision and the Fed's dot plot forecast provide guidance to the market about the long-run level of interest rates. This explanation is related to prior studies about the "Fed information effect" which argue that the Fed has better knowledge about the short-term trajectory of the economy. The seminal paper is Romer and Romer (2000), who argue that the Fed is better at forecasting inflation over the next few quarters than private-sector professional forecasters. Campbell et al. (2012) and Nakamura and Steinsson (2018) document similar evidence for unemployment and output growth expectations. More recently, Bauer and Swanson (2022) find that these results can alternatively be explained with a "Fed response to news" channel. I also provide a potential resolution to the arising puzzle whereby asset prices respond "Fed information" (Jarociński and Karadi, 2020; Cieslak and Schrimpf, 2019; Bianchi et al., 2022), but professional forecasters might not: if uncertainty about the long-run level of interest rates is high, then it is hard for informed investors to exploit their information. This leaves more room for the Fed to provide guidance to the market as a whole or to play a coordinating role in financial markets.

Third, this paper speaks to the empirical literature analyzing the reaction of financial assets to monetary policy. The overarching theme in the literature is that long-lived assets are surprisingly sensitive to monetary policy. Starting with Bernanke and Kuttner (2005), a number of studies have relied on high-frequency identification to examine the effects of monetary policy on financial assets, for example on

[3] There exists a large list of potential drivers for the fall in real interest rates. Potential reasons for the decline in real rates are a lack of capital investment opportunities (e.g. "secular stagnation") (Summers, 2014), a slowdown in productivity growth (Gordon, 2017), a rise in the savings of emerging economies (Bernanke, 2005), a fall in the price of capital due to technological change (Eichengreen, 2015), changes in demographics (Gagnon et al., 2016; Carvalho et al., 2016), increase in the liquidity and safety premium of Treasuries (Del Negro et al., 2017) and a decrease in sovereign default risk (Miller et al., 2021).

interest rates (Hanson and Stein, 2015; Nakamura and Steinsson, 2018, e.g.). Some articles also focus on the impact of the Fed's communication on asset prices (Gurkaynak et al., 2005; Schmeling and Wagner, 2019; Gómez-Cram and Grotteria, 2022; Swanson, 2021, e.g.). I add to this literature by providing evidence that a particular form of communication, namely the Fed's forecast for the long-run level of the federal funds rate, revealed through the dot plot, has a strong effect on long-term yields. Other studies have focused on asset price movements outside the high-frequency window. In their influential work, Lucca and Moench (2015) document the "pre-announcement drift", i.e. the empirical pattern that equity returns are excessively high in the 24 hours leading up to the FOMC meeting. Relatedly, Cieslak et al. (2019) argue that the entire equity premium is earned in the even weeks of a bi-weekly cycle of the FOMC announcements.[4] Bianchi et al. (2021, 2022) provide evidence for the impact of monetary policy on asset valuations at lower frequencies. I add to this evidence by showing that there are large and systematic movements of long-term nominal and real bond yields in the three days around FOMC meetings.

Finally, the paper relates to the theoretical bond market literature along several dimensions. First, I provide a theoretical justification for why long-term yields might react to the Fed's short rate decisions. Contrary to prior studies emphasizing the role of risk premia (Hanson and Stein, 2015; Drechsler et al., 2018; Kekre and Lenel, 2022; Pflueger and Rinaldi, 2022), I argue that bond investors might revise their expectations for the path of future short rates in response to Fed guidance, similar to the model of Nakamura and Steinsson (2018) and consistent with the findings of Bekaert et al. (2021). The paper also relates to prior work studying the dynamic interaction between the Fed and the bond market. Instead of focusing on the strategic interaction (Stein and Sunderam, 2018; Caballero and Simsek, 2022), I focus on the two-way learning interaction between the market and the Fed. Lastly, the paper relates to the vast macro-finance term structure literature, in particular to studies integrating macroeconomic variables and monetary policy rules into affine term structure models (Ang and Piazzesi, 2003; Diebold et al., 2006; Ang et al., 2007; Mönch, 2008). I explicitly model the market's beliefs about future monetary policy and integrate FOMC meetings into the model (Piazzesi, 2005). This allows the model to explain term structure movements at FOMC meetings.

2 Data

2.1 FOMC Meetings

The Federal Open Market Committee (FOMC) is the committee within the Federal Reserve that is responsible for conducting monetary policy.[5] The FOMC consists of twelve voting members – the seven members of the Board of Governors, the president of the Fed New York, and four of the remaining eleven Reserve Bank presidents, who serve one-year terms on a rotating basis. Monetary policy decisions are made by the FOMC based on a majority vote.

[4] Different explanations exist for the pre-announcement drift. Cieslak et al. (2019) provide anecdotal evidence that there is leakage of Fed-internal information. Morse and Vissing-Jorgensen (2020) provide further evidence on the information flow from the FOMC to the stock market. Laarits (2019) and Hu et al. (2022) argue that the pre-announcement drift is compensation for the uncertainty regarding the market impact of the FOMC announcement. Ying (2020) and Ai et al. (2021) explain the pre-announcement drift with informed trading.

[5] See Lucca and Moench (2015) for an excellent description of FOMC meetings and the conduct of monetary policy.

Since 1981, the FOMC has typically carried out eight scheduled meetings per year.[6] The majority of monetary policy decisions since 1994 have been made during these *scheduled* meetings, while only relatively few changes in monetary policy were decided during *unscheduled* meetings (typically in the form of conference calls). By contrast, prior to 1994, these *unscheduled* meetings accounted for a large fraction of federal funds rate target changes.[7]

Dates. Importantly, I want to obtain the dates when the meeting information was released to the public. For example, for scheduled FOMC meetings before 1994, the market learned about any change in monetary policy typically on the day following the meeting through the open market operations of the New York Fed. In order to correctly identify release dates of meeting news, I use two sources: dates of scheduled and unscheduled FOMC meetings from the website of the Federal Reserve, and dates that the market associated with a change in monetary policy as identified by Kuttner (2001, 2003). My main sample therefore starts in June 1989. Past 1994, monetary policy was conducted mostly in the form of scheduled meetings and the Fed always released a statement if there was a change in the federal funds rate. I use the day when the statement was released (this is typically the second day of any FOMC meeting).

In total, my sample contains 283 FOMC meetings, of which 256 are scheduled meetings and 27 are unscheduled meetings. A further description and a detailed list of the FOMC meeting dates can be found in the Internet Appendix.

Dot plot. In recent times, the Fed has released the "Statement of Economic Projections" on a quarterly basis – essentially at every other meeting – simultaneously with the monetary policy statement, also called the "FOMC statement". The Statement of Economic Projections contains the forecasts of all (voting and non-voting) FOMC meeting participants for GDP growth, unemployment, inflation and the federal funds rate over the short run and the longer run. The market and the financial press refer to the forecasts for the federal funds rate simply as the "dot plot" because of a prominent chart that reveals the individual forecasts. The dot plot has been released since the FOMC meeting on January 25, 2012.

I collect all individual (anonymized) forecasts of the federal funds rate of all FOMC meeting participants, i.e. all "dots", from Bloomberg. My sample contains all 38 dot plot observations since January 25, 2021 up to and including the FOMC meeting on June 16, 2021. In my analysis, I concentrate on the forecast for the federal funds rate over the "longer-run" (this is discussed further below). To get a forecast that is representative of the average Fed view, I compute the mean of the individual forecasts for the long-run level of the federal funds rate.[8]

2.2 Bond Market Data

Daily data. I use yield data on U.S. Treasury securities constructed by Gürkaynak et al. (2007). This data provides an interpolated zero-coupon (continuously-compounded) yield curve. For the yield curve

[6]The FOMC conducted only 7 *scheduled* meetings in 2020.

[7]Some of these unscheduled meetings were not followed by any immediate policy actions or by a statement. The public learned about these unscheduled meetings only with a significant time lag; I exclude these meetings from the list of unscheduled meetings.

[8]I have also computed the median forecast, but the median is quite stale until it jumps by 25bps from one meeting to the next. I therefore prefer to use the mean forecast. Outliers are also not an important consideration, as the forecasts typically lie close together.

interpolation, it uses a large set of U.S. Treasury Notes and Bonds, but excludes the two most recently issued securities (with maturities of two, three, four, five, seven, ten, twenty, and thirty years). Analogous to the data on nominal yields, I use interpolated zero-coupon yield curves for U.S. Treasury inflation-protected securities (TIPS) constructed by Gürkaynak et al. (2010) to obtain data on real yields and breakeven inflation. TIPS were first issued in 1997 and the data provided by Gürkaynak et al. (2010) is available from 1999 onwards. For both data sets, the quotes used to construct the daily yield series are as of 3 p.m. Eastern time.

In addition, I obtain yields of the on-the-run 10-year U.S. Treasury Notes (Ticker: "USGG10") and the on-the-run 10-year U.S. TIPS Notes (Ticker: "GTII10") from Bloomberg. The on-the-run security is the most recent issued security of a certain maturity, for example 10 years. This data has the advantage that yields are based on the traded quotes of individual securities instead of being extracted from the yield curve interpolation. On-the-run securities are also more liquid than off-the-run securities and therefore have slightly better price discovery. The disadvantage of this data is that the duration of the 10-year on-the-run issue has changed over time as the coupon rates have decreased over time because bonds are typically issued close to par value. Furthermore, the issuance of a new on-the-run bond requires a switch between securities. For these reasons, I preferably use interpolated yield curve data, but show robustness using on-the-run yields. I use mid-quotes. Bloomberg uses quotes as of 6 p.m. Eastern time to construct the daily yield series.

Intraday data. I also use intraday bond pricing data on the on-the-run 10-year U.S. Treasury Notes from GovPX. This data is based on quotes from the interdealer Treasury market. In particular, the data features the quotes that dealers submit to various voice-assisted brokerage systems (Fleming and Remolona, 1999). I use mid-quotes.

3 A New Fact: The Decline in Interest Rates around FOMC Meetings

In this section, I show that a 3-day window around FOMC meetings fully captures the decline in interest rates over the last decades. I define this 3-day window such that it includes, for every FOMC meeting, the day prior to the meeting, the day of the meeting and the day after the meeting. I set the day of each FOMC meeting to the day when monetary policy news were revealed to the public. As elaborated in Section 2, this is typically the day after the FOMC meeting prior to 1994 and the meeting day since 1994. I then distinguish between days that fall into the 3-day window around FOMC meetings and days that do not. Finally, I construct a hypothetical time series of the 10-year U.S. Treasury yield that takes into account only yield changes realized during the 3-day FOMC window and ignores the yield movement on days outside of the 3-day window, i.e. it sets these yield changes to zero.

The results of this analysis are shown in Panel A of Figure 1. The dark gray line shows the actual evolution of the 10-year U.S. Treasury yield. The line reveals that the 10-year yield declined by around 7% between June 1989 and June 2021. This is the secular decline in interest rates that has received substantial attention in the literature. By contrast, the red line shows the hypothetical time series of the 10-year U.S. Treasury yield when we consider only yield changes that were realized within the 3-day FOMC window. As the figure shows, the yield changes that occurred within this window not only add up to the entire cumulative yield change since 1989 but also capture the slow-moving component of the 10-year yield striking well. The 3-day window includes roughly 10% of trading days, since FOMC meetings take place on average every six weeks. Thus, 10% of trading days capture the secular decline in interest rates.

We can also illustrate the main result differently. Instead of constructing a hypothetical time series of the 10-year U.S. Treasury yield which considers only the yield movements on the 3 days around FOMC meetings, we can create an alternative hypothetical time series taking into account only the yield movements on days outside of the 3-day FOMC window – essentially the other 90% of trading days. This time series is shown as the light grey line in Panel B of Figure 1. Given the previous analysis, the results are hardly surprising: This hypothetical yield fluctuates around zero over the entire sample period and exhibits no cumulative decrease in the yield over the sample period. Putting it differently, these days do not account for the secular decline in long-term Treasury yields.

We can decompose the (continuously-compounded) 10-year U.S. Treasury yield y_{10y} into

$$y_{10y} = \frac{1}{2} y_{5y} + \frac{1}{2} y_{5y5y}, \tag{1}$$

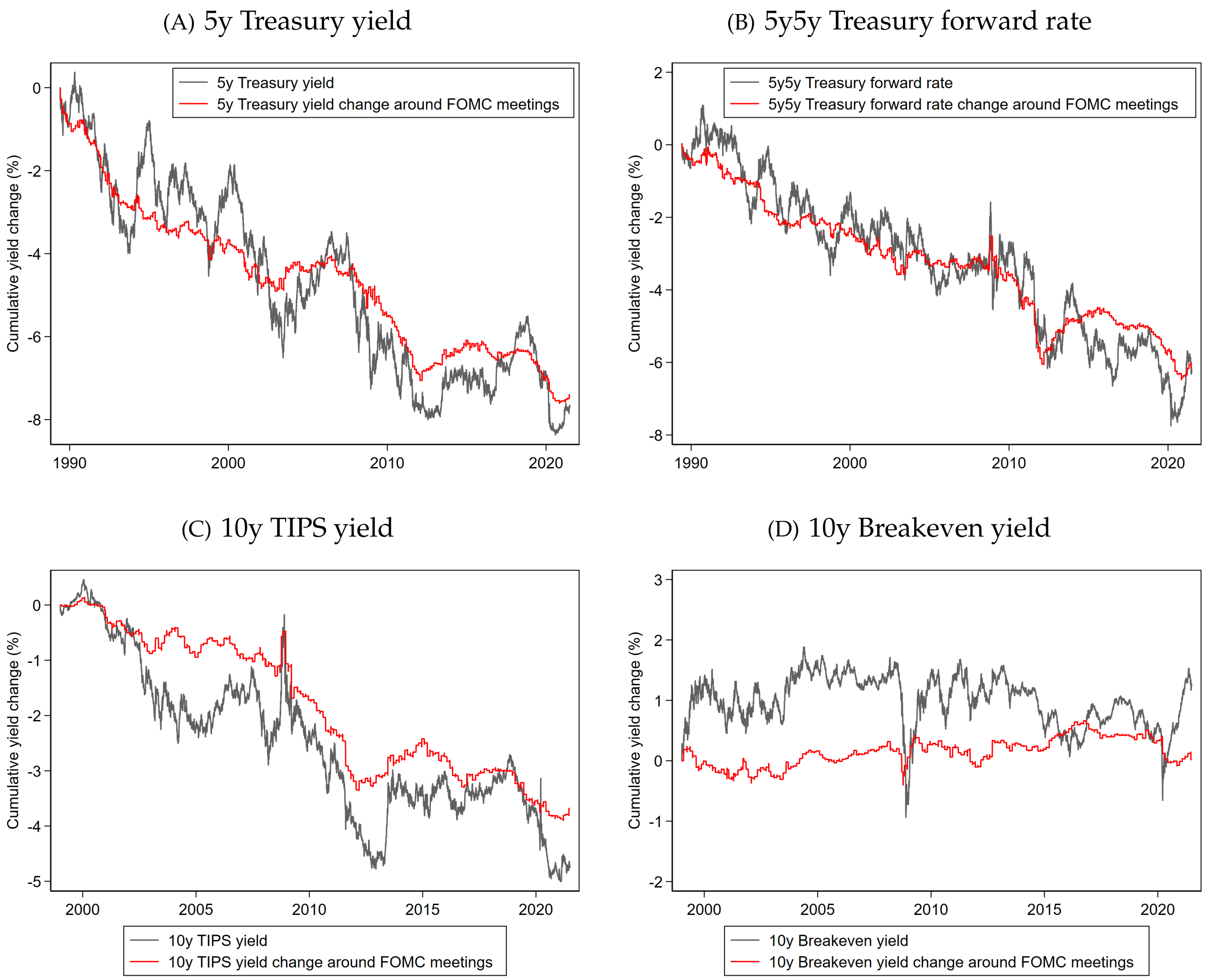
where y_{5y} is the 5-year Treasury yield and y_{5y5y} is the 5-year/5-year forward rate, i.e. the 5-year yield 5 years from now under current market prices. Similarly, for roughly the last two decades for which we have data on TIPS available, we can split the 10-year U.S. Treasury yield into

$$y_{10y} = y_{TIPS,10y} + y_{Bkeven,10y}, \tag{2}$$

where $y_{TIPS,10y}$ is the 10-year yield on TIPS and $y_{Bkeven,10y}$ is the 10-year breakeven inflation. I repeat the main analysis using these yield components, i.e. I add the yield changes that occurred within the 3-day window around Fed meeting for the 5-year yield, the 5-year/5-year forward rate, the 10-year TIPS yield, and 10-year breakeven inflation in Figure 2. The figure shows that the main empirical fact also holds for the 5-year yield (Panel A) and the 5-year/5-year forward rate (Panel B). In other words, the 3-day window around FOMC meetings accounts for the secular decline even in longer-term forward rates. That is, even the decline in longer-term forward rate, which are supposedly less affected by the current monetary policy stance, is fully captured by the narrow window around Fed meetings. When looking at the 10-year TIPS yield (Panel C) and 10-year breakeven inflation (Panel D), we see that the entire decline in nominal interest rates since 1999 was due to a decline in real interest rates, while breakeven inflation was very stable. Given the prior results, it is therefore unsurprising that we find a large decline in the TIPS yields around FOMC meetings, while breakeven inflation shows little movements around these meetings.

I also vary the starting point of my main analysis in Figure 3. First, I start the analysis in 1980 shortly after Volcker became the new chairman of the Fed. For this period it is somewhat harder to determine when the market learned about monetary policy news mainly for two reasons (for the same reasons it is not feasible to extend the sample further back). First, the Fed was deliberately opaque at the time (Lindsey, 2003) and the market learned about Fed actions through the Fed's open market operations. In addition, as there was also a lot of volatility in money markets, it was not always clear to markets whether a change in the fed funds rate represented a Fed action. Second, monetary policy was mainly

Figure 2: A Decomposition of the FOMC Decline

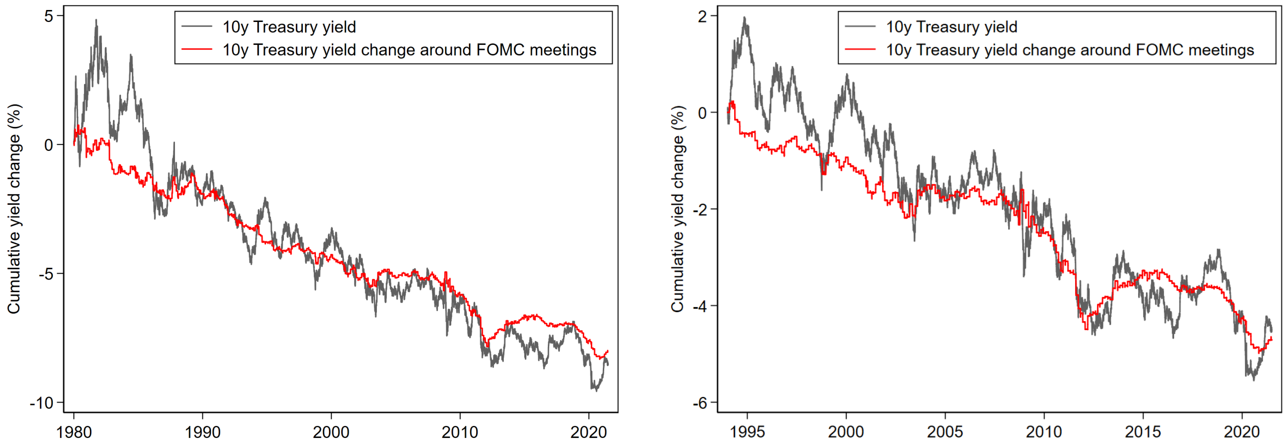


Note: The figure shows how much of the secular decline is captured by the 3-day window around FOMC meetings for various yields. This 3-day window includes, for every FOMC meeting, the day prior to the meeting, the day of the meeting and the day after the meeting. The dark gray line shows the actual evolution of a particular yield. The red line shows a hypothetical time series that is constructed by taking into account only the yield changes that were realized in the 3-day FOMC window; the yield changes that occurred on days outside this window are set to zero. U.S. Treasury and TIPS yields are obtained from Gürkaynak et al. (2007) and Gürkaynak et al. (2010), respectively. The analysis includes all FOMC meetings from June 1989 to June 2021 in Panel (A) and (B) and from January 1999 to June 2021 in Panel (C) and (D).

conducted during unscheduled meetings. I rely on two sources to collect the meeting dates prior to June 1989 (this is further discussed in the Internet Appendix): the website of the Federal Reserve for the scheduled meeting dates and the federal funds target rate series constructed by Thornton (2005) for unscheduled meetings. Panel A of Figure 3 shows that the main result also holds when starting the analysis in 1980 (although there are some larger deviations for the the period between 1980 and 1990). This is interesting, as the time period after 1980 was mainly characterized by a decline in long-term inflation expectations (Cieslak and Povala, 2015), which is quite different from the period since 2000 (or even 1990) during which inflation expectations have been fairly stable. Panel B shows that the main

Figure 3: Different Sample Periods

(A) Since 1980 (B) Since 1994



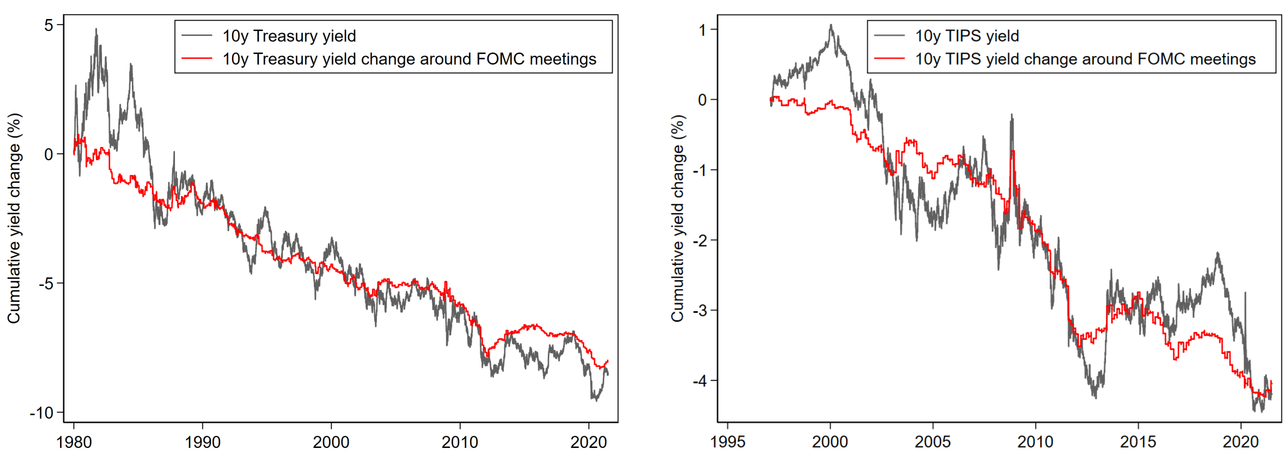
Note: The figure repeats the main analysis shown in Figure 1 starting in January 1980 (Panel A) and in 1994 (Panel B).

pattern also holds when starting in 1994. This was the year when the Fed started to communicate its decisions through statements.

Figure 4 shows that the documented pattern is not an artefact of the interpolated zero-coupon yield curve, but also hold when using quotes from on-the-run 10-year U.S. Treasury and TIPS Notes. In other words, the pattern also holds when we look at yield changes of actually traded, highly-liquid securities. Looking directly at market prices rules out the concern that the yield curve interpolation distorts the analysis.

Figure 4: On-the-run Yields

(A) 10y on-the run Treasury yield (B) 10y on-the-run TIPS yield



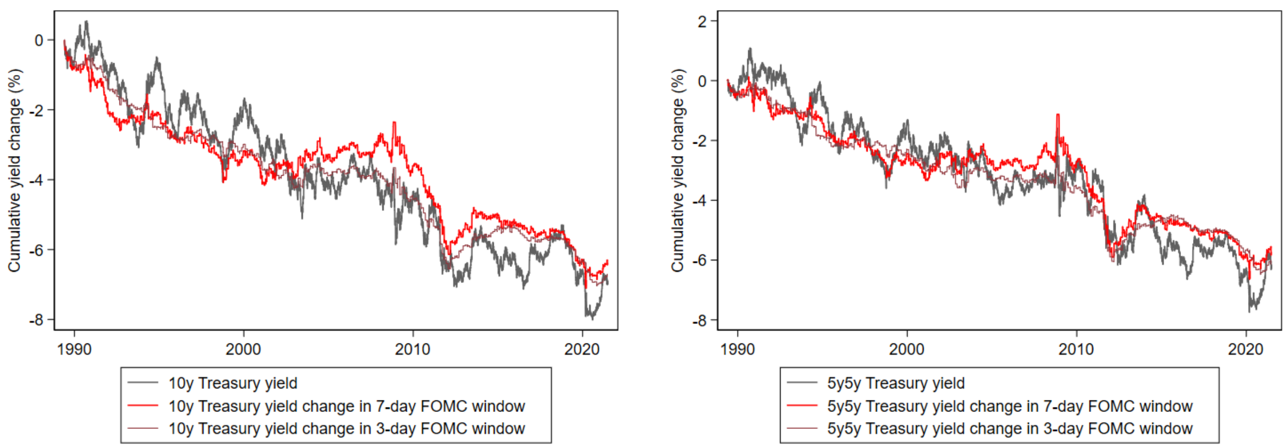
Note: The figure repeats the main analysis using yields of the on-the-run U.S. Treasury Notes (Panel A) and of the on-the-run U.S. TIPS Notes (Panel B).

Finally, Figure 5 documents that the main pattern also holds when we expand the window to include more days around FOMC meetings. In particular, the figure considers only yield movements that occurred in a symmetric 7-day window around FOMC meetings. That is, in addition to including the days $t-1$, t, and $t+1$, the window includes the days $t-3$, $t-2$, $t+2$, and $t+3$. This shows that the documented pattern is unlikely due to any market microstructure or liquidity events which would be mean-reverting.

Figure 5: 7-day Window around FOMC Meetings

(A) 10y Treasury yield

(B) 5y5y Treasury yield



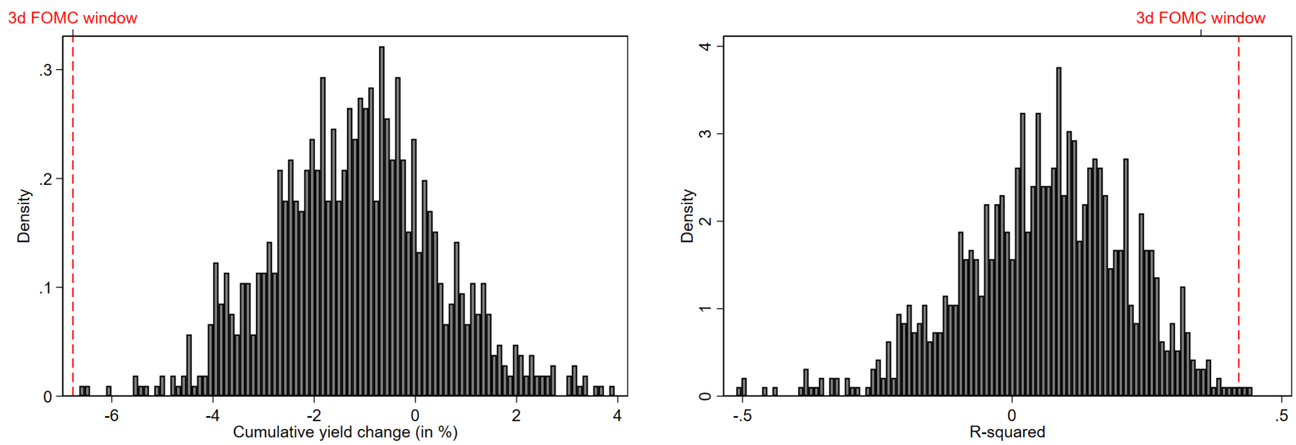
Note: The figure repeats the main analysis shown in Figure 1 starting in January 1980 (Panel A) and in 1994 (Panel B).

Can this be due to chance? One might wonder whether it is possible that the empirical pattern arose by coincidence. To address this question, I conduct the following placebo test. For each month over the sample, I randomly draw days in the amount equal to actual FOMC meetings within this month. These days represent "placebo FOMC meetings". Repeating this procedure for all months in the sample, gives a simulated path of placebo FOMC meetings. Analogous to the analysis above, we can then compute the cumulative yield change that occurred in the 3-day window around these placebo FOMC meetings. Panel A of Figure 6 shows the outcome of 1000 simulated paths. The figure illustrates that the likelihood of obtaining a yield decline as large as the yield decline around actual FOMC meetings (shown as the red vertical line) is near zero. Thus, the pattern is highly unlikely to arise solely due to pure coincidence.

However, the 3-day window around FOMC meetings not only adds up to the total yield decline, but also captures the slow-moving component of the 10-year U.S. Treasury yield strikingly well. To formalize this observation, we can ask how much of the total movement in the 10-year U.S. Treasury yield over a 2-year horizon is explained by the yield movement within the 3-day window around Fed

Figure 6: Placebo Test: Random FOMC Meetings

(A) Cumulative yield decline (B) Explanatory power - Yield changes over 2 years



Note: The figure compares two statistics for actual FOMC meetings with 1000 simulated paths of placebo FOMC meetings. Panel A shows the cumulative yield decline that is realized in the 3-day window around the (actual or placebo) Fed meetings. Panel B shows the variation of the changes in the 10-year yield over a 2 year horizon that is explained by the 3-day window around (actual or placebo) Fed meetings. Each placebo meeting path is obtained by sampling the same number of days within a month as actual FOMC meetings.

meetings over the same horizon.[9] Panel B of Figure 6 compares the variation explained by the actual FOMC meetings (shown again as the vertical red line) with the variation explained by the 1000 simulated FOMC meeting paths. Again, we draw the conclusion that the FOMC meetings are a statistical outlier: Less than 1% of the simulations reach a higher R^2 than the actual Fed meetings. To conclude, the empirical pattern is highly unlikely to have occurred just by chance.

We can also analyse the statistical significance of the FOMC decline in a simple regression. I regress the daily yield change of maturity-k bond on day t, $\Delta_{t-1,t}y_k$, on a dummy which equals one when day t falls into the 3-day window

$$\Delta_{t-1,t}y_k = \beta_0 + \beta_1 \, \text{Dummy(3-day FOMC window)}_t + \epsilon_t. \tag{4}$$

While this test is not a test of the overall pattern (that the FOMC window captures the low-frequency component of yields), this regression tests whether days within the 3-day FOMC window are different

[9]Formally, if we express the 10-year U.S. Treasury yield change that occurred between quarter $q-8$ and quarter q, i.e. over a 2-year horizon, as $\Delta_{q-9,q}y_{10y}$ and the yield change that occurred within the 3-day FOMC window over the same period as $\Delta^{FOMC}_{q-9,q}y_{10y}$, then we can write the explained variation as

$$R^2 = 1 - \frac{\sum_{q=0}^{T-3}\left(\Delta_{q-9,q}y_{10y} - \Delta^{FOMC}_{q-9,q}y_{10y}\right)^2}{\sum_{q=0}^{T-3}\left(\Delta_{q-9,q}y_{10y}\right)^2}, \tag{3}$$

where $q=0$ and $q=T$ denote 1989Q2 and 2021Q2, respectively. This equation is the (uncentered) R^2 in a regression without the intercept derived from the residual sum of squares (the numerator) and the total sum of squares (the denominator). Note that this statistic can go negative, if the residual sum of squares is greater than the total sum of squares.

in terms of the unconditional decline compared to days outside the window. Table 1 shows that the yield change was significantly lower within the 3-day FOMC window. In particular, the table shows that the change in the 1-year Treasury yield was on average 0.92 bps lower on days within the 3-day FOMC window compared to on all other days. For the 10-year Treasury yield, the average difference is 0.80 bps. The difference becomes smaller when go beyond 10 years and use yields derived from the interpolated yield curve. This seems be influenced by the fact the interpolation based on off-the-run securities is less accurate beyond 10 years, as the average difference is substantially higher using the on-the-run 30-year yield. The table also shows that changes in the 10-year TIPS yield are signficantly lower within the FOMC window compared to outside of the window. By contrast, the average yield change within the FOMC window was similar to the average yield change outside the window when we look at breakeven inflation and inflation swaps.

Table 1: Regression: Yield Changes Within vs. Outside the 3-day FOMC Window

		FOMC window		Constant		Start date
(1)	1y Treasury yield (GSW)	-0.92***	(-4.79)	-0.01	(-0.25)	Jun 1989
(2)	2y Treasury yield (GSW)	-0.85***	(-3.92)	-0.02	(-0.28)	Jun 1989
(3)	5y Treasury yield (GSW)	-0.88***	(-3.70)	-0.00	(-0.06)	Jun 1989
(4)	5y on-the-run Treasury yield (Bloomberg)	-0.78***	(-2.96)	-0.02	(-0.23)	Jun 1989
(5)	5y5y Treasury forward rate (GSW)	-0.73***	(-2.76)	-0.00	(-0.03)	Jun 1989
(6)	10y Treasury yield (GSW)	-0.80***	(-3.47)	-0.00	(-0.05)	Jun 1989
(7)	10y on-the-run Treasury yield (Bloomberg)	-0.76***	(-3.10)	-0.01	(-0.14)	Jun 1989
(8)	30y Treasury yield (GSW)	-0.46**	(-2.14)	-0.03	(-0.45)	Jun 1989
(9)	30y Treasury yield (Bloomberg)	-0.62***	(-2.91)	-0.02	(-0.27)	Jun 1989
(10)	10y Treasury yield (GSW)	-0.66**	(-2.21)	0.00	(0.02)	Jan 1999
(11)	10y TIPS yield (GSW)	-0.64**	(-2.43)	-0.02	(-0.35)	Jan 1999
(12)	10y on-the-run TIPS yield (Bloomberg)	-0.70***	(-2.66)	-0.00	(-0.05)	Feb 1997
(13)	10y Breakeven yield (GSW)	-0.02	(-0.12)	0.02	(0.47)	Jan 1999
(14)	10y Inflation swaps (Bloomberg)	0.16	(0.64)	-0.03	(-0.41)	Jul 2004
(15)	20y TIPS yield (GSW)	-0.60***	(-2.67)	-0.01	(-0.22)	Jan 1999
(16)	30y on-the-run TIPS yield (Bloomberg)	-0.55**	(-2.43)	-0.01	(-0.24)	Apr 1998

Note: The table shows the results from estimating regression (4). The regressions tests whether the average daily yield change in the 3-day FOMC window is different from the average daily yield change outside of the 3-day FOMC window. The dependent variable is the daily yield change (in bps). The unit of observation is a day. t-statistics based on Bell-McCaffrey standard errors are shown in parentheses. Significance levels: *(p<0.10), **(p<0.05), ***(p<0.01).

The Internet Appendix provides further results. First, I show that the results are not explained by other news releases that fell into the 3-day window around FOMC meetings, such as macroannouncements and corporate earnings news. Second, I split up the decline that took place around scheduled versus unscheduled meetings for both the 5-year yield and the 5-year/5-year forward rate. I find that unscheduled meetings are somewhat important for the decline in the 5-year yield consistent with the fact that the Fed cut rates more aggressively in bad times than the market expected (Cieslak, 2018; Schmeling et al., 2020). Unscheduled meetings, however, do not matter for longer-term forward rates such as the 5-year/5-year forward rates. Lastly, I conduct another placebo test by shifting the FOMC meetings in "FOMC cycle time" as in Cieslak et al. (2019). I do not find evidence of a cycle pattern.

Daily decomposition and state-dependence. The main analysis uses a 3-day window around FOMC meetings, i.e., it includes the day $t-1$, the day t (the meeting day), and day $t+1$. Tables 2 shows the cumulative yield change that occurred on these days separately. It shows that the day prior to the FOMC meeting contributed to the average yield decline in the 3-day window. The cumulative yield decline per decade on this day is between 70 and 99 bps. This also holds when we look directly at yield changes of the on-the-run securities. The contribution of the meeting day itself is a total yield decline of 296 bps between 1980 and 2000. Its importance for the unconditional yield decline over the past two decades depends on the yield measure used. The total decline using the off-the-run interpolated yield curve is 78 bps, while it is 139 bps using on-the-run securities. The intraday evidence (documented later in the paper) shows that this likely reflects the fact that the interpolated data uses quotes as of 3 p.m., while the on-the-run data uses quotes as of 6 p.m. In more recent times with expanded Fed communication, such as the press conference, it might take time for yields to incorporate information (Gómez-Cram and Grotteria, 2022). Accordingly, the day after plays a larger role when we use interpolated yield curve data, while it is less important when we use on-the-run data.

Table 2: Daily Decomposition of the 3-day FOMC window

	FOMC window			Other Days	All Days
	t-1	t	t+1		
10y Treasury yield (GSW)					
1980-1990	-0.80%	-1.94%	0.95%	-0.27%	-2.19%
1990-2000	-0.70%	-1.02%	-0.72%	1.15%	-1.21%
2000-2010	-0.90%	-0.13%	-0.53%	-0.95%	-2.52%
2010-2021	-0.99%	-0.65%	-0.58%	-0.44%	-2.65%
10y on-the-run Treasury yield (Bloomberg)					
1980-1990	-2.00%	-1.52%	1.07%	0.03%	-2.57%
1990-2000	-0.67%	-1.46%	-0.27%	0.80%	-1.49%
2000-2010	-0.98%	-0.42%	0.25%	-1.45%	-2.61%
2010-2021	-0.82%	-0.97%	-0.41%	-0.16%	-2.36%

Note: The table splits the 3-day FOMC window into days prior to FOMC meetings ($t-1$), FOMC meeting days (t), and days after FOMC meetings ($t+1$). It shows the cumulative yield change on each of these days.

Finally, I test whether the pattern is state-dependent. Putting it differently, I test whether the movement in the 10-year yield can be predicted or explained by various variables. To test this, I run the following regression

$$\Delta_{t_i-2,t_i+1}y_{10y} = \beta_0 + \beta_1 X_{t_i-2} + \epsilon_i, \tag{5}$$

where $\Delta_{t_i-2,t_i+1}y_{10y}$ measures the 3-day change in the 10-year U.S. Treasury yield around FOMC meeting i and X_{t_i-2} is a predictor variable measured two days ahead of the FOMC meeting, i.e., as of day t_i-2. I start using various financial variables as predictors. First, I consider the first two principal components of the yield curve extracted using the 1-year, 2-year, 5-year, 10-year and 30-year Treasury yields. Next, I include a dummy variable that indicates whether the VIX is above its mean and a dummy variable that indicates whether the past month's equity return was negative. Third, I consider the quarterly change in the S&P 500 index, in commodity price indices, and in the slope of the yield curve following Bauer and Swanson (2022). Fourth, I consider macro variables that capture economic activity such as Chicago Fed National Activity Index and the Brave-Butters-Kelley Index (Brave et al., 2019). I use the values from the month prior to the FOMC meeting in the regression. I also include the surprise in the latest nonfarm payroll announcement occurring prior to the 3-day FOMC window. The surprise is defined as the actual value minus economists' forecasts.[10] Next, I include an indicator of whether the Fed meeting took place during a recession. Finally, I include a post-1994 dummy (the year when the Fed started to release statements) and dummies for different Fed chairs. Table 3 find no evidence that the pattern depends on financial or economic conditions. None of the variable is statistically significant at the 10% level and the R-squared for any set of explanatory variables is below 1.1%. The post-1994 dummy indicates that the yield change around FOMC meeting is lower since 1994 (albeit the difference is not statistically significant). The pattern also does not depend on who is the Fed chair.

[10]The economists' forecasts are obtained from Bloomberg and are available from 1997 onwards. I use the actual values in the prior period. Both periods are standardized separately.

Table 3: State-Dependence of 10-year Yield Changes around FOMC Meetings

	10y yield change in 3-day FOMC window								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Constant	−2.42***	−2.38***	−1.83**	−2.55*	−2.67***	−2.26***	−2.43***	−3.89***	−2.48***
	(0.71)	(0.72)	(0.80)	(1.33)	(0.82)	(0.77)	(0.68)	(1.37)	(0.89)
Level - Yield Curve (PC1)		−0.21							
		(0.32)							
Slope - Yield Curve (PC2)		−0.43							
		(1.31)							
Dummy(High VIX)			−1.19						
			(1.43)						
Dummy(Negative 1-month S&P500 return)				0.22					
				(1.56)					
Δ log S&P500					14.73				
					(15.51)				
Δ log Bloomberg Commodity Index					1.30				
					(1.70)				
Δ log Yield Curve Slope (10y–3m)					0.31				
					(18.45)				
Chicago Fed National Activity Index						0.06			
						(1.50)			
Brave-Butters-Kelley Leading Index						0.64			
						(0.92)			
Nonfarm Payroll Surprise						−0.73			
						(0.88)			
Dummy(NBER Recession)							0.07		
							(3.38)		
Dummy(Year >= 1994)								1.82	
								(1.60)	
Dummy(Chairman = Bernanke)									−0.31
									(2.23)
Dummy(Chairman = Yellen)									2.48
									(1.58)
Dummy(Chairman = Powell)									−1.53
									(1.68)
R^2	0.000	0.002	0.002	0.000	0.011	0.008	0.000	0.004	0.007
N	283	283	283	283	283	283	283	283	283

Note: The table reports the results from regression (5), i.e., it regress the 3-day change in the 10-year yield around an FOMC meeting (measured in bps) on various predictor variables measured prior to the FOMC meeting. A unit of observation is an FOMC meeting. The sample contains all FOMC meetings between June 1989 and June 2021. The construction of the variables is described in the text. Bell-McCaffrey standard errors are shown in parentheses. Significance levels: *(p<0.10), **(p<0.05), ***(p<0.01).

4 Potential Explanations

The documented pattern is surprising from two angles. First, it is surprising that the secular decline in interest rates has shown up around FOMC meetings. Many theories stipulate that the forces behind the secular decline are unrelated to monetary policy. Second, it is surprising that long-term interest show such large and systematic movements around FOMC meetings.

From a theoretical point of view, we would have not expected these large movements, as the Fed only controls the nominal short rate (the overnight federal funds rate). Changes in the nominal rate transmit to real rates only because prices and inflation are supposedly sticky in the very short run. Thus, the impact on the real rate should be rather short-lived. In addition, the real economic effects of monetary policy do not seem to be long-lasting (Ramey, 2016). Thus, it is surprising that the prices of long-term bonds, in particular of long-term real bonds, exhibit such large movements around FOMC meetings. Viewed from this perspective, the main fact documented in this paper echoes the findings of prior studies document that long-lived assets react surprisingly sensitive to monetary policy (Bernanke and Kuttner, 2005; Hanson and Stein, 2015).

In light of theories on the secular decline, it is also surprising that the secular decline in interest rates has shown up around Fed meetings. The secular decline in interest rates started in the 1980s when inflation was at double-digit figures. The subsequent decline in the 1980s was most likely driven by a decrease in long-term inflation expectations (Cieslak and Povala, 2015, e.g.). Economists have seen the subsequent fall in interest rates over the next three decades mostly as a real phenomenon. For example, estimates of the natural rate – the real rate at which monetary policy is neither expansionary nor contractionary – have declined substantially (Laubach and Williams, 2003; Bauer and Rudebusch, 2020). While there is significant uncertainty about the level of the natural rate, declines in market-measures of real interest rates – available since the introduction of TIPS and inflation swaps – have painted a similar picture.

What are the main drivers for this decline, and why is the Fed not seen as the main "culprit" for low (real) interest rates? According to the mainstream view, other economic forces have driven down the natural rate over time, and the Fed has been required to re-adjust monetary policy by following this trend. Otherwise the Fed would have kept interest rates above the natural rate for a long time potentially leading to a deflationary spiral. In the words of Larry Summers, the Fed is a "follower rather than a leader with respect to real interest rates".[11] Why do we think that the natural rate has declined? Several explanations have been proposed, such as a slowdown in productivity (Gordon, 2017), a lack of capital investment opportunities or so-called "secular stagnation" (Summers, 2014), a rise in the savings of emerging economies (Bernanke, 2005), a fall in the price of capital due to technological change (Eichengreen, 2015), changes in demographics (Gagnon et al., 2016; Carvalho et al., 2016), an increase in the liquidity and safety premium of Treasuries (Del Negro et al., 2017) or a decrease in sovereign default risk (Miller et al., 2021). What is common among these forces is that they are slow-moving and they supposedly lie outside the Fed's control. Thus, from a theoretical perspective, it is puzzling that a narrow window around the the monetary policy meetings of the Fed accounts for the secular decline. The rest of the paper examines reasons for why this might have occurred.

[11] Larry Summers made these remarks in response to Ben Bernanke's article on "why are interest rates so low?": "*I agree with much of what Ben [Bernanke] writes and would highlight in particular his recognition that the Fed is in a sense a follower rather than a leader with respect to real interest rates – since they are determined by broad factors bearing on the supply and demand for capital – and his recognition that equilibrium real rates appear to have been trending downward for quite some time.*". See http://larrysummers.com/2015/04/01/on-secular-stagnation-a-response-to-bernanke/ and https://www.brookings.edu/blog/ben-bernanke/2015/03/30/why-are-interest-rates-so-low/.

4.1 Risk-based Explanations

Institutional frictions. Bond yields might have declined around FOMC meetings because of a compression of risk premia (or "term premia") around FOMC meetings. One such mechanism could be "reaching for yield" whereby yield-oriented investors purchase longer maturity bonds whenever short rates decline (Hanson and Stein, 2015, e.g.). Because of the upward-sloping nature of the yield curve, these longer maturity bonds typically provide a higher yield to yield-seeking investors. Another view is that monetary policy affects the liquidity premium of various assets (Drechsler et al., 2018; Lagos and Zhang, 2020; Jeenas and Lagos, 2022). Other channels, such as a redistribution of wealth from risk-averse to risk-tolerant investors (Kekre and Lenel, 2021) or a change in investors' risk aversion (Pflueger and Rinaldi, 2022) (which is not based on institutional frictions), might also explain why term premia respond to the short rate. While these explanations can account for the high sensitivity of long-term rates to the Fed's short rate decision, they, on their own, cannot explain the unconditional yield decline around FOMC meetings. In other words, we need a separate explanation for why the Fed has persistently surprised the market with rate cuts. But if some of the rate cuts were seen as permanent by investors, then reaching for yield could have contributed to the decline in long-term yields around FOMC meetings. The evidence for this explanation is mixed. On the one hand, term premium estimates from affine term structure models (Adrian et al., 2013; Kim and Wright, 2005) declined by between 100 and 200 bps around FOMC meetings (see the Internet Appendix). These results, however, might overstate the importance of term premia as the models do not explicitly account for the secular decline (Bauer and Rudebusch, 2020). On the other hand, reaching for yield predicts that the FOMC yield decline is stronger when the slope of term structure is steeper as this increases the incentive to reach for yield. Contrary to this, Table 3 finds no evidence that the yield decline is larger when the slope of the yield curve is higher.

Risk premium due to announcement exposure. Investors might require risk compensation for being exposed to news (Savor and Wilson, 2013; Ai and Bansal, 2018). It therefore seems possible that bond investors require compensation for being exposed to the information coming out of the Fed. This might explain why Treasury returns around FOMC meetings were positive – or equivalently why Treasury yields fell on these days. While this is possible, several observations speak against this explanation. First, as Figure 1, shows the FOMC window captures the low-frequency movements of the Treasury yield exceptionally well. That is, also when yields tended to drift sideways or upwards for a sustained period, the FOMC window captures this trend. Unless the risk premium associated with the announcement exposure coincidently flipped sign at the time, it cannot explain such an upward drift. Second, this explanation predicts that the yield decline is larger when there is more uncertainty in financial markets. However, Table 3 finds that the VIX does not predict movements around FOMC meetings. Third, the explanation does not explain why Treasury returns were high on days prior to FOMC meetings unless the uncertainty is already resolved prior to the FOMC meeting. Only if parts of the uncertainty were resolved prior to the FOMC meetings (Laarits, 2019; Hu et al., 2022), then this could explain why bond returns – and also equity returns (Lucca and Moench, 2015) – were high prior to FOMC meetings.

Fed put. When Greenspan became the Fed chair, the idea that the Fed could protect the economy from downturns with rate cuts became more prominent. Because these insurance rate cuts would eliminate or limit the downside risk of investors, this mechanism is often referred as the "Fed put". Cieslak et al. (2019) document that the Fed react to negative financial news in order to protect the economy. Following up on this idea, Cieslak and Vissing-Jorgensen (2021) provide evidence that these news leaking out in the even weeks FOMC meetings led to a reduction in the equity risk premium. This explanation is unlikely to be an important factor for the observed pattern. First, the stock market beta of Treasuries was negative for most of the sample period (Campbell et al., 2017, 2020). Thus, a reduction in the equity risk premia would imply that Treasury yields should have risen – instead of fallen – around FOMC meetings. Second, the Fed put explanation predicts that the Treasury yield decline around FOMC meetings is stronger when past equity returns were negative or when the economy entered a recession. Table 3 finds no such evidence.

4.2 Information-based Explanations

Rate extrapolation. There is growing evidence that investors extrapolate fundamental news.[12] Accordingly, investors might extrapolate the current short rate when forming expectations about distant short rates (Hanson et al., 2021). Several reasons are possible. Investors might hold diagnostic expectations and therefore overweight recent observations (Bordalo et al., 2019). Alternatively, they could just perceive monetary policy regimes as very persistent (Bianchi et al., 2021). This could explain why long-term rates respond to the Fed's short rate decision. However, this mechanism, on its own, cannot explain the documented pattern, as it only predicts random up-and-down movements in long-term (as well as short-term) yields that cancel out over time. Thus, one also needs an explanation of why the Fed has permanently surprised the market with rate cuts going into the FOMC meetings, and why the movement of short-term and long-term yields around FOMC meetings exactly adds up to the entire secular decline. The explanation also does not account for the decline in long-term rates due to the Fed's dot plot communication when short rates were stuck at the ZLB.

Learning about the business cycle or the Fed's business cycle response. Nakamura and Steinsson (2018) and Campbell et al. (2012) provide evidence that professional forecasters learn from the Fed about the near-state of the economy. Bauer and Swanson (2022) alternatively explain these findings with investors learning about the Fed's response to business cycle news (see also Bauer et al., 2022). In addition, Cieslak (2018) provides evidence that the Fed cut short rates more than the market expected during recessions. This might partially explain why short rates declined around FOMC meetings. However, in general, such news mostly impact the near-term rate outlook, and therefore should have a small effect on long-term yields and forward rates, such as the 10-year yield or the 5-year/5-year forward rate. Thus, one needs an additional explanation for why long-term bonds respond so much to these business cycle news. Consistent with this, Table 3 finds that the variables which predict the Fed's response to the business cycle (Bauer and Swanson, 2022) have no predictive power for the movement in long-term

[12]For example, there is a recent literature examining the effect of extrapolative cash flow forecasts and return forecasts on aggregate stock prices (De La O and Myers, 2021; Bordalo et al., 2022; McCarthy and Hillenbrand, 2022).

yields.[13] To conclude, while this explanation might be important for the movements in short-term rates, it is unlikely to be important for the movements in long-term rates.

Long-run Fed Guidance. One possibility for the observed pattern is that the Fed provides guidance to the market about the long-run level of interest rates at FOMC meetings – I refer to this idea as "Long-run Fed Guidance". Over the past decades, this would have meant that the market learned, at least to some degree, about the secular decline from the Fed. To gain more intuition for how this could work, we have to focus on two key drivers of long-term bonds yields: the long-run level of inflation and the natural rate. Thus, Long-run Fed Guidance can come in different forms.

First, the Fed might provide information about long-run inflation to the market. The Fed's information advantage might simply come from the fact that the Fed sets the inflation target. Thus, if inflation equals the inflation target over the long run, then information about the Fed's target is valuable to the market. Along these lines, the shift in the Fed's aversion against inflation might explain why nominal rates declined around FOMC meetings in the 1980s (Clarida et al., 1999).

Second, the market might also learn from the Fed about the level of the natural rate. Why might the Fed have an information advantage about the natural rate over many investors? The natural rate is a crucial input into monetary policy decision as it is the rate at which monetary policy is neutral. To get a sense of where the natural rate currently is, the Fed always monitors the effects of monetary policy on the economy. If monetary policy has contractionary effects on the economy, then the Fed can conclude that the natural rate is likely below current rates. And vice versa, if monetary policy has expansionary effects, then the natural rate is likely above current rates. Thus, the Fed obtains – by closely monetoring the effects of monetary policy – an implicit estimate for the level of the natural rate (in addition, it can obtain an explicit estimate by using models for the natural rate). Because it is the Fed's main task to do this, this potentially gives the Fed an information advantage over most market participants.

Why are sophisticated investors who might have the same capabilities as the Fed not pricing-in this long-run information themselves? One possibility is that the returns are not attractive enough for these investors. The secular decline was a very protacted phenomenon that has played out over several decades. Thus, the returns from the decline were realized over a long period of time making the risk-return tradeoff not overly attractive. For example, an investment strategy that went long the 10-year U.S. Treasury Note over the 3-day FOMC window and invested into the risk-free asset otherwise yielded a Sharpe ratio of around 0.48. While this is slightly higher than what an investment in the S&P 500 index would have achieved, it might not be enough for many sophisticated fixed income traders who aim for higher Sharpe ratios (Duarte et al., 2007; Brooks and Moskowitz, 2017). In addition, this trade involves significant risks. There is no model that yields perfect estimates for the natural interest rate. And even if an investor had the perfect model, other investors might not have access to the same model and the price might therefore not reflect the "correct" level for a sustained period of time. Moreover, there could

[13] Note that this is different from the regression results for short-term rates. The variables which predict the Fed's response to the business cycle have some (weak) predictive power for the movement of short-term yields around FOMC meetings (as we would expect from the results of Bauer and Swanson (2022)). This makes sense as the movement of short-term yields around FOMC meetings exhibits a more cylical pattern that overlays the secular decline. That is, short-term yields declined around monetary policy meetings during recession and increased during good times. This is consistent with the results in Cieslak (2018); Schmeling et al. (2020). For more information on the behavior of short-term rates see the Internet Appendix.

be timing uncertainty about when other investors will correct the mispricing (Abreu and Brunnermeier, 2002).

Market coordination or attention. To minimize these risks, informed investors might therefore find it optimal to trade on their private information prior to FOMC meetings. In particular, if the Fed provides important information for long-term bonds and yields therefore become more informative at the meetings, then informed investors might want to enter their trades prior to FOMC meetings. An alternative view might be that investors pay most attention to the long-run level of interest rates around FOMC meetings. One potential reason could be that investors having significant information processing costs and therefore focusing their attention on other sources of information on days outside of the FOMC window such as news about earnings or the near-term economy outlook. While a more extensive analysis of the market coordination hypothesis is beyond the scope of the paper, there is evidence that points in this direction. First, this might explain why yields already started to drift lower on days prior to FOMC meetings. Second, crowding-in of informed investors might also explain why intraday volatility is typically low before FOMC meetings (see the Internet Appendix, but also Lucca and Moench (2015)). Consistent with this explanation, Abdi and Wu (2023) find evidence for informed trading on days prior to FOMC meetings.

4.3 Monetary Policy-based Explanations

Monetary policy and the long-run real rate. An interpretation that is observationally equivalent to Long-run Fed Guidance is that the Fed has a causal impact on the long-run real rate or, alternatively, the Fed has substantial flexibility in setting real interest rates over longer periods. While this is not the mainstream (or "neo-Wicksellian") view, recent studies have entertained this possibility. Rungcharoenkitkul and Winkler (2021) argue that the Fed's natural rate estimate becomes self-fulfilling as the Fed faces a "hall of mirrors" problem. McKay and Wieland (2021) argue that expansionary monetary policy lowers the future path of the long-run real rate by bringing forward the purchase of durable goods. Consistent with this explanation, Bianchi et al. (2021) document that a large amount of the downward trend in the real short rate is due to a shift in Fed policy. This naturally links back to Long-run Fed Guidance. If the Fed has more control over real rates, then this automatically gives rise to the Fed having private information.

5 Long-run Fed Guidance

Long-run Fed Guidance is the idea that the Fed can provide guidance to the market about the long-run level of interest rates. This guidance can be implicit when the Fed sets the target for the federal funds rate or explicit form when the Fed releases its forecast for the long-run level of the federal funds rate. If the Fed's long-run guidance contains valuable (new) information to the market, then the market will subsequently revise its own long-run rate expectation. Thus, Long-run Fed Guidance could explain why long-term yields respond to FOMC meetings and in particular, why the secular decline in short-term as well as long-term rates has shown up around FOMC meetings.

This section provides evidence that supports the notion of Long-run Fed Guidance. First, using intraday bond pricing data, I show that a substantial part of the yield decline since 1994 happens immediately after the Fed announcements. Second, I directly test for Long-run Fed Guidance using the recently-introduced dot plot. As predicted by Long-run Fed Guidance, I find that long-term (real) bond yields respond strongly to the Fed's forecast for the long-run level of (real) interest rates. Third, I show that almost the entire decline in yields prior to the GFC, when the Fed did not yet release its dot plot, is concentrated at meetings where the Fed changed the Fed funds rate. I conclude the section by providing a formal model of Long-run Fed Guidance.

5.1 Intraday Evidence

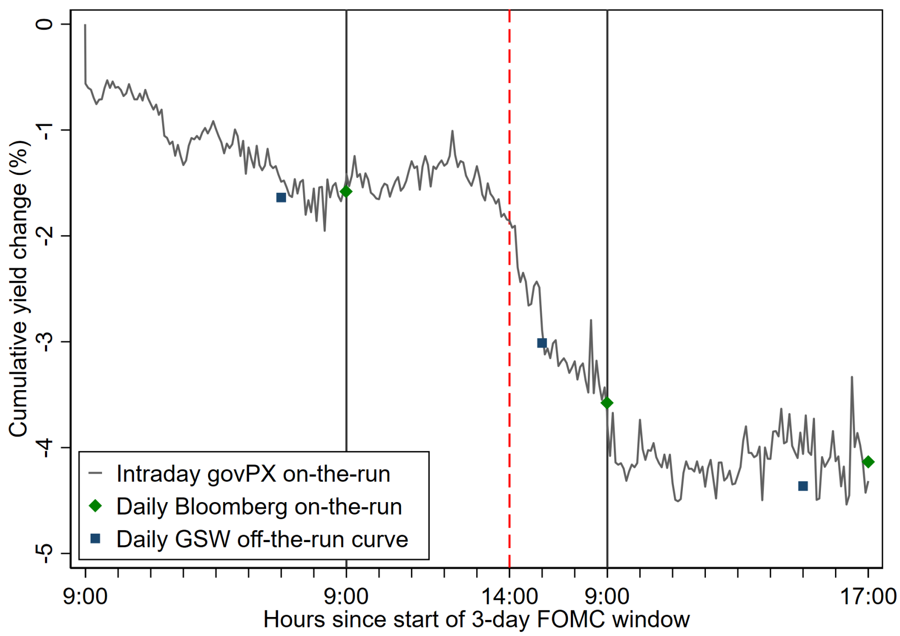
For a subset of meetings, it is possible to determine the time at which the Fed communicated the meeting outcomes to the public. For these meetings, I want to understand when exactly the decline in interest rates happened during the 3-day window. I use intraday data on the on-the-run 10-year U.S. Treasury Notes obtained from GovPX. This data is available from 1991 onwards, but I focus my analysis on the period starting in January 1994 (and ending in March 2020), because the exact time of the information release on the meeting day can be identified. I obtain the exact release times of the monetary policy announcements from Gorodnichenko and Weber (2016) and the website of the Federal Reserve. In total, this period contains 216 FOMC meetings at which the Fed announcement was mostly at or slightly after 2:00 p.m.[14] The total yield decline for this subset of meetings by slightly more than 4%.

The U.S. Treasury market is an over-the-counter market that operates around the clock. I restrict the analysis to the time interval from 9 a.m. (Eastern Time) to 5 p.m. to focus on times when liquidity is high. Whenever I refer to the "closing" or the "opening" price in the following, this is with regard to this time interval. Starting with the closing yield at 5 p.m. two days prior to the meeting day, I compute the cumulative yield change that occurred within the next three trading days for every 5-minute interval. I then sum this cumulative change across all meetings. To ensure that the analysis based on intraday data aligns with daily yield data, I also compute the cumulative yield change based on daily data for the same subset of meetings taking into account that different data sources use closing prices as of different times. To summarize, I find that the intraday data aligns well with the daily data.

Figure 7 shows that there is a cumulative yield decrease from the close of the day two days prior to the FOMC meeting to the open of the next day. Then, yields gradually decline until the FOMC meeting which is somewhat similar to the "pre-drift" in the equity market (Lucca and Moench, 2015). Leading up until the FOMC meeting, the cumulative decline across all meetings is 1.91%. This is followed by a sharp drop in yields when the meeting information is released after 2 p.m. One hour later, yields have decreased to 3.15%, and they further decrease until 5 p.m. when the cumulative decline is 3.78%. This likely reflects the fact that it takes time for the market digest the news, as, for example, various experts speak on financial media. This is also consistent with intraday volatility in the 10-year U.S. Treasury Note remaining elevated for a long time after the meeting announcement (see the Internet Appendix). Relatedly, Gómez-Cram and Grotteria (2022) also document a strong positive correlation between the price movements directly following the announcements and the price movements during the Fed chair's

[14] I drop 2 meetings that had an announcement in the morning to have a common announcement time across all meetings. These meetings were on February 4, 1994, and March 26, 1996. During 8 meetings in 2011 and 2012, the FOMC statement and the Statement of Economic Projections were already released at 12:30 p.m. despite the press conferences being conducted at 2:15 p.m. Moreover, the information release for the meeting on August 16, 1994 was at 1:18 p.m. I keep these meetings in my sample. The rest of these scheduled meetings had an announcement at or after 2 p.m.

Figure 7: Intraday Yield Movements for Subset of Meetings



Note: The figure shows the cumulative yield movement of the on-the-run 10-year U.S. Treasury Note in the 3-day window around FOMC meetings from 9 a.m. to 5 p.m. for 5-minute intervals. The data is from GovPX, and the sample includes all scheduled meetings between January 1994 and March 2020 where the announcement was either at 12.30 p.m. or at 2 p.m. The meetings on February 4, 1994 and March 26, 1996 are excluded because the announcement happened earlier. The red dashed line is set at 2 p.m. on the meeting day, at or shortly before the meeting information is released to the public. The green and blue dots provide the cumulative yield change based on daily data for the on-the-run 10-year Note from Bloomberg (green dots, closing price at 6 p.m.), and the 10-year yield based on yield curve interpolation from Gürkaynak et al. (2007) (blue dots, closing price at 3 p.m.).

press conferences for several assets. On the day following each FOMC meetings, yields drop slightly in the beginning of the day and then stay roughly flat until the end of the day.

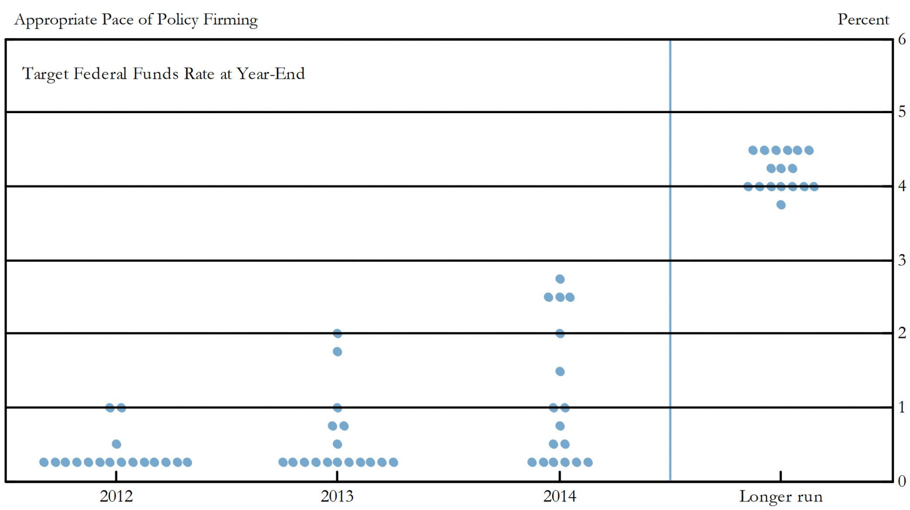
Thus, the intraday evidence is consistent with a substantial part of the decline being due to Long-run Fed Guidance. That is, the information coming out of the Fed leads to downward revisions of the market's expectation about the future path of short rates. The drift of yields prior to FOMC meetings might reflect trading by informed market participants in the run-up to meetings, consistent with the evidence provided in Abdi and Wu (2023).

5.2 A Direct Test for Long-run Fed Guidance using the Dot Plot

In the following, I directly test for Long-run Fed Guidance. The theory of Long-run Fed Guidance predicts that the market pays strong attention to the Fed's guidance about the future (long-run) path of interest rates. Fortunately, this can be tested in the data. Since January 25, 2012, the Fed has released its forecast for the long-run level of the federal funds rate in the so-called "dot plot". Thus, I test how bond yields – which reflect the market's (risk-adjusted) expectations about future interest rates – respond to the release of the Fed's forecasts. In support of Long-run Fed Guidance, I find a very strong response in long-term bond yields. Maybe even more importantly, the results imply that the dot plot releases have lowered bond yields by around 130 bps over the past decade. It is worth re-emphasizing that this likely only reflects the Fed's information release and not its causal impact on yields.

What exactly is the dot plot? The dot plot is contained in the Statement of Economic Projection (SEP) on a quarterly basis – essentially at every other meeting – and is released simultaneously with the FOMC statement; see Figure 8 for the dot plot released at the meeting on January 25, 2012. The dot plot contains the (voting and non-voting) FOMC members' forecasts for the federal funds rate over the next three years as well as their forecasts for the federal funds rate over the "longer run". In the words of the Fed, these longer-run projections "represent each participant's assessment of the value to which each variable would be expected to converge, over time, under appropriate monetary policy and in the absence of further shocks to the economy". Fed officials also report (with a delay) the horizon over which the convergence is expected to occur. The reported horizon varies between 2.5 and 10 years with the median response being approximately 5-6 years (see the Internet Appendix for more details). Thus, the longer-run projections corresponds to the Fed's assessment of the natural rate plus long-run inflation.

Figure 8: Example: The Dot Plot from January 25, 2012



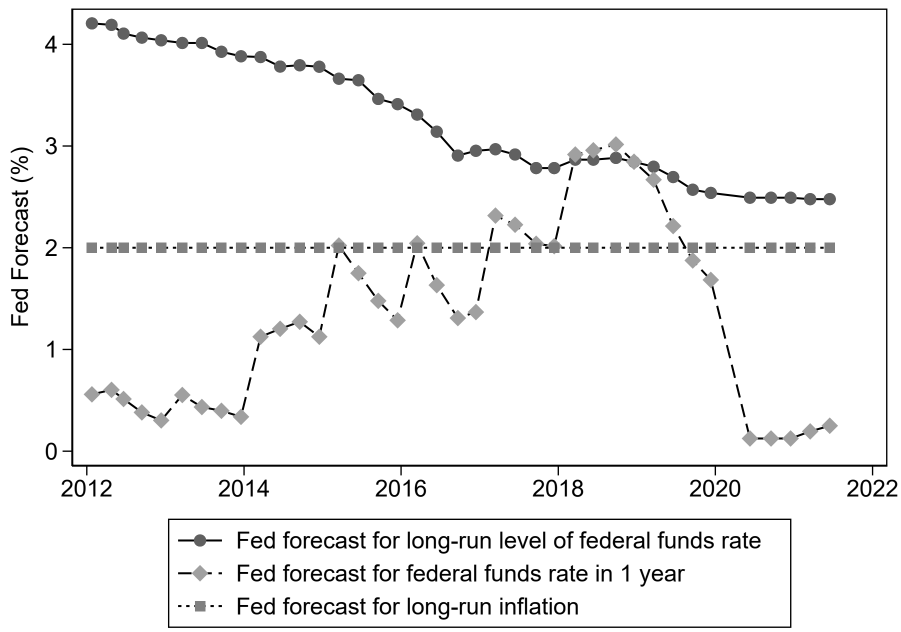
Note: The figure shows the dot plot released in the Statement of Economic Projections at the FOMC meeting on January 25, 2012. Each dot represents the forecast of a single (voting or non-voting) FOMC member for the level of the federal funds rate at the end of the next three years as well as a longer-run forecast for the federal funds rate.

The time-series of these projections is shown in Figure 9. Three things are noteworthy. First, the long-run projections for the federal funds rate (dark gray dots) decline smoothly over the sample period. The projections do not show any cyclical behavior, which is in stark contrast to the Fed's forecast for the federal funds rate in one year (light gray diamonds). For example, the long-run forecasts do not drop during the Covid-19 outbreak. This underpins the long-run nature of these forecasts. Second, the figure shows that the Fed's forecasts for long-run inflation (medium gray squares) have been stable at 2%. This means the forecasts align with the Fed's stated inflation target of 2%.[15] Thus, the decline in the Fed's forecast for the long-run nominal rate is entirely driven by the Fed's view about the long-run real rate.

[15]The Fed might not truthfully reveal its expectation for the long-run level of inflation in order to the public's influence inflation expectations. However, this is unlikely to be an important consideration during my sample period as economists' long-term inflation expectations (as, for example, reported in the Livingston survey) were also stable up until June 2021.

This is also exactly how FOMC members discuss these long-run forecasts. For example, one respondent stated in the SEP released on December 17, 2014 : "I have lowered my long-run value of the federal funds by 25 bps based on my view that the long-run real rate of interest is somewhat lower". The Internet Appendix contains additional quotes from FOMC members, including their views on which factors have driven down the long-run rate. When asked about why they lowered their forecasts, Fed officials mention lower potential GDP growth, higher global global savings and lower model estimates for equilibrium rates consistent with the mainstream view of why real interest rates have declined. Third, the total decline in the long-run projections between January 2012 and June 2021 was 183 bps.

Figure 9: The Time Series of the Dot Plot Forecasts



Note: The figure shows the Fed's forecasts for (i) the long-run level of the federal funds rate, (ii) the level of the federal funds rate at the end of the next year and (iii) the long-run level of inflation (PCE inflation). The Fed forecast is the mean of the individual FOMC members' forecasts.

In the following, I examine how market interest rates react to the release of the long-run dots, i.e., how the disclosure of the Fed's expectation about the long-run level of the federal funds rate impacts market interest rates. I focus on real yields since the Fed has revised down its forecasts because of real economic forces. Accordingly, I regress the change in the 10-year U.S. TIPS yield on the day of the information release on the change in the Fed's expectation from the past meeting to the current meeting. Let t_i be the date of meeting i, then the regression specification is

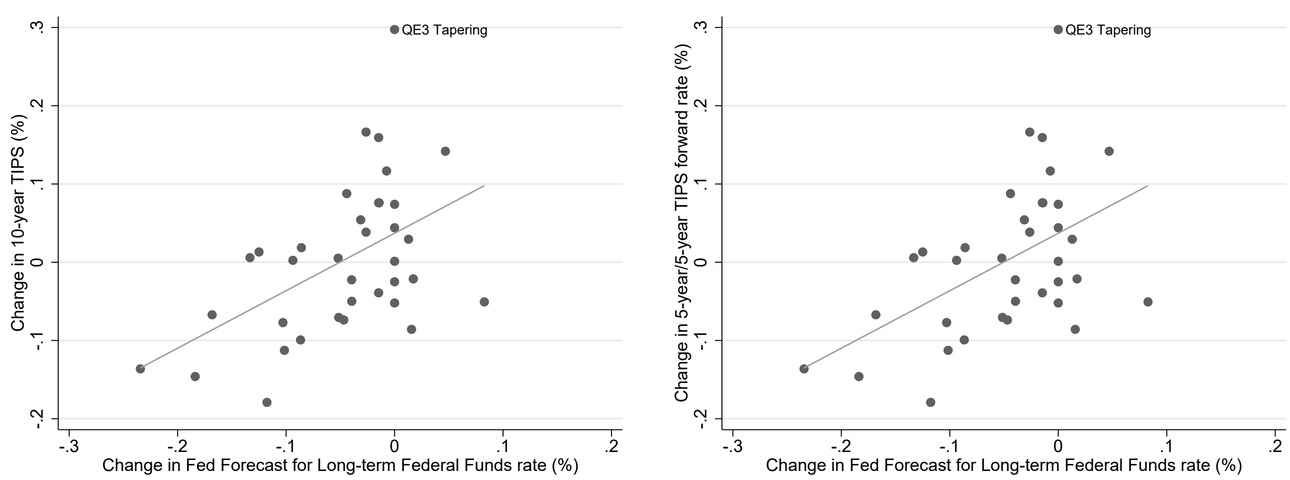
$$\Delta_{t_i-1,t_i+1} y_{TIPS,10y} = \beta_0 + \beta_1 \, \Delta_{i-1,i} \mathbb{E}^F \left[\text{Long-run fed funds rate}\right] + \epsilon_i, \tag{6}$$

where $\Delta_{i-1,i}\mathbb{E}^F$ [Long-term fed funds rate] is the change in the Fed's forecast for the long-term federal funds rate from meeting $i-1$ to meeting i and $\Delta_{t_i-1,t_i+1} y_{TIPS,10y}$ is the change in the 10-year U.S. TIPS yield on the day of meeting i (and the next day). I use the 2-day change in the yield, i.e. the change from $t_i - 1$ to $t_i + 1$, as the closing yields of Gürkaynak et al. (2007) are based on quotes at 3 p.m. (Eastern Time). The unit of observation in the regression is an FOMC meeting during which the dot plot is released. For example, when the unit of observation is the meeting day on June 16, 2021, then the dependent variable would be the change in the 10-year TIPS yield from the close on June 15, 2021 to the close on June 17, 2021, while the explanatory variable would be the change in the FOMC forecast from March 17, 2021 (the last prior FOMC meeting with a dot plot release) to June 16, 2021.

For this regression to have a causal interpretation, the following assumptions have to hold. First, for there to be no reverse causality, the dot plot must not be influenced by the yield movements on the meeting day. In other words, the dot plot must reflect the FOMC members' forecasts as of the day prior to the meeting. This seems plausible, as it takes time to prepare the SEP. Second, there cannot be an omitted variable that is correlated with the Fed's forecast and the market's reaction. This might be the case if the bond market mainly reacts to other information released during the meeting. However, this seems less likely, as the dot plot contains the information that is most relevant for long-term bonds. Nevertheless, I include various controls in the empirical specification; (i) the meeting-to-meeting change in the Fed's forecast for the federal funds rate level at the end of next year, (ii) the quarterly change in the log of the S&P 500 index, in the log of the Bloomberg Commodity index, and in the slope of the yield curve and (iii) the Chicago Fed National Activity Index, the Brave-Butters-Kelley Index (for both I use the prior month's value) and the most recent nonfarm payroll surprise. These variables rule out that business cycle news revealed between meetings are an omitted variable (Bauer and Swanson, 2022; Karnaukh and Vokata, 2022), if, for example, the Fed reacted stronger to negative news than the market expected (Cieslak, 2018; Schmeling et al., 2020).

Figure 10: The Reaction of Bond Yields to the Long-run Dot Plot

(A) 10y TIPS yield (B) 5y5y TIPS forward rate



Note: The figure shows a scatterplot of the 2-day change in the 10-year U.S. TIPS yield (Panel (A)) and in the 5-year/5-year TIPS forward rate at the FOMC meeting and the meeting-to-meeting change in the FOMC meeting participants' forecast for the long-term level of the federal funds rate – taken from the dot plot. The unit of observation is an FOMC meeting during which the dot plot is released. The 10-year U.S. Treasury yield is from Gürkaynak et al. (2007).

The empirical results strongly support Long-run Fed Guidance. Figure 10 shows a strong positive relationship between the change in long-term real yields at FOMC meetings and the change in the Fed's forecast for the long-term level of the federal funds rate relative to the prior meeting. This holds for the 10-year U.S. TIPS yield (Panel A), as well as for the 5-year/5-year U.S. TIPS forward rate (Panel B). The relationship is not driven by outliers.

Table 4: The Reaction of Bond Yields to the Long-run Dot Plot

	Δ10y real yield				Δ5y5y real forward rate			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\Delta\mathbb{E}^F$[Long-run fed funds rate]	0.77***	0.59**	0.82**	0.71**	0.73***	0.50*	0.78***	0.71***
	(0.26)	(0.26)	(0.31)	(0.29)	(0.22)	(0.29)	(0.27)	(0.24)
$\Delta\mathbb{E}^F$[1-year fed funds rate]		0.09***				0.12		
		(0.02)				(0.09)		
Δ log S&P500			−0.52				−0.59	
			(0.41)				(0.55)	
Δ log Yield Curve Slope (10y–3m)			0.27				0.34	
			(0.36)				(0.36)	
Δ log Bloomberg Commodity Index			0.01				0.02	
			(0.06)				(0.05)	
Chicago Fed National Activity Index				0.01				0.02
				(0.06)				(0.06)
Brave-Butters-Kelley Leading Index				−0.01				−0.00
				(0.03)				(0.03)
Nonfarm Payroll Surprise				−0.01				−0.02
				(0.04)				(0.14)
R^2	0.20	0.26	0.24	0.25	0.21	0.34	0.28	0.35
N	37	37	37	37	37	37	37	37

Note: The table shows the results of regression (6). The unit of observation is an FOMC meeting during which the dot plot was released. The dependent variable is the 2-day change in the 10-year U.S. TIPS yield in columns (1)-(4) and in the 5-year/5-year TIPS forward rate in columns (5)-(8). The main explanatory variable is the meeting-to-meeting change in the FOMC participants' mean forecast for the long-run level of the federal funds rate. Control variables in columns (2) & (6) are the meeting-to-meeting change in the FOMC participants' mean forecast for the federal funds rate in one year. The rest of the control variables are the same as in Table 3 and are further described in the text. The yields are obtained from Gürkaynak et al. (2010). Davidson-MacKinnon standard errors are shown in parentheses. Significance levels: *(p<0.10), **(p<0.05), ***(p<0.01).

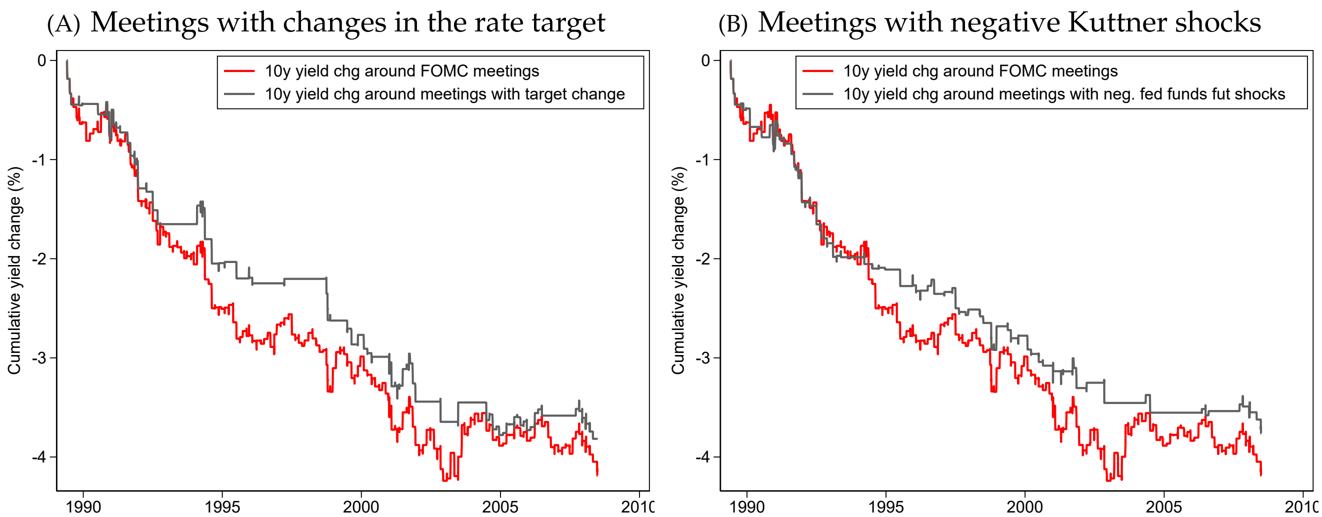
Table 4 shows the regression results. There is a statistically and economically strong relationship between the long-run dots and bond yields. A 100 bps decrease in the Fed's expectation for the long-run level of the federal funds rate leads to a 77 bps decrease in the 10-year U.S. TIPS yield on the FOMC meeting day and the day after (Column 1). The R^2 is also high, the dot plots for the long-term federal funds rate explain 21% of the 2-day movement in the 10-year TIPS yield. Including the control variables in columns (2), (3) and (4) changes the regression coefficient only slightly. Columns (5) to (8) use the 2-day change in the 5-year/5-year forward rate as the dependent variable. This forward rate reflects the market's (risk-adjusted) expectation of short rates further out in the future. Columns (5) to (8) document that the Fed's long-run forecast has a similar impact on the 5-year/5-year TIPS yield than on the 10-year TIPS yield.

The results suggest that the market updates its expectation about the future path of real short rates in response to observing the Fed's dot plot forecasts. They also imply that long-term rates declined by around 134 bps ($\approx 0.73 \times 183$ bps) in response to observing the dot plots over the sample period. This evidence is also consistent with the Fed's perceived effectiveness of the dot plot. For example, Stanley Fisher stated in a speech about "Monetary Policy Expectations and Surprises" in 2017 that "the SEP [which contains the dot plot] in particular has been useful in providing information on policymakers' assessment of the potential growth rate of the economy and r*, the equilibrium real interest rate, both of which help guide the market's expectations of the eventual path of policy" (Fischer, 2017).

5.3 Long-run Fed Guidance through the Federal Funds Rate Target

The conduct of monetary policy have changed substantially over the past decades. While the Fed was often deliberately opaque in the 1970s and 1980s – going as far as trying to hide the level of the federal funds rate – the Fed started to become more transparent over time. In the 1990s, the Fed put more emphasis on the market understanding the Fed's intended federal funds rate target, which was the main policy tool until the Fed hit the zero lower bound (ZLB) in 2008. As a result, the Fed started to release statements whenever there was a change in the policy rate in 1994. The length of these statement has increased over time, and the Fed has used this to provide the market with information about its view of the economy and the future outlook for interest rates. As a result of hitting the ZLB during the Global Financial Crisis (GFC), the Fed engaged in even more extensive communication with the market, such as releasing the dot plot, i.e., its explicit forecast for the future path of the policy rate. In addition, the Fed conducted asset purchases ("quantitative easing") to influence longer-term interest rates. Thus, the Fed has had a variety of tools to influence market expectations. For example, quantitative easing could have been interpreted by the market as a signal that interest rates were going to stay lower for longer (Eggertsson et al., 2003).

Figure 11: The FOMC Decline and Fed Funds Target Changes



Note: The figure shows the change in the 10-year Treasury yield in a 3-day window around FOMC meetings between June 1989 until June 2008 (shortly before the GFC broke out and the Fed reached the ZLB). The red lines includes all FOMC meetings, while the gray line includes only FOMC meetings during which the Fed changed the federal funds target in Panel (A), and it includes only FOMC meetings during which the Fed lowered the federal funds rate more than the market expected based on the current month's fed funds futures contract following Kuttner (2001) in Panel (B).

However, prior to the financial crisis – when the Fed's communication with the market was still evolving – Long-run Fed Guidance might have worked mostly through the policy rate itself. In other words, when the Fed lowered the federal funds rate target, the market might have interpreted this as information that rates were going to stay low over the long run. Figure 11 provides evidence that supports this interpretation. Panel (A) shows that the meetings during which the Fed changed the fed funds rate – which comprise 80 out of 177 meetings (45%) – can account for almost the entire decline in long-term yields around FOMC meetings up until the GFC. Alternatively, we can consider at meetings at which the Fed set the new target for the federal funds rate below the level that the market expected (which can be observed from the current month's federal funds futures contract (Kuttner, 2001)). Panel B shows that this alternative split (which is closely correlated with the former split) can also account for most of the decline in long-term rates up until the GFC.

Table 5 analyzes this more formally by regressing the yield change in the FOMC window on a dummy that is one if the Fed moved its target for the federal funds rate. The regression coefficient in column (2) shows that the yield decline was on average 4.77 bps at meetings with a target change and 0.47 bps at all other meetings. In addition, I construct a dummy that is one if the unexpected monetary policy action was "dovish". More concretely, I use the surprise component of the first federal funds futures ("Kuttner shock") to get the unexpected monetary policy actions (Kuttner, 2001). The regression in column (3) shows that the yield decline is concentrated at meetings at which monetary policy was surprisingly dovish. Columns (4) to (6) test whether the relationship changes after June 2008 when the Fed set the target below the markets expected target. Movements in the federal funds rate seem to have a smaller effect on yields (albeit this is not statistically significant as the power of this test is low). This is consistent with the argument that the nature of Long-run Fed Guidance likely changed over time, with other tools, such as the dot plot, becoming more important over time.

Table 5: The FOMC Decline and Fed Funds Target Changes

	10y yield change in 3-day FOMC window					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	−2.41***	−0.47	−0.51	−2.41***	−0.47	−0.51
	(0.82)	(1.01)	(1.12)	(0.82)	(1.01)	(1.12)
Meeting with target change		−4.30***			−4.30***	
		(1.65)			(1.65)	
Meeting with negative MP surprise (Kuttner)			−4.31***			−4.31***
			(1.61)			(1.61)
Dummy(After 2008:Q2)				−0.02	−1.83	−0.92
				(1.57)	(1.68)	(1.73)
Meeting with target chg. x Dummy(After 2008:Q2)					3.44	
					(5.21)	
Meeting with neg. MP surprise x Dummy(After 2008:Q2)						0.06
						(4.36)
R^2	0.000	0.039	0.039	0.000	0.020	0.028
N	177	177	177	283	283	283
Sample period	1989–2008	1989–2008	1989–2008	1989–2021	1989–2021	1989–2021

Note: The table reports the results of the regression $\Delta_{t_i-2,t_i+1} y_{10y} = \beta_0 + \beta_1$ FFR Change$_i + \epsilon_i$. The dependent variable is the 3-day in the 10-year yield around FOMC meeting i. The unit of observation is an FOMC meeting. The explanatory variable in columns (2) and (5) is a dummy variables that equals one if the Fed changed the target for the federal funds rate at meeting i. The explanatory variable in columns (3) and (6) is a dummy variables that equals one if the monetary policy shock based on the current month federal funds futures contract (the "Kuttner shock") is negative at meeting i (Kuttner, 2001). Davidson-MacKinnon standard errors are show in parentheses. Significance levels: *(p<0.10), **(p<0.05), ***(p<0.01).

5.4 A Model of Long-run Fed Guidance

The goal of this section is (i) to formalize Long-run Fed Guidance, (ii) to provide insights into when it is likely important for markets and (iii) to quantify the empirical results. To do so, I develop a Bayesian learning model in which the bond market and the Fed, in addition to processing their own information about the economy, learn from each other: the Fed learns from the yield curve, and the market learns from the Fed's monetary policy decision. The latter gives rise to bond yield changes at Fed meetings and allows the model to speak to the empirical evidence.

5.4.1 The Idea of Long-run Fed Guidance

In the model, the Fed F sets the log short rate $y_{1,t}$ – or in other words, the yield of a one-period bond – according to a standard Taylor rule (Taylor, 1993).[16] Because it does not know the current state of the economy with certainty, it has to form an expectation about the state of economy when setting the short rate

$$y_{1,t} = \pi^*_t + \mathbb{E}^F_t\left[r^*_t\right] + \phi_x \mathbb{E}^F_t\left[\hat{x}_t\right] + \phi_\pi \mathbb{E}^F_t\left[\hat{\pi}_t\right], \tag{7}$$

[16] Later in the model, t will represent a six-week interval. In practice, the Fed targets overnight rates (the federal funds rate) instead of a six-week rate. However, I choose this simplification as the correlation between overnight rates and quarterly USD Libor rates is 0.98 in the data.

where π_t^* is the Fed's inflation target, $\mathbb{E}_t^F$ is the Fed's expectation at time t, r_t^* is the natural rate, ϕ_x and ϕ_π are Taylor rule coefficients, $\hat{x}_t$ is the output gap that measures the deviation of current output from potential output and $\hat{\pi}_t$ measures the deviation of current inflation from the inflation target. Thus, we can immediately see that the Fed's implementation of the short rate reveals its expectations about the underlying states of the economy (albeit imperfectly).

What about long-term bond yields and forward rates? These are determined by the Market M and therefore reflect the Market's expectations about future short rates. For simplicity, let us imagine that the Market is risk-neutral, such that the expectation hypothesis holds, then the one-period forward rate at time $t+k$, $f_{1,t,k}$, is priced according to

$$f_{1,t,k} = \mathbb{E}_t^M \left[y_{1,t+k} \right], \tag{8}$$

where $\mathbb{E}_t^M$ is the expectation of the Market M at time t. The Market knows that the short rate at time $t+k$, $y_{1,t+k}$, is controlled by the Fed who follows equation (7). Therefore, the Market has to form an expectation about the Fed's expectation at time $t+k$ about the underlying economy at time $t+k$. As I will show below, the Market expectation about the Fed's expectation is equal to the Market's intrinsic expectation about the underlying states,[17] if the Fed extracts the information that is contained in the yield curve. In addition, if k is large enough – say, five years – and the Fed is able to eliminate deviations from full output and deviations from the inflation target over this horizon, then only the Fed's inflation target and the natural rate matter for the forward rate $f_{1,t,k}$. If we further assume that π_t^* and r_t^* follow random walks, consistent with the idea that these variables are very persistent (Bauer and Rudebusch, 2020), we can write the one-period forward rate as

$$\text{For } k >> 0: \quad f_{1,t,k} \approx \mathbb{E}_t^M \left[\pi_t^* + r_t^* \right]. \tag{9}$$

The equation says that, under risk-neutrality, only the Market's estimate for the natural rate and for the Fed's inflation target matter for long-term yields and forward rates.

We can now get an idea of how Long-run Fed Guidance works. When the Fed sets the short rate $y_{1,t}$, then this reveals its inflation target, π_t^*, and its expectation about the natural rate, $\mathbb{E}_t^F \left[r_t^* \right]$. If this information is valuable to the market, then the market updates its own expectations, $\mathbb{E}_t^M \left[\pi_t^* + r_t^* \right]$. As a result, long-term rates, $f_{1,t,k}$, change. This is the key idea behind Long-run Fed Guidance. The stylized model integrates this idea into a dynamic setting.

5.4.2 Stylized Model

Time t is discrete, and each period t can be thought of as a six-week interval, which is the usual time between two FOMC meetings. The Market and the Fed learn dynamically about the unobserved economic states. To convey the intuition more clearly, the stylized model makes a few simplifying assumptions that are later relaxed in the full term structure model. First, the model assumes that the Market is risk-neutral, such that the expectation hypothesis holds. Second, the model assumes that monetary policy only depends on the long-run variables π_t^* and r_t^*. Putting it differently, the Taylor rule coefficient ϕ_x

[17] Formally, this means for the natural rate, $\mathbb{E}_t^M \left[\mathbb{E}_{t+k}^F \left[r_{t+k}^* \right] \right] = \mathbb{E}_t^M \left[r_{t+k}^* \right]$.

and ϕ_π are assumed to equal zero. We can see from equation (9) that this is a plausible simplification if we are mainly concerned about long-term rates. Third, the model collapses the Fed's inflation target and the long-run *real* rate into one state variable (Bauer and Swanson, 2022), the long-run *nominal* rate i^*

$$i_t^* = \pi_t^* + r_t^*. \tag{10}$$

The long-run nominal rate is assumed to follow a random walk

$$i_t^* = i_{t-1}^* + \epsilon_t, \qquad \epsilon_t \sim \mathcal{N}(0, \sigma_\epsilon^2). \tag{11}$$

Each period, after the fundamental shock ϵ_t is realized, the Market and the Fed conduct their own research leading to different private signals about the unobserved state i_t^*. The Markets's signal relates to the underlying state according to

$$m_t = i_t^* + \nu_t^m, \qquad \nu_t^m \sim \mathcal{N}(0, \sigma_m^2). \tag{12}$$

Similarly, the Fed collects the signal

$$f_t = i_t^* + \nu_t^f, \qquad \nu_t^f \sim \mathcal{N}(0, \sigma_f^2), \tag{13}$$

where the signal noise terms ν_t^f and ν_t^m are assumed to be independent. Thus, we can think of ν_t^f as reflecting the Fed's signal component that is orthogonal to the Market's signal. In reality, this might arise because the Fed might use a different model than the Market to obtain a proxy for the long-run real rate. In addition, the Fed might also have an advantage over long-run inflation (the other component of the nominal rate) because it determines the inflation target.

Each period t is divided into three subperiods. First, the fundamental shock ϵ_t is realized and the agents collect their private signals about the new unobserved state i_t^*. This is also the time when maturing bonds pay out their principal. I use "-" to denote bond yields y_{k,t^-} and the Market's expectation $\mathbb{E}_{t^-}^M$ at this point in time. Second, the FOMC meeting occurs, at which the Fed sets the short rate. Third, after the meeting, the Market updates its expectation to $\mathbb{E}_{t^+}^M$ and re-prices bond yields to y_{k,t^+}, where "+" is used to mark the time after the FOMC meeting. The timing within period t is further illustrated in Figure 12.

We can now sequentially solve for equilibrium bond yields and the Fed's monetary policy decision. Under the expectation hypothesis, longer-term bond yields are the average of future short rates. Thus, the log yield on a bond with maturity k prior to the FOMC meeting is given by

$$y_{k,t^-} = \frac{1}{k} \sum_{j=0}^{k-1} \mathbb{E}_{t^-}^M \left[y_{1,t+j} \right] \quad \forall k \geq 1. \tag{14}$$

Under the assumption that the Fed backs out information contained in the publicly-observed yield curve, the Market's expectations for the Fed's expectation about the long-run rate converges to the Market's own expectation about the long-run rate, i.e., it holds that $\mathbb{E}_t^M \left[\mathbb{E}_{t+k}^F \left[i_{t+k}^* \right] \right] = \mathbb{E}_t^M \left[i_{t+k}^* \right]$. The

Figure 12: Timeline within period t

Before the Fed meeting		At the Fed meeting		After the Fed meeting	
After shock ϵ_t, agents collect signals m_t and f_t about unobs. i_t^*	Market prices bonds. Bond yields y_{k,t^-}	Fed observes bond yields y_{k,t^-}	Fed sets short rate $y_{1,t}$	Market observes short rate $y_{1,t}$	Market prices bonds. Bond yields y_{k,t^+}
Market beliefs about i_t^* $\mathbb{E}_{t^-}^M[i_t^*]$, σ_-^M		Fed beliefs about i_t^* $\mathbb{E}_t^F[i_t^*]$, σ^F		Market beliefs about i_t^* $\mathbb{E}_{t^+}^M[i_t^*]$, σ_+^M	

Note: The figure shows the timeline of events and the summary of the stylized model.

intuition here is that, if the Fed observes both signals, then the Market's information set is a subset of the Fed's information set. We can apply the tower property of the conditional expectation (see the Internet Appendix for more details). This assumption is mainly to keep the model simple and tractable, but it is not the main mechanism for why the Fed can provide guidance to the Market (since the Market already knows its own information). Using the fact that the long-run rate follows a random walk, we can then determine bond yields to be

$$y_{k,t^-} = \frac{1}{k}\sum_{j=0}^{k-1}\mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+j}^F\left[i_{t+j}^*\right]\right] = \mathbb{E}_{t^-}^M\left[i_t^*\right] \quad \forall k \geq 1. \tag{15}$$

Thus, the yield curve is perfectly flat, and all bond yields are equal to the Market's expectation of the long-run nominal rate. To understand how the Market forms its beliefs, we can use the Kalman filter

$$\mathbb{E}_{t^-}^M\left[i_t^*\right] = \frac{\sigma_m^2}{(\sigma_+^M)^2+\sigma_m^2}\mathbb{E}_{t-1^+}^M\left[i_{t-1}^*\right] + \frac{(\sigma_+^M)^2}{(\sigma_+^M)^2+\sigma_m^2}m_t, \tag{16}$$

where σ_+^M is the steady-state belief uncertainty at the end of each period.[18] Thus, the Market's expectation is a weighted average of the prior expectation and the newly obtained signal, where the weight on the new signal – the so-called Kalman gain – decreases in the signal noise σ_m and increases in the prior belief uncertainty σ_+^M.

When setting the short rate according to the rule $y_{1,t} = \mathbb{E}_t^F[i_t^*]$, the Fed wants to use all available information. That is, it wants to use its own signal, f_t, as well as the information contained in the yield curve. We can immediately see from equation (15) that bond yields perfectly reveal the Market's expectation. Because this will also be true for end-of-period yields (see equation (18) below), the Fed can back out the Market signal, m_t, using equation (16). The Fed's updated expectation at the FOMC

[18] I impose steady-state in the learning process, i.e. that sufficient time has passed. This ensures that (i) the initial beliefs of the agents do not matter and (ii) the belief uncertainty stays the same across time. Regarding the timing convention: σ_+^M reflects the uncertainty about next period's long-run state i_{t+1}^* after observing the signal m_t, i.e. $(\sigma_+^M)^2 = \mathbb{V}_{t^+}^M\left(i_{t+1}^*\right) = \mathbb{E}_{t^+}^M\left[\left(i_{t+1}^* - \mathbb{E}_{t^+}^M\left[i_t^*\right]\right)^2\right]$. This is for notational convenience only. σ^F is defined accordingly below. The relation between the forecast and the "nowcast" uncertainty is given by $\mathbb{V}_t^M\left(i_{t+1}^*\right) = \mathbb{V}_t^M\left(i_t^*\right) + \sigma_\epsilon^2$.

meeting is then

$$\mathbb{E}_t^F\left[i_t^*\right] = \frac{1}{(\sigma^F)^2\sigma_m^2 + (\sigma^F)^2\sigma_f^2 + \sigma_m^2\sigma_f^2}\left(\sigma_m^2\sigma_f^2\,\mathbb{E}_{t-1}^F\left[i_{t-1}^*\right] + (\sigma^F)^2\sigma_m^2\,f_t + (\sigma^F)^2\sigma_f^2\,m_t\right). \tag{17}$$

Note that the right-hand side of this equation also yields the short rate.

How does the Market update its expectation in response to observing the Fed's short rate decisions? Note that, in this simple economy, there is only one variable that affects monetary policy and therefore the short rate $y_{1,t}$ perfectly reveals the Fed's expectation $\mathbb{E}_t^F\left[i_t^*\right]$. In a more complex environment, the Fed would need to explicity release its long-run forecast (for example, through the dot plot). Because the Fed forms its expectation incorporating all available information, i.e., using both signals m_t and f_t, it is optimal for the Market to adopt the Fed's beliefs, i.e. this means $\mathbb{E}_{t^+}^M\left[i_t^*\right] = \mathbb{E}_t^F\left[i_t^*\right]$ and $\sigma_+^M = \sigma^F$. Bond yields at the end of period t will therefore be[19]

$$y_{k,t^+} = \mathbb{E}_{t^+}^M\left[i_t^*\right] = \mathbb{E}_t^F\left[i_t^*\right]. \tag{18}$$

To summarize, the Market learns from two sources in this economy: (i) its own signal and (ii) the Fed's signal revealed at the Fed meeting. Accordingly, we can decompose the yield change over period t, $y_{k,t^+} - y_{k,t-1^+}$, into

$$y_{k,t^+} - y_{k,t-1^+} = \left(y_{k,t^-} - y_{k,t-1^+}\right) + \left(y_{k,t^+} - y_{k,t^-}\right), \tag{19}$$

where the first term reflects the yield change occuring prior to the Fed meeting, and the second term reflects the yield change at the FOMC meeting due to Long-run Fed Guidance.

The Importance of Long-run Fed Guidance. I derive two statistics to understand the parameters that determine the importance of Long-run Fed Guidance.

First, the model implies a dot plot regression coefficient. As in the data, this coefficient is obtained from regressing the yield change at the Fed meeting onto the meeting-to-meeting change in the Fed's forecast for the long-run nominal rate

$$y_{k,t^+} - y_{k,t^-} = \alpha_{\text{Dots}} + \beta_{\text{Dots}}\left(\mathbb{E}_t^F\left[i_t^*\right] - \mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right) + \omega_t. \tag{20}$$

We can derive the coefficient β_{Dots} to be

$$\beta_{\text{Dots}} = \frac{Co\mathbb{V}\left(y_{k,t^+} - y_{k,t^-}, \mathbb{E}_t^F\left[i_t^*\right] - \mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right)}{\mathbb{V}\left(\mathbb{E}_t^F\left[i_t^*\right] - \mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right)} = \frac{1}{1 + \left(\frac{\sigma_f}{\sigma_m}\right)^2}\cdot\left[1 - \frac{(\sigma_+^M)^2}{(\sigma_+^M)^2 + \sigma_m^2}\right]. \tag{21}$$

where the term $(\sigma_+^M)^2/((\sigma_+^M)^2 + \sigma_m^2)$ reflects the Market's Kalman gain prior to the FOMC meetings (see equation (16)).

Second, the model makes a prediction about the fraction of long-run yield changes occurring at FOMC meetings. Starting with equation (19) and summing yield changes over several periods, we can

[19] Note that because $\mathbb{E}_t^F\left[i_t^*\right] = \mathbb{E}_{t^+}^M\left[i_t^*\right]$, equation (18) also holds for the one-period bond, i.e. $y_{1,t^+} = y_{1,t}$. In other words, the one-period bond yield is consistent with the Fed decision.

decompose the total yield change occuring between period t^+ and $t+T^+$ (over T periods) into

$$y_{k,t+T^+} - y_{k,t^+} = \sum_{t=t+1}^{t+T} \left(y_{k,\tau^-} - y_{k,\tau-1^+} \right) + \sum_{\tau=t+1}^{t+T} \left(y_{k,\tau^+} - y_{k,\tau^-} \right). \tag{22}$$

Taking the covariance with the total yield change and dividing by the variance of the total yield change, we get

$$1 = \frac{Co\mathbb{V}\left(\sum_{\tau=t+1}^{t+T} \left(y_{k,\tau^-} - y_{k,\tau-1^+} \right), y_{k,t+T^+} - y_{k,t^+} \right)}{\mathbb{V}\left(y_{k,t+T^+} - y_{k,t^+} \right)} + \frac{Co\mathbb{V}\left(\sum_{\tau=t+1}^{t+T} \left(y_{k,\tau^+} - y_{k,\tau^-} \right), y_{k,t+T^+} - y_{k,t^+} \right)}{\mathbb{V}\left(y_{k,t+T^+} - y_{k,t^+} \right)} \tag{23}$$

where the first term measures the fraction of total yield changes occurring before FOMC meetings and the second term measures the fraction of total yield changes occurring at FOMC meetings. Let us denote the first term by $\delta_{\text{T,FOMC}}$. There exists another interpretation for this quantity. Imagine we have a yield decline of ψ over T periods, then $\delta_{\text{T,FOMC}}$ yields the fraction of the yield decline that we expect to occur at Fed meetings. Therefore, we can write alternatively

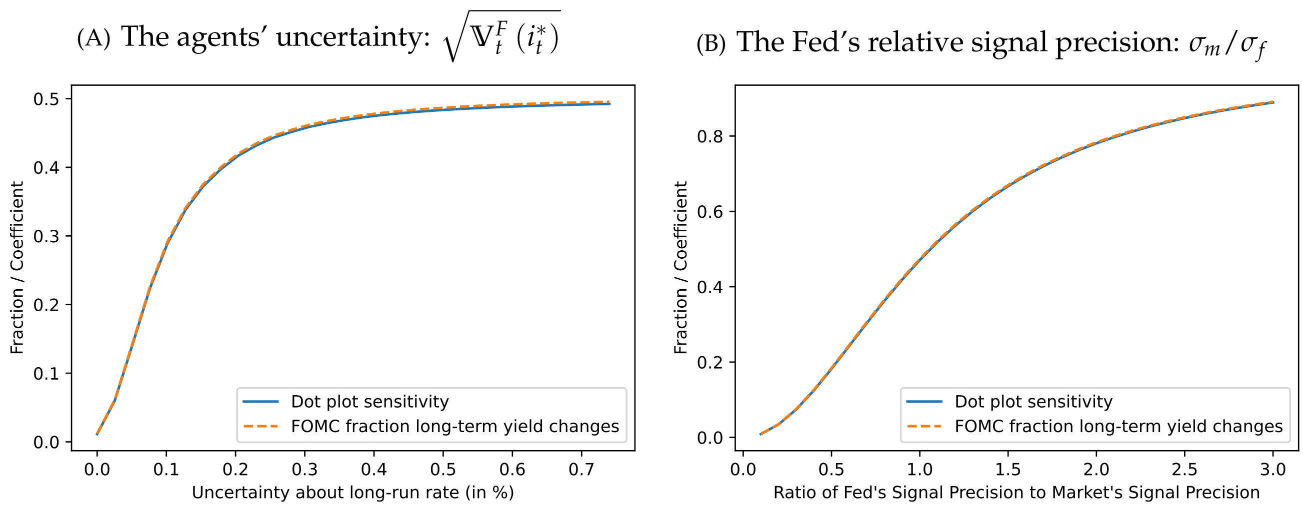
$$\delta_{T,\text{FOMC}} = \frac{Co\mathbb{V}\left(\sum_{\tau=t+1}^{t+T} \left(y_{k,\tau^+} - y_{k,\tau^-} \right), y_{k,t+T^+} - y_{k,t^+} \right)}{\mathbb{V}\left(y_{k,t+T^+} - y_{k,t^+} \right)} = \mathbb{E}\left[\frac{\sum_{\tau=t+1}^{t+T} \left(y_{k,\tau^+} - y_{k,\tau^-} \right)}{y_{k,t+T^+} - y_{k,t^+}} \mid y_{k,t+T^+} - y_{k,t^+} = \psi \right]. \tag{24}$$

If we are only interested in one-period changes, i.e., $T = 1$, the fraction of yield changes explained by Fed meetings, $\delta_{1,\text{FOMC}}$, converges back to the dot plot coefficient. To see this, note that $y_{k,t+T^+} - y_{k,t^+} = \mathbb{E}_t^F \left[i_t^* \right] - \mathbb{E}_{t-1}^F \left[i_{t-1}^* \right]$. Thus, the total yield change over period t is equal to the change in the Fed's expectation and therefore $\beta_{\text{Dots}} = \delta_{1,\text{FOMC}}$. Figure 13 also shows a close relationship when T is larger than 1.

The stylized model yields two main insights. First, as equation (21) shows, the importance of Long-run Fed Guidance depends on two factors: (i) the precision of the Fed's signal relative to the Market's signal, σ_m / σ_f, and (ii) the Kalman gain, $(\sigma_+^M)^2 / ((\sigma_+^M)^2 + \sigma_m^2)$. The former quantity is straightforward to interpret: the higher the relative precision of the Fed signal, the more attention the Market pays to the Fed. The latter quantity is also intuitive: the more information the Market already incorporates into yields prior to the FOMC, the less important the information received at the FOMC meeting becomes. Thus, the larger the Kalman gain, the less important Fed guidance is. The Kalman gain is decreasing in the Market's uncertainty about the long-run rate. Importantly, this implies that Long-run Fed Guidance can only be important when there is high uncertainty about the long-run rate. In reality, this seems to be the case, as the real long-run rate is unobserved and empirical estimates are highly uncertain (Laubach and Williams, 2003; Hamilton et al., 2016). For that same reason, the Market is likely to learn more from the Fed about the long-run rate than about other variables that are easier to measure, such as unemployment. These insights are also illustrated in Figure 13. Panel A shows that the importance of Long-run Fed Guidance is increasing in the Fed's uncertainty about the level of the long-run rate (which is equal to the Market's uncertainty in the stylized model). Panel B shows that the importance of Long-run Fed Guidance is increasing in the Fed's relative signal precision.

Second, the model shows that there is a link between the dot plot coefficient, β_{Dots}, and the fraction of long-run yield changes occurring at Fed meetings, $\delta_{T,\text{FOMC}}$. Intuitively, this make sense: the more the Market learns from the Fed about secular trends, the more the Market also updates yields in response to observing the Fed's long-run rate forecast. In the data, the dot plot coefficient is around 0.7 suggesting that around 70% of the secular decline was learned from the Fed (at least over the last decade, during which the dot plot was available). The following section evaluates this argument for a more realistic term structure model.

Figure 13: The Importance of Long-run Fed Guidance in the Stylized Model



Note: The figure shows the importance of Long-run Fed Guidance in the form of (i) the dot plot sensitivity, β_{Dots} and (ii) the fraction of 10-year changes in yields occurring at FOMC meetings, $\delta_{10y,\text{FOMC}}$. Panel A varies the Fed's uncertainty (which is equivalent to the Market's end-of-period uncertainty) about the long-run rate i_t^*; the Fed's signal precision is assumed to be equal to the Market's signal precision. Panel B varies the Fed's signal precision relative to the Market's signal precision; the agents' uncertainty is assumed to be equal to 0.37%. The fundamental volatility, σ_ϵ, is held constant at 0.37%. More information on the calibration of these parameters is provided below.

5.4.3 Full Model

In the full model, yields are not just a function of the long-run rate but also a function of the current state of the business cycle. Thus, monetary policy follows the standard Taylor rule specified in equation (7) and also responds to the output gap $\hat{x}_t$ and the deviation of inflation from the target $\hat{\pi}_t$. The short rate therefore depends on the Fed's expectation about the entire state vector $s_t' = \left(i_t^*, \hat{x}_t, \hat{\pi}_t\right)$

$$y_{1,t} = \Phi' \mathbb{E}_t^F \left[s_t\right], \tag{25}$$

where $\Phi' = (1, \phi_x, \phi_\pi)$. The dynamic evolution of the states follows an AR(1) structure

$$s_t = P s_{t-1} + \epsilon_t, \quad \epsilon_t \sim \mathcal{N}\left(\mathbf{0}, \Sigma_\epsilon\right). \tag{26}$$

where P is a 3x3 matrix, $\mathbf{0}$ is a three-dimensional vector of zeros and Σ_ϵ is 3x3 matrix. I assume that the Taylor rule coefficients are known to the Market and that the short-run economic states $\hat{x}_t$ and $\hat{\pi}_t$ are observed with uncertainty.[20] After the fundamental shocks ϵ_t are realized, the Fed collects independent information about all three state components in a three-dimensional signal

$$f_t = s_t + \nu_t^f, \quad \nu_t^f \sim \mathcal{N}\left(\mathbf{0}, \Sigma_f\right), \tag{27}$$

where Σ_f is assumed to be a diagonal 3x3 matrix with the diagonal elements $\sigma^2_{i,m}$, $\sigma^2_{x,f}$, and $\sigma^2_{\pi,f}$. Similarly, the Market collects a three-dimensional signal

$$m_t = s_t + \nu_t^m, \quad \nu_t^m \sim \mathcal{N}\left(\mathbf{0}, \Sigma_m\right), \tag{28}$$

where Σ_m is a diagonal matrix with the diagonal elements $\sigma^2_{i,m}$, $\sigma^2_{x,m}$, and $\sigma^2_{\pi,m}$. As before, ν_t^f and ν_t^m are assumed to be independent.

The Market is no longer assumed to be risk-neutral but prices bonds according to an Euler equation. Drawing on the affine term structure literature (Duffie and Kan, 1996; Duffee, 2002, e.g.), I specify the stochastic discount factor (sdf) at time t^-, i.e., *before* the FOMC meeting in period t, pricing cash flows that are realized in the next period at time $t+1^-$ as

$$\mathcal{M}_{t^-,t+1^-} = \exp\left\{-\mathbb{E}^M_{t^-}\left[y_{1,t}\right] - \Lambda'_{t^-}\left(\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right] - \mathbb{E}^M_{t^-}\left[s_{t+1}\right]\right) - \frac{1}{2}\Lambda'_{t^-}\mathbb{V}^M_{t^-}\left(\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]\right)\Lambda_{t^-}\right\}, \tag{29}$$

where the price of risk is $\Lambda_{t^-} = \Lambda_0 + \Lambda_1 \mathbb{E}^M_{t^-}\left[s_t\right]$ and $\mathbb{V}^M_{t^-}\left(\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]\right)$ is the Market's conditional uncertainty about its own expectation in the next period. In traditional affine term structure models, the sdf depends on shocks to the state variables. However, as these shocks are unobserved by the Market in this model, the sdf instead depends on the shocks to the Market's expectation about the underlying states of the economy, $\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right] - \mathbb{E}^M_{t^-}\left[s_{t+1}\right]$. The last term in equation (29) reflects the usual convexity adjustment term and ensures that $y_{1,t^-} = \mathbb{E}^M_{t^-}\left[y_{1,t}\right]$. I assume a similar form for the sdf at time t^+, i.e, *after* the FOMC meeting in period t, $\mathcal{M}_{t^-,t+1^-}$. Under these assumptions, bond prices and yields follow the usual recursion in affine term structure models as is further illustrated in the Internet Appendix.

How do agents learn in this economy? Except in knife-edge cases (Duffee, 2011; Joslin et al., 2014), the Fed is able to back out the Market's expectations perfectly from the yield curve. The intuition here is that different states have different persistence and therefore have a unique effect on the yield curve. Thus, the level, slope and curvature of the yield curve perfectly reveal the Market's expectation about each state (yield are invertible). However, in contrast to the stylized model, the short rate decision of the Fed does not (perfectly) reveal the Fed's expectation about the three underlying state variables. As such, it provides only a noisy signal about the Fed's expectation for the long-run rate. As an extension, we can therefore allow the Fed to additionally signal its long-run rate estimate through the dot plot. This means the Market is able to extract more information from FOMC meetings, as it not only observes the short rate $y_{1,t}$, but also the dot plot $\mathbb{E}^F_t\left[i^*_t\right]$.

Calibration. We want to use the model to explain the empirical evidence. To fit the model to the data, I perform two independent steps. First, I estimate the term structure parameters, and second, I calibrate

[20] An alternative specification would be to let the Market instead learn about the Taylor rule coefficients ϕ_x and ϕ_π and let the Market perfectly observe the short-run fundamentals $\hat{x}_t$ and $\hat{\pi}_t$ (see, for example, Bauer et al., 2022).

the signal precision parameters. In the first step, several term structure parameters need to be estimated: (i) the Taylor rule coefficient, (ii) the AR(1) matrix P, (iii) the covariance matrix of the fundamental shocks Σ_ϵ and (iv) the prices of risk Λ_0 and Λ_1. Using survey expectations and the r^* estimate from Laubach and Williams (2003) to proxy for the agents' expectations, I estimate these parameters using a two-step procedure following Ang et al. (2007). The Internet Appendix provides additional details. Despite using only macro variables, I obtain a satisfactory fit of the term structure dynamics. In the second step, I calibrate the signal noise parameter Σ_m and Σ_f. The key parameters that we are interested in are the precision of the signals about the long-run rate, σ_{im} and σ_{if}. I use the fact that these two parameters directly map onto the Fed's (as well as the Market's) uncertainty about the long-run rate, $\mathbb{V}_t^F(i_t^*)$. To calibrate the signal precision terms, I therefore fix the Fed's uncertainty about the long-run rate and vary the ratio of the signal precision terms, σ_{im}/σ_{if}. This yields a unique pair of σ_{im} and σ_{if} which can then be used in the quantitative exercise. For the other macrovariables, I assume that the Fed's and the Market's signal have the same precision, i.e., $\sigma_{xm}/\sigma_{xf} = 1$ and $\sigma_{\pi m}/\sigma_{\pi f} = 1$.

Table 6: The Importance of Long-run Fed Guidance in the Full Term Structure Model

	Calibrated Parameters:		*Short rate + dot plot*		*Only short rate*
	i^*-Uncertainty	Signal precision	Dot plot	FOMC fraction	FOMC fraction
	$\sqrt{\mathbb{V}_t^F(i_t^*)}$	$\frac{\sigma_{im}}{\sigma_{if}}$	β_{Dots}	$\delta_{10y,\text{FOMC}}$	$\delta_{10y,\text{FOMC}}$
(1)	0.37%	1/2	0.16	31.1%	27.6%
(2)	0.37%	1	0.43	46.2%	39.7%
(3)	0.37%	2	0.70	62.4%	58.2%
(4)	0.74%	2	0.72	65.3%	60.5%

Note: The table shows the importance of Long-run Fed Guidance in form of (i) the dot plot sensitivity, β_{Dots} and (ii) the fraction of 10-year changes in yields occurring at FOMC meetings, $\delta_{10y,\text{FOMC}}$. Columns 4 and 5 report results for the economy in which the Fed sets the short rate and releases the dot plot; column 6 reports results for the economy in which the Fed only sets the short rate. The maturity of the bond is 10 years. The term structure parameters are estimated as described in the text. The remaining signal parameters are calibrated such that $\mathbb{V}_t^F(\hat{x}_t) = (\sigma_{x,\epsilon})^2 = (1.30\%)^2$, $\mathbb{V}_t^F(\hat{\pi}_t) = (\sigma_{\pi,\epsilon})^2 = (1.09\%)^2$, $\sigma_{xm}/\sigma_{xf} = 1$, $\sigma_{\pi m}/\sigma_{\pi f} = 1$.

As before, I ask the model to explain two key quantities: (a) the dot plot regression coefficient β_{Dots} (when the Fed releases its dot plot forecast) and (b) the fraction of 10-year changes of bond yields occurring at FOMC meetings $\delta_{10y,\text{FOMC}}$ (when the Fed does release its dot plot forecast as well as when it does not). Table 6 reports the results. Scenario (1) shows the case where the Fed's signal about the long-run rate has half the precision of the Market's signal. In this case, long-term yields are (counterfactually) insensitive to the Fed's dot plot release. Scenarios (2) and (3) therefore increase the signal precision of the Fed. Scenario (3) shows that, when the Fed's signal is twice as precise as the Market's signal, then the dot plot coefficient equals 0.70. This is close to the empirical estimate reported in Table 4. This calibration suggest that about 62% of long-run yield changes occur at FOMC meetings when the Fed releases the dot plot. Interestingly, the results are similar (58%) when the Fed does not release its dot plot. This suggests that Market participants can already extract a majority of information just by observing the short rate. This might explain why the empirical pattern also exists even before the Fed releases its dot plot. Scenario (4) increases the agents' uncertainty about the long-run rate. Consistent with the intuition in the stylized model, the importance of long-run Fed Guidance increases. To conclude, the theoretical analysis shows that – in order to explain what we see in the data – there must be substantial uncertainty about the long-run level of interest rates and the Fed must have a comparative advantage at estimating this level.

6 Conclusion

Prior studies have documented that real, long-term assets are surprisingly sensitive to monetary policy (Bernanke and Kuttner, 2005; Lucca and Moench, 2015; Hanson and Stein, 2015; Bianchi et al., 2021). This is puzzling, because the Fed only controls the federal funds rate. I add to this evidence by documenting a large decline in long-term nominal and real interest rates around Fed meetings. Moreover, this decline lines up remarkably well with the general secular decline in interest rates. I offer a potential explanation for this pattern: Long-run Fed Guidance. Guidance by the Fed about the long-run level of interest rates leads the market to update its own belief about the future path of short rates. This can explain why long-term yields respond so sensitively to the Fed's dot plot as well as to the Fed's short rate decisions. It could also explain why the Fed has such a large impact on other long-term assets such as stocks.

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Internet Appendix for "The Fed and the Secular Decline in Interest Rates"

Sebastian Hillenbrand

A FOMC Meetings – Additional Information

A.1 FOMC Meeting Dates Since June 1989

Tables A.1 and A.2 provide a list of scheduled and unscheduled FOMC meetings, respectively. The text provides a further description of how monetary policy was conducted and when it became know to the market.

Meeting dates June 1989 – December 1993. In late 1989, the federal funds rate became the sole target of monetary policy. Furthermore, after some erroneous market reaction in November 1989, the Fed put higher emphasis on signaling the intended funds rate to the public.[1] The Fed nevertheless still relied on open market operations to signal any changes in monetary policy to the public. In order to the obtain the dates when monetary policy decisions were revealed, I use the dates of monetary policy shocks from Kuttner (2001, 2003) who performs a careful examination of the dates when the market reacted to monetary policy news for the period from June 1989 to June 2008. This allows me to determine the dates when the market learned about the outcome of scheduled and unscheduled FOMC meetings that were associated with a change in the federal funds rate target. For scheduled meetings that did not lead to any change in the federal funds rate, I use the day after the meeting.

Meeting dates since 1994. Monetary policy decisions have been fairly transparent since 1994. Between 1994 and 1997, the Fed released a statement for scheduled FOMC meetings if there was a change in the federal funds rate target. Since 1998, the Fed has released a statement for every scheduled meeting. FOMC statements clearly state the target for the federal funds rate and were usually released on the (last) day of the meeting.[2] For this reason, I use the actual date of the FOMC meeting, since this is also the day when the market learned about monetary policy decision. In addition to that, most monetary policy decisions were made during scheduled meetings since 1994. The few unscheduled meetings that took place over this period were often unrelated to monetary policy, but focused for example on the correct functioning of money markets. I exclude unscheduled meetings that were not related to monetary policy.[3] Furthermore, the Fed did not release a statement for some unscheduled meeting. I also exclude these meetings since the market was not able to infer that Fed officials had met in real-time. My final sample therefore includes all unscheduled meetings that were related to monetary policy and for which the Fed released a statement.

[1] Shortly before Thanksgiving 1989, the trading desk of the New York Fed increased the amount of reserves for reasons unrelated to monetary policy, while the federal funds rate had slipped below the FOMC's funds rate expectations just before the operations. The market falsely interpreted this as monetary easing (see Lindsey (2003)).

[2] There are three exceptions to this rule. For three unscheduled meetings (August 16, 2007, January 21, 2008, and October 7, 2008), the Fed released the statement on the following day. For these unscheduled meetings, I use the date when the statement was released to the public.

[3] This is common in the literature (see for example Kuttner (2001)) and does not affect the results. More specifically, the dates which I drop for this reason are August 10, 2007, August 16, 2007, January 21, 2008, March 10, 2008, May 9, 2009, October 4, 2019, March 19, 2020, March 23, 2020 and March 31, 2020.

Table A.1: Dates of Scheduled FOMC Meetings Since June 1989

Year	N	Scheduled FOMC Meetings 1.	2.	3.	4.	5.	6.	7.	8.
1989	5				7-Jul	23-Aug	4-Oct	15-Nov	20-Dec
1990	8	8-Feb	28-Mar	16-May	5-Jul	22-Aug	3-Oct	14-Nov	18-Dec
1991	8	7-Feb	27-Mar	15-May	5-Jul	21-Aug	2-Oct	6-Nov	18-Dec
1992	8	6-Feb	1-Apr	20-May	2-Jul	19-Aug	7-Oct	18-Nov	23-Dec
1993	8	4-Feb	24-Mar	19-May	8-Jul	18-Aug	22-Sep	17-Nov	22-Dec
1994	8	4-Feb	22-Mar	17-May	6-Jul	16-Aug	27-Sep	15-Nov	20-Dec
1995	8	1-Feb	28-Mar	23-May	6-Jul	22-Aug	26-Sep	15-Nov	19-Dec
1996	8	31-Jan	26-Mar	21-May	3-Jul	20-Aug	24-Sep	13-Nov	17-Dec
1997	8	5-Feb	25-Mar	20-May	2-Jul	19-Aug	30-Sep	12-Nov	16-Dec
1998	8	4-Feb	31-Mar	19-May	1-Jul	18-Aug	29-Sep	17-Nov	22-Dec
1999	8	3-Feb	30-Mar	18-May	30-Jun	24-Aug	5-Oct	16-Nov	21-Dec
2000	8	2-Feb	21-Mar	16-May	28-Jun	22-Aug	3-Oct	15-Nov	19-Dec
2001	8	31-Jan	20-Mar	15-May	27-Jun	21-Aug	2-Oct	6-Nov	11-Dec
2002	8	30-Jan	19-Mar	7-May	26-Jun	13-Aug	24-Sep	6-Nov	10-Dec
2003	8	29-Jan	18-Mar	6-May	25-Jun	12-Aug	16-Sep	28-Oct	9-Dec
2004	8	28-Jan	16-Mar	4-May	30-Jun	10-Aug	21-Sep	10-Nov	14-Dec
2005	8	2-Feb	22-Mar	3-May	30-Jun	9-Aug	20-Sep	1-Nov	13-Dec
2006	8	31-Jan	28-Mar	10-May	29-Jun	8-Aug	20-Sep	25-Oct	12-Dec
2007	8	31-Jan	21-Mar	9-May	28-Jun	7-Aug	18-Sep	31-Oct	11-Dec
2008	8	30-Jan	18-Mar	30-Apr	25-Jun	5-Aug	16-Sep	29-Oct	16-Dec
2009	8	28-Jan	18-Mar	29-Apr	24-Jun	12-Aug	23-Sep	4-Nov	16-Dec
2010	8	27-Jan	16-Mar	28-Apr	23-Jun	10-Aug	21-Sep	3-Nov	14-Dec
2011	8	26-Jan	15-Mar	27-Apr	22-Jun	9-Aug	21-Sep	2-Nov	13-Dec
2012	8	25-Jan	13-Mar	25-Apr	20-Jun	1-Aug	13-Sep	24-Oct	12-Dec
2013	8	30-Jan	20-Mar	1-May	19-Jun	31-Jul	18-Sep	30-Oct	18-Dec
2014	8	29-Jan	19-Mar	30-Apr	18-Jun	30-Jul	17-Sep	29-Oct	17-Dec
2015	8	28-Jan	18-Mar	29-Apr	17-Jun	29-Jul	17-Sep	28-Oct	16-Dec
2016	8	27-Jan	16-Mar	27-Apr	15-Jun	27-Jul	21-Sep	2-Nov	14-Dec
2017	8	1-Feb	15-Mar	3-May	14-Jun	26-Jul	20-Sep	1-Nov	13-Dec
2018	8	31-Jan	21-Mar	2-May	13-Jun	1-Aug	26-Sep	8-Nov	19-Dec
2019	8	30-Jan	20-Mar	01-May	19-Jun	31-Jul	18-Sep	30-Oct	11-Dec
2020	7	29-Jan	29-Apr	10-Jun	29-Jul	16-Sep	5-Nov	16-Dec	
2021	4	27-Jan	17-Mar	28-Apr	16-Jun				

Note: This table shows the dates of scheduled FOMC meetings from June 1989 to June 2021. These dates represents the days when monetary policy actions (or "non-actions") after scheduled meetings became known to the public. Since 1994, the Fed communicated its decision on the day of the FOMC meeting. Prior to 1994, the market learned about monetary policy through open market operations conducted typically on the day after the FOMC meeting.

A.2 FOMC Meeting Dates between January 1980 – May 1989

As an addition, I repeat the main analysis of the paper starting in 1980.

Meeting dates January 1980 – September 1982. Until September 24, 1982, non-borrowed reserves were the Fed's main policy instrument. Through this instrument, the Fed hoped to gain better control of the growth in the money supply that they thought was an important driver for the high inflation prevailing at that time. For scheduled FOMC meetings, I assume that the market became aware of any policy change on the day following the meeting from the open market operations. I exclude any unscheduled meetings over this period, because I am not able to tell whether there was any policy actions taken as a consequence of each meeting. I therefore cannot determine whether any unscheduled meeting became known to the market.

Meeting dates September 1982 – May 1989. In the fall of 1982, the Fed started to put again more focus on

Table A.2: Dates of Unscheduled FOMC Meetings Since June 1989

		Unscheduled FOMC Meetings								
Year	N	1.	2.	3.	4.	5.	6.	7.	8.	9.
1989	4				5-Jun	26-Jul	16-Oct	6-Nov		
1990	3	13-Jul	29-Oct	7-Dec						
1991	9	8-Jan	1-Feb	8-Mar	30-Apr	6-Aug	13-Sep	31-Oct	6-Dec	20-Dec
1992	2	9-Apr	4-Sep							
1993	0									
1994	1	18-Apr								
1995	0									
1996	0									
1997	0									
1998	1	15-Oct								
1999	0									
2000	0									
2001	3	3-Jan	18-Apr	17-Sep						
2002	0									
2003	0									
2004	0									
2005	0									
2006	0									
2007	0									
2008	2	22-Jan	8-Oct							
2009	0									
2010	0									
2011	0									
2012	0									
2013	0									
2014	0									
2015	0									
2016	0									
2017	0									
2018	0									
2019	0									
2020	2	3-Mar	15-Mar							
2021	0									

Note: This table shows the dates of unscheduled FOMC meetings from June 1989 to June 2021. These dates represents the days when monetary policy actions (or "non-actions") after unscheduled meetings became known to the public. For unscheduled meetings after 1994, I include only unscheduled meetings that were followed by a statement released to the public and whose main purpose was the conduct of monetary policy. Prior to 1994, the dates correspond to dates when the market learned about changes in the federal funds rate as identified by Kuttner (2001).

the federal funds rate as it had done before 1979. Officially, the Fed was targeting borrowed reserves and it used the federal funds rate to adjust the amount of borrowed reserves up or down. During this time period the Fed was deliberately opaque about its policy instruments (see Lindsey (2003)). The public learned about monetary policy through the open market operations that were conducted by the Federal Reserve Bank of New York in order to change the federal funds rate. Typically, this happened the day after the meeting, but there are some exceptions. In order to more accurately identify the dates of the open market operations, I obtain daily estimates of the federal funds rate target available from FRED. This time-series is based on the federal funds rate target series constructed by Thornton (2005) for the period September 27, 1982 through December 31, 1993 using several sources: the verbatim transcripts of FOMC meetings, the FOMC Blue Book, the Report of Open Market Operations and Money Market Conditions, and data that the author obtained from the Desk for the Federal Reserve Bank of New York dealing with open market operations after March 1984. Using this time-series allows me to observe the approximate dates of monetary policy changes.[4] For scheduled FOMC meetings, I take the day after a meeting, unless there is a change in the federal funds rate within 3 days after the meeting. In this case, I take the date of the rate change. For intermeeting changes in the federal funds rate, I rely completely on Thornton (2005). Several of these intermeeting changes were not the outcome of an unscheduled meeting. These were changes made under the discretion of Chairman Volcker whenever he judged that monetary conditions differed from what was decided during the last FOMC meeting (See Thornton (2005) and the Transcript, March 1984, meeting, p.87). I include these dates in my sample.

Table A.3: Dates of Scheduled FOMC Meetings between September 1982 and May 1989

		Scheduled FOMC Meetings										
Year	N	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1980	11	10-Jan	6-Feb	19-Mar	23-Apr	21-May	10-Jul	13-Aug	17-Sep	22-Oct	19-Nov	22-Dec
1981	8	4-Feb	1-Apr	19-May	8-Jul	19-Aug	7-Oct	18-Nov	23-Dec			
1982	8	3-Feb	31-Mar	19-May	2-Jul	25-Aug	7-Oct	19-Nov	22-Dec			
1983	8	10-Feb	31-Mar	25-May	14-Jul	24-Aug	5-Oct	16-Nov	21-Dec			
1984	8	1-Feb	29-Mar	23-May	19-Jul	22-Aug	3-Oct	8-Nov	19-Dec			
1985	8	14-Feb	28-Mar	22-May	11-Jul	21-Aug	2-Oct	6-Nov	18-Dec			
1986	8	13-Feb	2-Apr	22-May	11-Jul	21-Aug	24-Sep	6-Nov	17-Dec			
1987	8	12-Feb	1-Apr	22-May	8-Jul	19-Aug	24-Sep	4-Nov	17-Dec			
1988	8	11-Feb	30-Mar	18-May	1-Jul	17-Aug	21-Sep	2-Nov	15-Dec			
1989	8	9-Feb	29-Mar	17-May	*Main sample starts*							

Note: This table shows the dates of scheduled FOMC meetings from January 1980 to May 1989. These dates represents the days when monetary policy actions or non-actions after scheduled meetings likely became known to the public.

Table A.4: Dates of Unscheduled FOMC Meetings between September 1982 and May 1989

		Unscheduled FOMC Meetings								
Year	N	1.	2.	3.	4.	5.	6.	7.	8.	9.
1980	0									
1981	0									
1982	3	27-Sep	1-Oct	14-Dec						
1983	5	24-Jun	20-Jul	11-Aug	17-Aug	15-Sep				
1984	9	5-Jul	9-Aug	20-Sep	27-Sep	11-Oct	18-Oct	23-Nov	6-Dec	24-Dec
1985	5	24-Jan	25-Apr	20-May	25-Jul	6-Sep				
1986	3	7-Mar	21-Apr	5-Jun						
1987	6	5-Jan	30-Apr	2-Jul	27-Aug	3-Sep	4-Sep			
1988	9	28-Jan	9-May	25-May	22-Jun	19-Jul	8-Aug	9-Aug	17-Nov	22-Nov
1989	7	5-Jan	14-Feb	24-Feb	*Main sample starts*					

Note: This table shows the dates of unscheduled FOMC meetings from January 1980 to May 1989. These dates represents the days when monetary policy actions (or "non-actions") after unscheduled meetings likely became known to the public. The dates correspond to dates when the market learned about changes in the federal funds rate as identified by Thornton (2005).

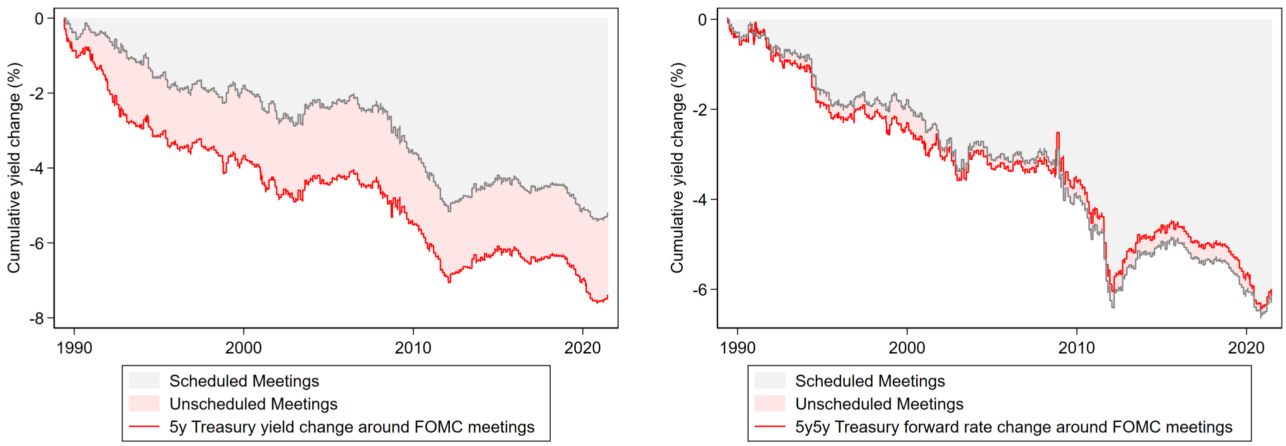
[4] As Thornton (2005) describes, it is not always clear that the market immediately realized that the target had changed, because there was considerable volatility in the federal funds rate at the time.

B Main Fact – Additional Information

B.1 Additional Results

Figure B.1: Scheduled vs. Unscheduled FOMC Meetings

(A) 5y yield (B) 5y5y Forward rate



Note: The figure repeats the main analysis shown in Figure 1 for the 5-year yield (Panel A) and the 5-year/5-year forward rate, but splits FOMC meetings into scheduled and unscheduled meetings.

B.2 Alternate News

In this section, I show that the observed pattern was not the coincidence of other information coming out during 3-day window. Before I discuss the analysis, note that any alternate explanation requires that these alternate news constantly pushed down yields in the FOMC window over the three decades. In the analysis, I try to control for directly observed news in the following: (i) macroeconomic releases, (ii) corporate earnings announcements and (iii) general news sentiment as provided by Shapiro et al. (2020).

Macroannouncements. I obtain announcement surprises for an extensive list of macroeconomic variables from Bloomberg.[5] This data is available since 1998. The announcement surprise compares the median forecast of the economists reporting to Bloomberg to the actual value of the economic series released on a particular day.

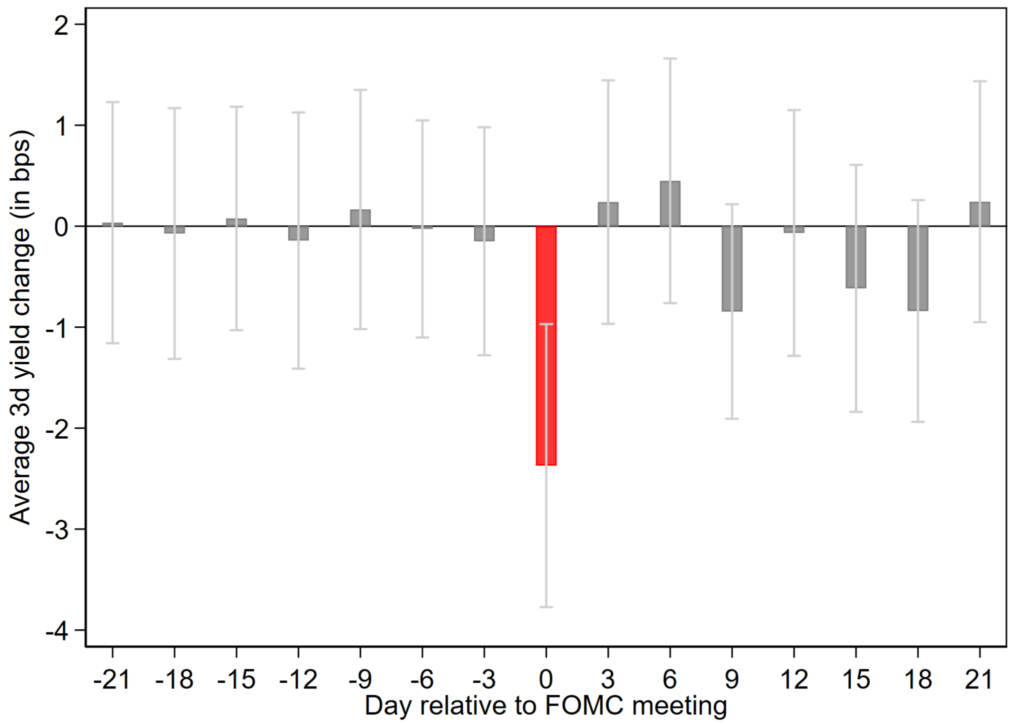
I then ask whether the announcement surprises have explanatory power for the yield changes that occurred in the 3-day FOMC window by estimating the following equation

$$\Delta_t y_{10y} = \beta_0 + \beta_1 \text{ 3-day FOMC window}_t + \sum_i \beta_{2,i} \text{ Surprise}_{i,t} + \epsilon_t, \tag{B.1}$$

where $\Delta_t y_{10y}$ is the change in the 10-year Treasury yield on day t, 3-day FOMC window$_t$ is a dummy variable that is 1 if day t falls into the 3-day FOMC window, and Surprise$_{i,t}$ denotes the announcement

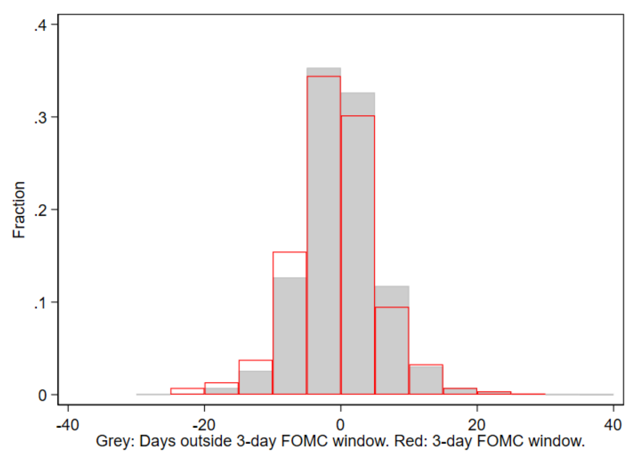
[5] These macroeconomic variables are industrial production, nonfarm payrolls, consumer price index (CPI), producer price index (PPI), purchasing manager index (PMI), unemployment rate, gross domestic product (GDP), consumer sentiment, initial jobless claims, retail sales, durable good orders, housing starts, construction spending, capacity utilization, the Leading Index, the trade balance, factory orders and new home sales.

Figure B.2: Placebo Test - Shift within "FOMC Cycle"



Note: This figures conducts a placebo test by shifting the actual FOMC meeting in FOMC cycle time as in Cieslak et al. (2019). Each bar is constructed by shifting each FOMC meeting that took place over the sample period by x days and then computing the average yield change that occurred in the 3-day window around these "placebo FOMC meetings". The sample period runs from June 1989 to June 2021. 10% confidence intervals are shown.

Figure B.3: Distribution of Yield Changes



Note: The figure shows the distribution of daily changes in the 10-year Treasury yield for days that fall into the 3-day FOMC windows and days that do not. The sample period runs from June 1989 to June 2021.

surprise of macroeconomic series i on day t. If there is no surprise on a given day, then the variable is set equal to zero. The coefficient $\beta_{2,i}$ captures the sensitivity of yields with respect to surprises in the macroeconomic series i. The main coefficient of interest is β_1. Specifically, we are interested in how the coefficient β_1 changes once we control for macroannouncement surprises.

Corporate Earnings Announcements. Additionally, I collect information on corporate earning announcements. To construct a news measure on the aggregate level I proceed in the following steps. First, I obtain the announcement date of the quarterly reports of all active S&P 500 firms from Compustat.[6] Second, I obtain the firm's stock return on the day of the announcement and the day following the announcement from CRSP. More specifically, let $\text{AnnReturns}_{i,t}$ be the return of stock i on day t, where t is either the day of the announcement or the day following the announcement. For all other days in a given quarter, the announcement return of firm i will be set to zero. Third, I construct an aggregate announcement return according to

$$\text{AnnReturns}_t = \sum_{i \in \text{S\&P500}} \text{AnnReturns}_{i,t} \times \frac{\text{MarketCap}_{i,t-1}}{\sum_{k \in \text{S\&P500}} \text{MarketCap}_{k,t-1}}. \tag{B.2}$$

Thus, the aggregate announcement return, AnnReturns_t, is a market-cap-weighted-average of the individual stocks' announcement returns. Thus, this is a proxy for the news released during corporate earnings announcements on the aggregate level.

News Sentiment identified through Textual Analysis. Finally, I download the Daily News Sentiment Index from the website of the Federal Reserve Bank of San Francisco.[7] The Daily News Sentiment Index is a high-frequency measure of the sentiment in the US based on an analysis of economics-related articles appearing in major U.S. newspaper (Shapiro et al. (2020)). I include the daily change in news sentiment as a control variable in the regression.

Results. Column 1 of Panel A in Table B.1 shows that the average daily decline in the 10-year Treasury yield during the 3-day FOMC window was 0.67 bps since 1998. Column 2 controls for the macroannouncement surprises – the specification therefore follows equation (B.1). The coefficient of the 3-day FOMC window is almost unchanged from the inclusion of the macroannouncement surprises. Column 3 interacts the macroannouncement surprises with year fixed effects in order to allow for a time-varying sensitivity of Treasury notes with respect to macroeconomic news (Campbell et al. (2017, 2020)). The R^2 rises to 13% indicating that these controls are able to explain a substantial fraction of daily yield movements. Nevertheless, the controls cannot explain the decline in the 10-year Treasury yield happening around FOMC meeting as the coefficient of the 3-day FOMC window remains stable.

Panel B of Table B.1 shows regressions that control jointly for corporate earnings announcements and changes in news sentiment. The coefficient does not change between column 1 and 2 indicating that the controls fail to explain the decline during the 3-day FOMC window. The conclusion is the same when interacting the controls with year fixed effect. Note that the R^2 rises again, but remains lower than when we control for macroannouncement surprises.

[6] The announcement date of the quarterly report is the item *rdq* in the Compustat data set *fundq*. First, note that this includes annual reports. Second, because I do not know the exact time of the earnings announcements during the day – in particular whether it was released before or after equity trading was conducted – , I also integrate the return on the day following the announcement into the analysis. This ensures that I am able to control for announcements that are made after market close.

[7] https://www.frbsf.org/economic-research/indicators-data/daily-news-sentiment-index/

Table B.1: Controlling for Alternate News

(A) Macroannouncements

	10y Treasury yield change (bps)		
	(1)	(2)	(3)
3-day FOMC window	−0.67**	−0.63**	−0.62**
	(−2.31)	(−2.16)	(−2.11)
Constant	−0.01	−0.01	0.04
	(−0.07)	(−0.17)	(0.46)
Macroannouncement Surprises	No	Yes	No
Macroannouncement Surprises x Year	No	No	Yes
Sample start date	1998	1998	1998
Observations	5875	5875	5875
R-squared	.0012	.017	.13

(B) News Sentiment and Earnings Announcements

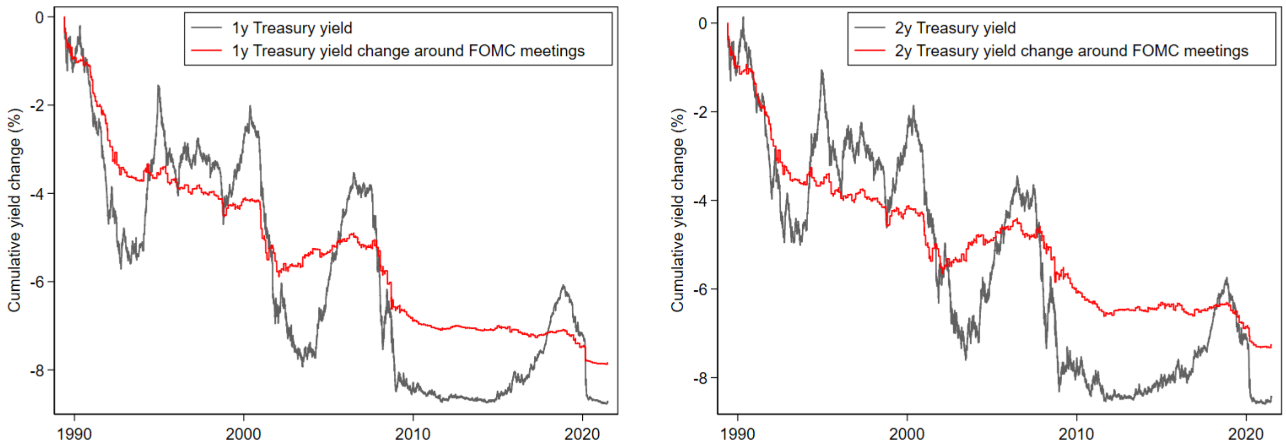
	10y Treasury yield change (bps)		
	(1)	(2)	(3)
3-day FOMC window	−0.80***	−0.87***	−0.88***
	(−3.47)	(−3.74)	(−3.84)
Constant	−0.00	0.03	0.10
	(−0.05)	(0.38)	(1.48)
Change in News Sentiment	No	Yes	No
Earnings Announcement Returns	No	Yes	No
Change in News Sentiment x Year	No	No	Yes
Earnings Announcement Returns x Year	No	No	Yes
Sample start date	1989	1989	1989
Observations	8008	8007	8007
R-squared	.0018	.0081	.055

Note: This table tries to rule out that the yield decline in the 3 days surrounding FOMC meetings was caused by the release of alternate news. The regression specification is outlined in equation (B.1). The dependent is the change (in bps) in the 10-year Treasury yield from Gürkaynak et al. (2007). Panel A controls for macroannouncement surprises as reported by Bloomberg. Panel B controls for corporate earnings announcement returns and changes in the Daily News Sentiment Index. To account for a non-contemporaneous relationship in Panel B, the controls are the (a) same-day announcement returns, the (b) lagged announcement returns, (c) the same-day change in news sentiment, (d) the lagged change and the (e) forward-lagged change in sentiment. t-statistics using Bell-McCaffrey standard errors are reported. Significance levels: *(p<0.10), **(p<0.05), ***(p<0.01). The sample runs from January 1998 to June 2021 in Panel A and from June 1989 to June 2021 in Panel B.

B.3 The Behavior of Short-term Rates around FOMC Meetings

Figure B.4: Short-term Rates

(A) 1-year Treasury yield (B) 2-year Treasury yield



Note: The figure repeats the main analysis using the 1-year U.S. Treasury yield in Panel (A) and the 2-year U.S. Treasury yield in Panel (B).

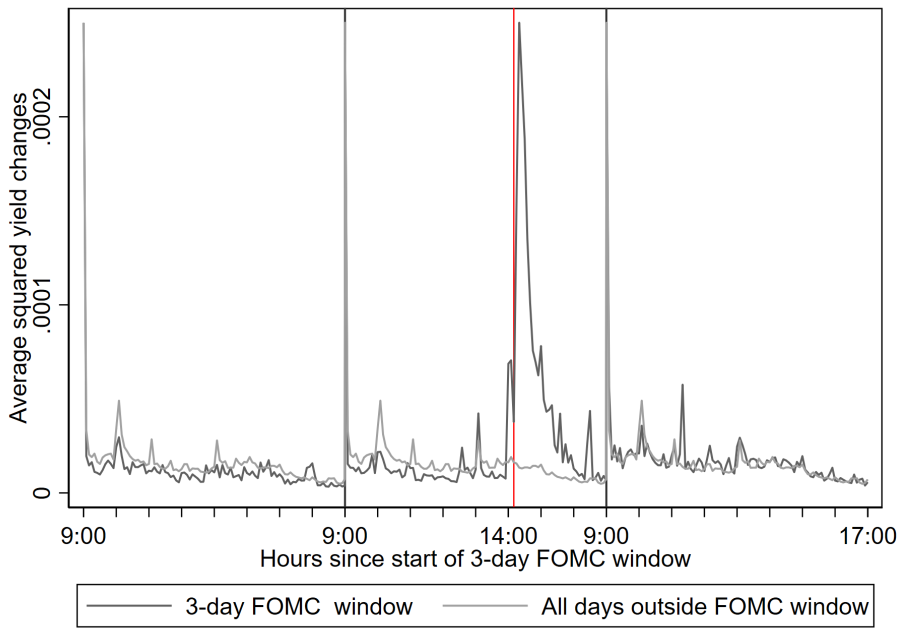
Table B.2: State-Dependence of 1-year Yield Changes around FOMC Meetings

	1y yield change in 3-day FOMC window								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Constant	−2.78***	−2.67***	−2.34***	−3.07***	−2.98***	−2.78***	−2.09***	−6.82***	−3.22***
	(0.59)	(0.57)	(0.70)	(1.18)	(0.64)	(0.65)	(0.55)	(1.42)	(0.88)
Level - Yield Curve (PC1)		−0.71***							
		(0.24)							
Slope - Yield Curve (PC2)		0.20							
		(1.10)							
Dummy(High VIX)			−0.89						
			(1.19)						
Dummy(Negative 1-month S&P500 return)				0.47					
				(1.33)					
Δ log S&P500					15.32				
					(9.38)				
Δ log Bloomberg Commodity Index					−2.66*				
					(1.41)				
Δ log Yield Curve Slope (10y–3m)					10.54				
					(13.00)				
Chicago Fed National Activity Index						1.63			
						(1.09)			
Brave-Butters-Kelley Leading Index						−0.41			
						(0.77)			
Nonfarm Payroll Surprise						0.22			
						(1.11)			
Dummy(NBER Recession)							−5.76**		
							(2.79)		
Dummy(Year >= 1994)								5.01***	
								(1.56)	
Dummy(Chairman = Bernanke)									0.06
									(1.56)
Dummy(Chairman = Yellen)									3.13***
									(1.07)
Dummy(Chairman = Powell)									0.68
									(1.55)
R^2	0.000	0.025	0.002	0.001	0.039	0.023	0.035	0.040	0.010
N	283	283	283	283	283	283	283	283	283

Note: The table reports the results from regression (5), i.e., it regress the 3-day change in the 1-year yield around an FOMC meeting (measured in bps) on various predictor variables measured prior to the FOMC meeting. A unit of observation is an FOMC meeting. The sample contains all FOMC meetings between June 1989 and June 2021. The construction of the variables is described in the text. Bell-McCaffrey standard errors are shown in parentheses. Significance levels: *(p<0.10), **(p<0.05), ***(p<0.01).

B.4 Realized Intraday Volatility

Figure B.5: Realized Intraday Yield Volatility

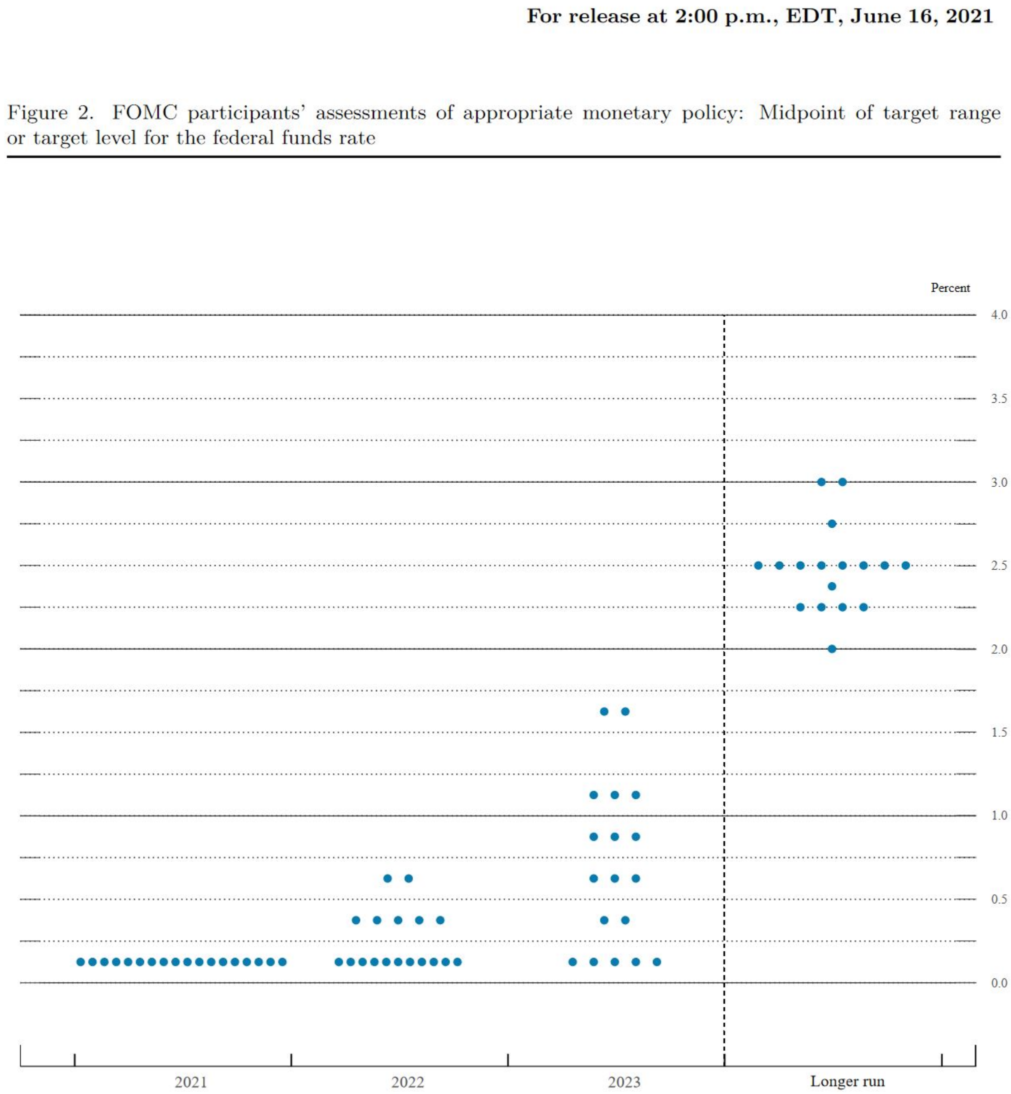


Note: The figure shows the realized intraday yield volatility of the on-the-run 10-year U.S. Treasury Note over 3-day windows. The dark gray line is the average of squared yield changes for each 5-min interval between 9:00 a.m. ET to 5:00 a.m. ET for the 3-day FOMC window. The light gray line is the same calculation on 3-day windows that do not contain FOMC meetings. The data is from GovPX and the sample runs from January 1994 to March 2020. The meetings on February 4, 1994, August 16, 1994, and March 26, 1996 are excluded because the announcement happened before 2:00 p.m. The red dashed line is set at 2:10 p.m. ET on the meeting day, shortly before the meeting information is released to the public.

C Dot Plot – Additional Information

C.1 More Recent Example of the Dot Plot

Figure C.1: Example: The Dot Plot from June 16, 2021

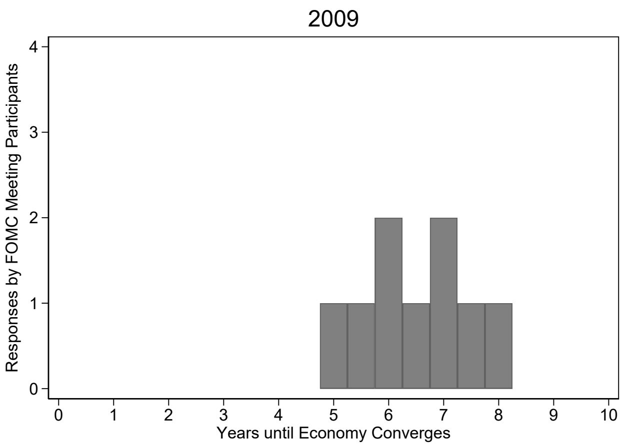


Note: The figure shows the dot plot released in the Statement of Economic Projections at the FOMC meeting on June 16, 2021. Each dot represents the forecast of a single (voting or non-voting) FOMC member for the level of the federal funds rate at the end of the next three years as well as a longer-run forecast for the federal funds rate.

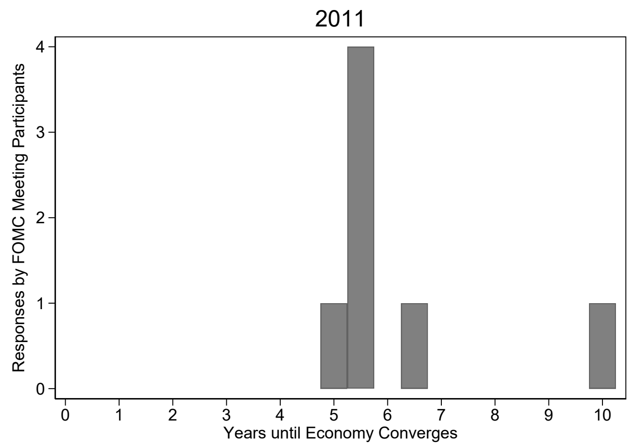
C.2 The Fed's Own Assessment of the Long-run Dots

Figure C.2: Fed's Assessment: Years until Convergence to Longer-run Estimate

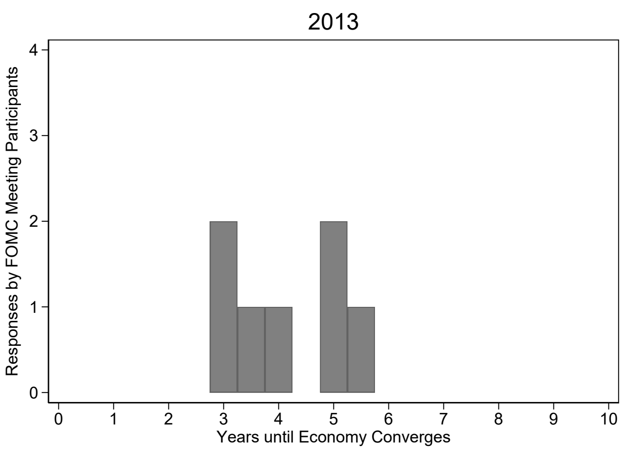
(A) 4 November, 2009



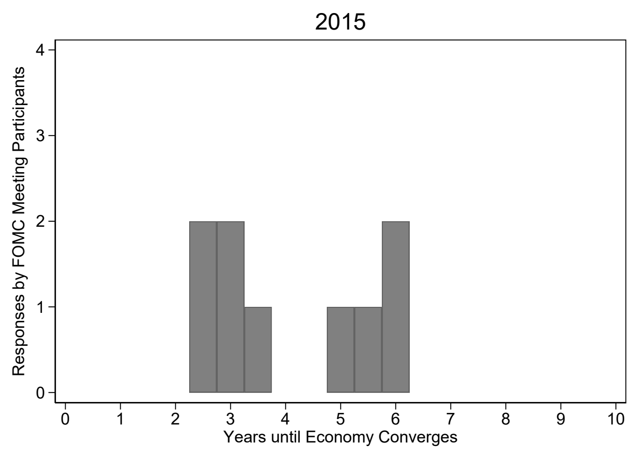
(B) 2 November, 2011



(C) 18 December, 2013



(D) 16 December, 2015



Note: The figure shows the FOMC members' forecast for how many years to takes until the economy and monetary policy converges to their "longer-run" estimate. The exact question regarding the *"Longer-run Projectons"* that Fed officials get asked is *"If you anticipate that the convergence process will take SHORTER OR LONGER than about five or six years, please indicate below your best estimate of the duration of the convergence process."* Theses responses (as well as other detailed information contained in the Statement of Economic Projections) are released with a lag of 6 years.

Table C.1: Fed's Assessment: Factors Behind Decline in Long-run Dots

June 18, 2014 – Respondent 1:
"Factors explaining lower long term rate of FF: Lower potential growth; lower real interest rates; lower investment and perhaps higher saving as well."

June 18, 2014 – Respondent 9:
"The data suggests that there has been a sharp fall in the neutral real rate of interest since 2007. We remain below maximum employment and below target inflation, even though the market real rate of interest (over any horizon) is much lower than in 2007. This means that the neutral real rate of interest - consistent with target inflation and maximum employment - has fallen by even more."

June 18, 2014 – Respondent 14:
"My estimate of the longer-run normal level of the nominal (and real) federal funds rate of 3.5% (and 1.5%) are consistent with estimates from the staff's three factor model. This estimate likely reflects some pessimism about the prospects for longer-run growth, consistent, for example, with current Laubach-Williams estimates of trend GDP growth."

June 18, 2014 – Respondent 15:
"Another factor informing our assessment of the appropriate path for the target FFR is our estimate of the equilibrium real short-term interest rate. We assume that in normal times this rate is in the range of 1% - 3%; adding the objective for inflation (2%) then gives our estimated range for nominal equilibrium rate as 3.0 - 5.0%. Given the behavior of nominal and real Treasury yields and productivity growth since the end of the recession, we see this rate over the longer run as more likely to be in the lower half of the indicated range, ... "

June 18, 2014 – Respondent 16:
"As regards the longer-run equilibrium interest rate, long-forward TIPs rates have moved downward by about a percentage point since the 2007:Q4 business-cycle peak. Also, estimates of the economy's growth potential have shifted downward by nearly a percentage point over the past ten years, and theory suggests that changes in growth prospects translate into changes in the equilibrium real interest rate in the same direction. However, it's likely that some of the reduction in long-forward TIPs rates is due to an unusually low term premium. And it may well be that analysts are being unduly pessimistic about future growth prospects. Nevertheless, I've penciled in a 3.75 percent longer-run policy rate, down from the 4.0 percent rate I submitted last time."

December 17, 2014 – Respondent 3:
"There is an enormous amount of uncertainty around a point forecast of unemployment that far into the future, and around the natural rate as well."

December 17, 2014 – Respondent 14:
"I have lowered my longer-run normal value of the federal funds by 25 basis points based on my view that the long-run real rate of interest is somewhat lower."

March 17, 2015 – Respondent 2:
"I reduced my estimate of the equilibrium real rate from 1.75% to 1.5%, and therefore reduced my estimate of the long run nominal federal funds rate from 3.75% to 3.5%. There are many reasons, including the longer term trend to ever lower rates, higher global saving, greater risk aversion, slower growth and lower investment."

March 17, 2015 – Respondent 5:
"I reduced my long-run federal funds rate to 4.0% from 4.25%. This change reflects a reduction in my estimate of long-run real GDP growth to 2.0% from 2.3%."

March 17, 2015 – Respondent 6:
"The longer-run neutral value of the federal funds rate has been reduced from 3.75 percent to 3.5 percent, to reflect in part a downward revision to the longer-run estimate of the growth of potential GDP."

March 17, 2015 – Respondent 8:
"I have reduced my estimate of the longer-run normal value of the federal funds rate since the previous SEP because longer-term nominal market interest rates have fallen even further in the last six months."

March 17, 2015 – Respondent 9:
"My estimates of the longer-run normal level of the nominal and real federal funds rate are unchanged at 3.5% and 1.5%, respectively, and are the same as the staff's newly revised estimates."

June 17, 2015 – Respondent 5:
"Also, I have again marked down my projection of the longer run target federal funds rate, which has also prompted me to make the path from zero to fully normalized still less steep."

June 17, 2015 – Respondent 6:
"I have increased my estimate of the longer-run normal value of the federal funds rate since the previous SEP because longer-term nominal market interest rates have come back up in the last quarter."

September 17, 2015 – Respondent 4:
"I reduced my estimate of the longer-run federal funds rate from 4.25 percent to 3.75 percent, and my estimate of longer-run real GDP growth from 2.3 percent to 1.8 percent. The revision to longer-run real GDP growth reflects demographics that I now anticipate will exert a bit more influence on trend growth sooner than previously estimated. Productivity growth has also been low, so I've taken on as part of my forecast a slightly slower trend in productivity growth. To appropriately reflect lower longer-run real GDP growth, I marked down my estimate of the longer-run real federal funds rate."

September 17, 2015 – Respondent 5:
"However, with the reduction in our assumptions for trend productivity growth and potential GDP growth, we now assess that the equilibrium rate is more likely to be further in the lower half of that range, leading to our point estimate of 3 1/4%, ... Estimates of the equilibrium rate using DSGE models and the Laubach-Williams model also suggest that the equilibrium rate remains low."

Note: The table shows FOMC members assessment on why long-run rates have declined. The exact question regarding *"Key Factors Informing Your Judgement regarding the Appropriate Path of the Federal Funds Rate"* that Fed officials get asked is *"If you have reduced your estimate of the longer-run normal value of the federal funds rate since the previous SEP [Statement of Economic Projections], please indicate the factor or factors accounting for the change."*. Theses responses (as well as other detailed information contained in the Statement of Economic Projections) are released with a lag of 6 years.

C.3 Reaction of Other Financial Assets to the Long-run Dots

Table C.2: Reaction of Other Financial Assets to the Long-run Dots

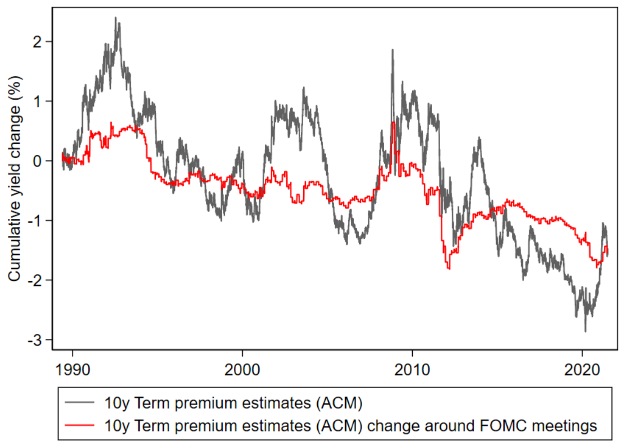
5y Treasury yield	0.57**	(0.25)
10y Treasury yield	0.52**	(0.21)
5y5y Treasury forward rate	0.47**	(0.19)
Equity return (S&P500) (1 day change)	-2.79	(1.68)
Equity return (S&P500) (2 day change)	-3.96	(4.15)
5y TIPS yield	0.81**	(0.33)
10y TIPS yield (5 day change)	0.78**	(0.35)
5y5y TIPS forward rate (5 day change)	0.72**	(0.30)

Note: Table shows the results of regression (6). The unit of observation is an FOMC meeting during which the dot plot was released. The dependent variable is the 2-day change in any of the financial assets specified. The explanatory variable is the meeting-to-meeting change in the FOMC partipicants' mean forecast for the long-term level of the federal funds rate. U.S. Treasury and TIPS yields are obtained from Gürkaynak et al. (2007) and Gürkaynak et al. (2010). The S&P500 return is obtained from Bloomberg. Davidson-MacKinnon standard errors are shown in parentheses. Significance levels: *(p<0.10), **(p<0.05), ***(p<0.01).

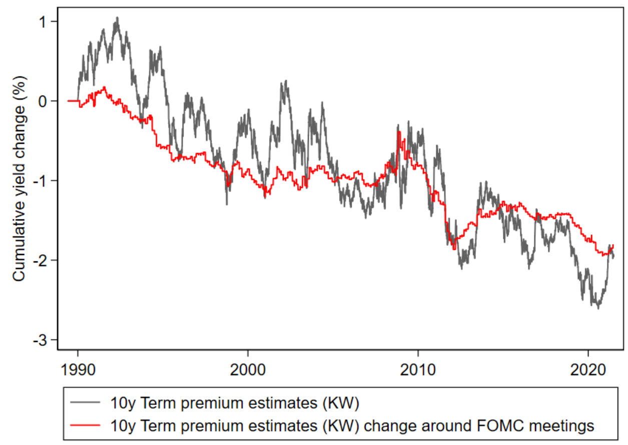
D Alternative Explanations – Additional Information

Figure E.1: Term Premia Estimates around FOMC Meetings

(A) Estimates from Adrian et al. (2013)



(B) Estimates from Kim and Wright (2005)



Note: This figure documents how 10y term premium estimates changed in the 3-day window around FOMC meetings. The 3-day window includes for every FOMC meeting the day prior to the meeting, the day of the meeting and the day after the meeting. The analysis includes all FOMC meetings from June 1989 to June 2021.

E A Model of Long-run Fed Guidance – Additional Information

E.1 General Kalman Filter

The paper relies on the frequent application of the Kalman filter. As a result, I re-state the general Kalman filter here closely following Ljungqvist and Sargent (2018). To bring the notation closer to my paper I use, $\hat{x}_t = \hat{s}_{t+1|t}$, $A_o = P$, $R = \Sigma_y$, $CC' = \Sigma_\epsilon$.

There is a hidden state s that evolves according (state equation)

$$s_{t+1} = Ps_t + w_{t+1}, \qquad w_{t+1} \sim \mathcal{N}(0, \Sigma_\epsilon). \tag{D.1}$$

The agent observes only a noisy signal y_t, which is a function of the underlying hidden state s_t. The relationship between the variables is given by the measurement equation

$$y_t = Gs_t + v_t, \qquad v_t \sim \mathcal{N}(0, \Sigma_y), \tag{D.2}$$

where w_{t+1} and v_t are assumed to be orthogonal.

The Kalman filter then gives the recursion of the agent's beliefs for the unobserved state s in one-period

$$\begin{aligned} \widetilde{K}_t &= P\Sigma_{t|t-1}G' \left(G\Sigma_{t|t-1}G' + \Sigma_y\right)^{-1} \\ \hat{s}_{t+1|t} &= P\hat{s}_{t|t-1} + \widetilde{K}_t \left(y_t - G\hat{s}_{t|t-1}\right) \\ \Sigma_{t+1|t} &= \Sigma_\epsilon + \widetilde{K}_t\Sigma_y\widetilde{K}_t' + \left(P - \widetilde{K}_tG\right)\Sigma_{t|t-1}\left(P - \widetilde{K}_tG\right)', \end{aligned} \tag{D.3}$$

where $\hat{s}_{t+1|t} = \mathbb{E}[s_{t+1}|y_t, y_{t-1}, ...]$ and $\Sigma_{t+1|t} = \mathbb{V}(s_{t+1}|y_t, y_{t-1}, ...)$.

Using $\hat{s}_{t+1|t} = P\hat{s}_t$, where $\hat{s}_t = \mathbb{E}[s_t|y_t, y_{t-1}, ...]$, we can derive the recursion of the mean belief for the unobserved state s in the current period

$$\begin{aligned} K_t &= \Sigma_{t|t-1}G' \left(G\Sigma_{t|t-1}G' + \Sigma_y\right)^{-1} \\ \hat{s}_t &= P\hat{s}_{t-1} + K_t\left(y_t - GP\hat{s}_{t-1}\right). \end{aligned} \tag{D.4}$$

As time passes and $t \to \infty$, the uncertainty matrix $\Sigma_{t+1|t}$ converges to a constant matrix Σ and this matrix is given by the matrix Ricatti equation

$$\Sigma = \Sigma_\epsilon + \widetilde{K}\Sigma_y\widetilde{K}' + \left(P - \widetilde{K}G\right)\Sigma\left(P - \widetilde{K}G\right)', \tag{D.5}$$

which uses the fact that the Kalman gain K is now also constant over time.

E.2 Derivations – Stylized Model

E.2.1 Derivation of Equation (15) – Solving for Higher-order Beliefs

I focus on the case in which the Market conjectures that the Fed backs out the signal m_t by observing bond yields and then optimally forms its expectation given its information set. I will later verify that this conjecture is indeed an equilibrium.

Under the assumed conjecture, the Fed observes all available information (both signals f_t and m_t), and we can use the tower property of the conditional expectation to derive the market's expectation of the Fed'expectation about i^*, i.e. $\mathbb{E}^M_{t^-}\left[\mathbb{E}^F_t\left[i^*_t\right]\right] = \mathbb{E}^M_{t^-}\left[i^*_t\right]$. To illustrate this further, denote the filtration generated by the available information to the Market at time t^- as $\mathcal{F}^M_{t^-}$ and the filtration generated by the available information to the Fed at time t as $\mathcal{F}^F_t$, then it follows that $\mathcal{F}^M_{t^-} \subset \mathcal{F}^F_t$. Then, we can apply the tower property

$$\mathbb{E}^M_{t^-}\left[\mathbb{E}^F_t\left[i^*_t\right]\right] \overset{\text{def}}{=} \mathbb{E}\left[\mathbb{E}\left[i^*_t|\mathcal{F}^F_t\right]|\mathcal{F}^M_{t^-}\right] = \mathbb{E}\left[i^*_t|\mathcal{F}^M_{t^-}\right] \overset{\text{def}}{=} \mathbb{E}^M_{t^-}\left[i^*_t\right]. \tag{D.6}$$

Thus, the Market has the same expectation for the Fed belief $\mathbb{E}^F_t\left[i^*_t\right]$ as its expectation for i^*_t. A similar results holds for the Market's expectation about the future Fed belief, i.e. for $j > 1$

$$\begin{aligned}\mathbb{E}^M_{t^-}\left[\mathbb{E}^F_{t+j}\left[i^*_{t+j}\right]\right] &\overset{\text{def}}{=} \mathbb{E}\left[\mathbb{E}\left[i^*_{t+j}|\mathcal{F}^F_{t+j-1}\right]|\mathcal{F}^M_{t^-}\right] = \mathbb{E}\left[\mathbb{E}\left[i^*_t + \sum_{l=1}^{j}\epsilon_{t+l}|\mathcal{F}^F_{t+j-1}\right]|\mathcal{F}^M_{t^-}\right] \\ &= \mathbb{E}\left[i^*_t|\mathcal{F}^M_{t^-}\right] + \sum_{l=1}^{j}\mathbb{E}\left[\epsilon_{t+l}|\mathcal{F}^M_{t^-}\right] = \mathbb{E}\left[i^*_t|\mathcal{F}^M_{t^-}\right] \overset{\text{def}}{=} \mathbb{E}^M_{t^-}\left[i^*_t\right].\end{aligned} \tag{D.7}$$

Combining equations (D.6) and (D.7), we can derive bond yields before the FOMC meeting as

$$y_{k,t^-} = \frac{1}{k}\sum_{j=0}^{k-1}\mathbb{E}^M_{t^-}\left[y_{1,t+j}\right] = \frac{1}{k}\sum_{j=0}^{k-1}\mathbb{E}^M_{t^-}\left[\mathbb{E}^F_{t+j}\left[i^*_{t+j}\right]\right] = \mathbb{E}^M_{t^-}\left[i^*_t\right] \quad \forall k \geq 1. \tag{D.8}$$

Thus, the yield curve is perfectly flat and all bond yields are equal to the Market's expectation of the long-run nominal rate i^*.

Verification of equilibrium: We need to verify that the conjecture of the market indeed constitutes an equilibrium. For this, we need to verify that the Fed can indeed back out the Market signal m_t from interest rates, i.e. that the Market conjecture is fulfilled in equilibrium. Note that the Fed knows from equation (D.8) that bond yields equal the Market's belief about the long-run rate, i.e. $y_{k,t^-} = \mathbb{E}^M_{t^-}\left[i^*_t\right]$, and the same will be true for the observed bond yields at the end of the prior period $t-1^+$, i.e. $y_{k,t-1^+} = \mathbb{E}^M_{t-1^+}\left[i^*_{t-1}\right]$. Re-arranging the evolution of the Market belief (derived in equation (16)), we can write

$$\begin{aligned}m_t &= \frac{1}{(\sigma^M_+)^2}\left[\left((\sigma^M_+)^2 + \sigma^2_m\right)\mathbb{E}^M_{t^+}\left[i^*_t\right] - \sigma^2_m\mathbb{E}^M_{t-1^+}\left[i^*_{t-1}\right]\right] \\ &= \frac{1}{(\sigma^M_+)^2}\left[\left((\sigma^M_+)^2 + \sigma^2_m\right)y_{k,t^-} - \sigma^2_m y_{k,t-1^+}\right]\end{aligned} \tag{D.9}$$

As all right-hand side objects are observed by the Fed, the Fed can back out the left-hand side, i.e., the Market signal m_t. This verifies the conjectured equilibrium.

E.2.2 Derivation of Equation (16) – Update in Market beliefs after observing Market signal.

Using the Kalman filter stated in equation (D.4) and plugging in $\hat{s}_{t-1} = \mathbb{E}^M_{t-1^+}\left[i^*_{t-1}\right]$, $P = 1$, $G = 1$, $\Sigma = (\sigma^M_+)^2$, and $\Sigma_y = \sigma_m$ we can easily derive

$$\begin{aligned} K &= \frac{(\sigma^M_+)^2}{(\sigma^M_+)^2 + \sigma^2_m} \\ \mathbb{E}^M_{t^-}\left[i^*_t\right] &= \mathbb{E}^M_{t-1^+}\left[i^*_{t-1}\right] + K\left(m_t - \mathbb{E}^M_{t-1^+}\left[i^*_{t-1}\right]\right) \end{aligned} \tag{D.10}$$

E.2.3 Derivation of Equation (17) – Evolution of Fed belief.

Note that the measurement equation of the Fed is given by, as it observes both the Market and the Fed signal,

$$\begin{pmatrix} m_t \\ f_t \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \end{pmatrix} i^*_t + \begin{pmatrix} \nu^m_t \\ \nu^m_t \end{pmatrix}, \quad \begin{pmatrix} \nu^m_t \\ \nu^F_t \end{pmatrix} \sim \mathcal{N}\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma^2_m & 0 \\ 0 & \sigma^2_f \end{pmatrix}\right) \tag{D.11}$$

The Fed updates its mean beliefs according to

$$\begin{aligned} \mathbb{E}^F_t\left[i^*_t\right] &= \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right] + (\sigma^F)^2 \begin{pmatrix} 1 & 1 \end{pmatrix} \left(\begin{pmatrix} 1 \\ 1 \end{pmatrix} (\sigma^F)^2 \begin{pmatrix} 1 & 1 \end{pmatrix} + \begin{pmatrix} \sigma^2_m & 0 \\ 0 & \sigma^2_f \end{pmatrix}\right)^{-1} \begin{pmatrix} m_t - \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right] \\ f_t - \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right] \end{pmatrix} \\ &= \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right] + (\sigma^F)^2 \begin{pmatrix} 1 & 1 \end{pmatrix} \begin{pmatrix} (\sigma^F)^2 + \sigma^2_m & (\sigma^F)^2 \\ (\sigma^F)^2 & (\sigma^F)^2 + \sigma^2_f \end{pmatrix}^{-1} \begin{pmatrix} m_t - \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right] \\ f_t - \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right] \end{pmatrix} \\ &= \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right] + \frac{(\sigma^F)^2}{((\sigma^F)^2 + \sigma^2_m)\left((\sigma^F)^2 + \sigma^2_f\right) - ((\sigma^F)^2)^2} \left[\sigma^2_f\left(m_t - \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right]\right) + \sigma^2_m\left(f_t - \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right]\right)\right] \\ &= \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right] + \frac{(\sigma^F)^2}{(\sigma^F)^2\sigma^2_m + (\sigma^F)^2\sigma^2_f + \sigma^2_m\sigma^2_f} \left[\sigma^2_f\left(m_t - \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right]\right) + \sigma^2_m\left(f_t - \mathbb{E}^F_{t-1}\left[i^*_{t-1}\right]\right)\right] \end{aligned} \tag{D.12}$$

The posterior variance evolves according to

$$(\sigma^F)^2 = \sigma^2_\epsilon + K^F \begin{pmatrix} \sigma^2_m & 0 \\ 0 & \sigma^2_f \end{pmatrix} K^{F\prime} + \left(1 - K^F \begin{pmatrix} 1 \\ 1 \end{pmatrix}\right)^2 (\sigma^F)^2 \tag{D.13}$$

where

$$K^F = \frac{(\sigma^F)^2}{(\sigma^F)^2\left(\sigma^2_m + \sigma^2_f\right) + \sigma^2_m\sigma^2_f} \begin{pmatrix} \sigma^2_f & \sigma^2_m \end{pmatrix}$$

Solving this:

$$\begin{aligned}(\sigma^F)^2 &= \sigma_\epsilon^2 + \frac{(\sigma^F)^4\sigma_f^2\sigma_m^2\left(\sigma_f^2+\sigma_m^2\right)}{\left((\sigma^F)^2\sigma_m^2+(\sigma^F)^2\sigma_f^2+\sigma_m^2\sigma_f^2\right)^2} + \frac{\sigma_m^4\sigma_f^4}{\left((\sigma^F)^2\sigma_m^2+(\sigma^F)^2\sigma_f^2+\sigma_m^2\sigma_f^2\right)^2}(\sigma^F)^2 \\ &= \sigma_\epsilon^2 + \frac{(\sigma^F)^2\sigma_m^2\sigma_f^2}{(\sigma^F)^2\sigma_m^2+(\sigma^F)^2\sigma_f^2+\sigma_m^2\sigma_f^2}\end{aligned} \tag{D.14}$$

E.2.4 Derivation of Equation (21) – Dot Plot Regression Coefficient

To shorten the terms, let define

$$\alpha = (\sigma_+^M)^2\sigma_m^2 + (\sigma_+^M)^2\sigma_f^2 + \sigma_m^2\sigma_f^2. \tag{D.15}$$

We want to find the regression coefficient

$$\beta_{\text{Dots}} = \frac{Co\mathbb{V}\left(y_{k,t^+}-y_{k,t^-}, \mathbb{E}_t^F\left[i_t^*\right]-\mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right)}{\mathbb{V}\left(\mathbb{E}_t^F\left[i_t^*\right]-\mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right)} = \frac{Co\mathbb{V}\left(\hat{i}_{t+}^M-\mathbb{E}_{t^-}^M\left[i_t^*\right], \mathbb{E}_t^F\left[i_t^*\right]-\mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right)}{\mathbb{V}\left(\mathbb{E}_t^F\left[i_t^*\right]-\mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right)} \tag{D.16}$$

We can re-arrange the explanatory variable

$$\begin{aligned}\mathbb{E}_t^F\left[i_t^*\right]-\mathbb{E}_{t-1}^F\left[i_{t-1}^*\right] &= \frac{1}{\alpha}\left(\sigma_m^2\sigma_f^2\mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]+(\sigma^F)^2\sigma_m^2 f_t+(\sigma^F)^2\sigma_f^2 m_t\right)-\mathbb{E}_{t-1}^F\left[i_{t-1}^*\right] \\ &= \frac{1}{\alpha}\left((\sigma^F)^2\sigma_m^2\nu_t^f+(\sigma^F)^2\sigma_f^2\nu_t^m+(\sigma^F)^2\left(\sigma_m^2+\sigma_f^2\right)\left(i_t^*-\mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right)\right)\end{aligned} \tag{D.17}$$

To get an expression for the dependent variable, first note that we can write

$$\begin{aligned}y_{k,t^+}-y_{k,t^-} &= \mathbb{E}_{t^+}^M\left[i_t^*\right]-\mathbb{E}_{t^-}^M\left[i_t^*\right] \\ &= \frac{1}{\alpha}\left(\sigma_m^2\sigma_f^2\,\mathbb{E}_{t-1^+}^M\left[i_{t-1}^*\right]+(\sigma_+^M)^2\sigma_m^2\,f_t+(\sigma_+^M)^2\sigma_f^2\,m_t\right)-\left(\frac{\sigma_m^2}{(\sigma_+^M)^2+\sigma_m^2}\mathbb{E}_{t-1^+}^M\left[i_{t-1}^*\right]+\frac{(\sigma_+^M)^2}{(\sigma_+^M)^2+\sigma_m^2}m_t\right) \\ &= \frac{(\sigma_+^M)^2\sigma_m^2}{\alpha\left((\sigma_+^M)^2+\sigma_m^2\right)}\left(\left((\sigma_+^M)^2+\sigma_m^2\right)f_t-\sigma_m^2\mathbb{E}_{t-1^+}^M\left[i_{t-1}^*\right]-(\sigma_+^M)^2 m_t\right) \\ &= \frac{(\sigma_+^M)^2\sigma_m^2}{\alpha\left((\sigma_+^M)^2+\sigma_m^2\right)}\left(\sigma_m^2(f_t-\mathbb{E}_{t-1^+}^M\left[i_{t-1}^*\right])+\sigma_f^2(f_t-m_t)\right) \\ &= \frac{(\sigma_+^M)^2\sigma_m^2}{\alpha\left((\sigma_+^M)^2+\sigma_m^2\right)}\left(\sigma_m^2\nu_t^F+\sigma_f^2(\nu_t^F-\nu_t^M)+\sigma_m^2(i_t^*-\mathbb{E}_{t-1^+}^M\left[i_{t-1}^*\right])\right)\end{aligned} \tag{D.18}$$

Using the fact that, at the end of each period, the Fed's and the Market's belief, i.e., $\mathbb{E}_{t-1^+}^M\left[i_{t-1}^*\right] = \mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]$ and $(\sigma^F)^2 = (\sigma_+^M)^2$, we can write this as

$$y_{k,t^+}-y_{k,t^-} = \frac{(\sigma^F)^2\sigma_m^2}{\alpha\left((\sigma^F)^2+\sigma_m^2\right)}\left(\sigma_m^2\nu_t^F+\sigma_f^2(\nu_t^F-\nu_t^M)+\sigma_m^2(i_t^*-\mathbb{E}_{t-1}^F\left[i_{t-1}^*\right])\right) \tag{D.19}$$

Then we can determine the covariance term where we can use the fact that $\mathbb{V}\left(i_t^* - \mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right) \stackrel{\text{def}}{=} (\sigma^F)^2$

$$CoV\left(y_{k,t^+} - y_{k,t^-}, \mathbb{E}_t^F\left[i_t^*\right] - \mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right) = \\ = \frac{(\sigma^F)^2\sigma_m^2}{\alpha^2\left((\sigma^F)^2 + \sigma_m^2\right)}\left[(\sigma^F)^2\sigma_m^2\left(\sigma_m^2+\sigma_f^2\right)\sigma_f^2 - (\sigma^F)^2\sigma_m^4\sigma_f^4 + (\sigma^F)^4\left(\sigma_m^2+\sigma_f^2\right)\sigma_m^2\right] \tag{D.20}$$

and the variance of $\mathbb{E}_t^F\left[i_t^*\right] - \mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]$

$$\mathbb{V}\left(\mathbb{E}_t^F\left[i_t^*\right] - \mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right) = \frac{1}{\alpha^2}\left[(\sigma^F)^4\sigma_m^4\sigma_f^2 + (\sigma^F)^4\sigma_f^4\sigma_m^2 + (\sigma^F)^4\left(\sigma_m^2+\sigma_f^2\right)(\sigma^F)^2\right] \tag{D.21}$$

Putting everything together, we obtain

$$\begin{aligned}\beta_{\text{Dots}} &= \frac{CoV\left(y_{k,t^+} - y_{k,t^-}, \mathbb{E}_t^F\left[i_t^*\right] - \mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right)}{\mathbb{V}\left(\mathbb{E}_t^F\left[i_t^*\right] - \mathbb{E}_{t-1}^F\left[i_{t-1}^*\right]\right)} \\ &= \frac{\frac{(\sigma^F)^2\sigma_m^2}{\alpha^2\left((\sigma^F)^2+\sigma_m^2\right)}\left[(\sigma^F)^2\sigma_m^2\left(\sigma_m^2+\sigma_f^2\right)\sigma_f^2 - (\sigma^F)^2\sigma_m^4\sigma_f^4 + (\sigma^F)^4\left(\sigma_m^2+\sigma_f^2\right)\sigma_m^2\right]}{\frac{1}{\alpha^2}\left[(\sigma^F)^4\sigma_m^4\sigma_f^2 + (\sigma^F)^4\sigma_f^4\sigma_m^2 + (\sigma^F)^4\left(\sigma_m^2+\sigma_f^2\right)(\sigma^F)^2\right]} \\ &= \left[1 - \frac{(\sigma^F)^2}{(\sigma^F)^2 + \sigma_m^2}\right]\cdot\frac{1}{1+\left(\frac{\sigma_f}{\sigma_m}\right)^2}.\end{aligned} \tag{D.22}$$

E.2.5 Equivalence result – Equation (24)

We want to have a solution to

$$\mathbb{E}\left[\frac{\sum_{t=\tau+1}^{\tau+T}\left(y_{k,t^+} - y_{k,t^-}\right)}{y_{k,\tau+T^+} - y_{k,\tau^+}} \mid y_{k,\tau+T^+} - y_{k,\tau^+} = \psi\right]. \tag{D.23}$$

Note that we can equivalently write

$$\mathbb{E}\left[\frac{\sum_{t=\tau+1}^{\tau+T}\left(y_{k,t^+} - y_{k,t^-}\right)}{y_{k,\tau+T^+} - y_{k,\tau^+}} \mid y_{k,\tau+T^+} - y_{k,\tau^+} = \psi\right] = \mathbb{E}\left[\frac{1}{\psi}\sum_{t=\tau+1}^{\tau+T}\left(y_{k,t^+} - y_{k,t^-}\right) \mid y_{k,\tau+T^+} - y_{k,\tau^+} = \psi\right] \tag{D.24}$$

Because we have two jointly normally distributed variables, we can use the following formulas to derive the conditional expectation

$$\mathbb{E}\left[X \mid Y = y\right] = \mathbb{E}[X] + \frac{CoV(X,Y)}{\mathbb{V}(Y)}\left(y - \mathbb{E}[Y]\right). \tag{D.25}$$

Thus, plugging in $X=\sum_{t=\tau+1}^{\tau+T}\left(y_{k,t^+}-y_{k,t^-}\right)$ and $Y=y_{k,\tau+T^+}-y_{k,\tau^+}$, we can write

$$\begin{aligned}
&\mathbb{E}\left[\frac{\sum_{t=\tau+1}^{\tau+T}\left(y_{k,t^+}-y_{k,t^-}\right)}{y_{k,\tau+T^+}-y_{k,\tau^+}}\mid y_{k,\tau+T^+}-y_{k,\tau^+}=\psi\right]= \\
&=\frac{1}{\psi}\mathbb{E}\left[\sum_{t=\tau+1}^{\tau+T}\left(y_{k,t^+}-y_{k,t^-}\right)\right]+\frac{\frac{1}{\psi}Co\mathbb{V}\left(\sum_{t=\tau+1}^{\tau+T}\left(y_{k,t^+}-y_{k,t^-}\right),y_{k,\tau+T^+}-y_{k,\tau^+}\right)}{\mathbb{V}\left(y_{k,\tau+T^+}-y_{k,\tau^+}\right)}\left(\psi-\mathbb{E}\left[y_{k,\tau+T^+}-y_{k,\tau^+}\right]\right) \\
&=\frac{\frac{1}{\psi}Co\mathbb{V}\left(\sum_{t=\tau+1}^{\tau+T}\left(y_{k,t^+}-y_{k,t^-}\right),y_{k,\tau+T^+}-y_{k,\tau^+}\right)}{\mathbb{V}\left(y_{k,\tau+T^+}-y_{k,\tau^+}\right)}\psi \\
&=\frac{Co\mathbb{V}\left(\sum_{t=\tau+1}^{\tau+T}\left(y_{k,t^+}-y_{k,t^-}\right),y_{k,\tau+T^+}-y_{k,\tau^+}\right)}{\mathbb{V}\left(y_{k,\tau+T^+}-y_{k,\tau^+}\right)}=\delta_{T,\text{FOMC}}.
\end{aligned} \tag{D.26}$$

Note that the first line follows from the fact that the expected FOMC yield decline and the expected total yield decline are both zero, as all shocks are mean zero.

E.3 Derivations – Multivariate Model

E.3.1 The System in Matrix Notation

Dynamics. The state vector s_t is three-dimensional and contains the long-run rate i_t^*, the output gap x_t and inflation π_t. The state dynamics are given by

$$s_t=Ps_{t-1}+\epsilon_t,\qquad \text{where } \epsilon_t\sim\mathcal{N}\left(\begin{pmatrix}0\\0\\0\end{pmatrix},\begin{pmatrix}\sigma_{i,\epsilon}^2 & \sigma_{ix,\epsilon}^2 & \sigma_{i\pi,\epsilon}^2\\ \sigma_{ix,\epsilon}^2 & \sigma_{x,\epsilon}^2 & \sigma_{x\pi,\epsilon}^2\\ \sigma_{i\pi,\epsilon}^2 & \sigma_{x\pi,\epsilon}^2 & \sigma_{\pi,\epsilon}^2\end{pmatrix}\right) \tag{D.27}$$

In full matrix notation:

$$\begin{aligned}
\begin{pmatrix}i_t^*\\x_t\\\pi_t\end{pmatrix}&=\begin{pmatrix}\rho_i & \rho_{ix} & \rho_{i\phi}\\ \rho_{xi} & \rho_x & \rho_{x\pi}\\ \rho_{\pi i} & \rho_{\pi x} & \rho_\pi\end{pmatrix}\begin{pmatrix}i_{t-1}^*\\x_{t-1}\\\pi_{t-1}\end{pmatrix}+\begin{pmatrix}\epsilon_{i,t}\\\epsilon_{x,t}\\\epsilon_{\pi,t}\end{pmatrix} \\
&=\begin{pmatrix}\rho_i i_{t-1}^*+\rho_{ix}x_{t-1}+\rho_{i\pi}\pi_{t-1}+\epsilon_{i,t}\\ \rho_{xi}i_{t-1}^*+\rho_x x_{t-1}+\rho_{x\pi}\pi_{t-1}+\epsilon_{x,t}\\ \rho_{\pi i}i_{t-1}^*+\rho_{\pi x}x_{t-1}+\rho_\pi\pi_{t-1}+\epsilon_{\pi,t}\end{pmatrix}.
\end{aligned} \tag{D.28}$$

Signals.

The Fed receives a private three-dimensional private signal vector

$$f_t=s_t+\nu_t^f,\qquad \text{where}\quad \nu_t^f\sim\mathcal{N}\left(\begin{pmatrix}0\\0\\0\end{pmatrix},\begin{pmatrix}\sigma_{i,f}^2 & 0 & 0\\ 0 & \sigma_{x,f}^2 & 0\\ 0 & 0 & \sigma_{\pi,f}^2\end{pmatrix}\right) \tag{D.29}$$

In full matrix notation:

$$\begin{pmatrix} f_{i,t} \\ f_{x,t} \\ f_{\pi,t} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} i_t^* \\ x_t \\ \pi_t \end{pmatrix} + \begin{pmatrix} \nu_{i,t}^f \\ \nu_{x,t}^f \\ \nu_{\pi,t}^f \end{pmatrix} = \begin{pmatrix} i_t^* + \nu_{i,t}^f \\ x_t + \nu_{x,t}^f \\ \pi_t + \nu_{\pi,t}^f \end{pmatrix} \tag{D.30}$$

Similarly, the Market also receives a private signal vector about the states

$$m_t = s_t + \nu_t^m, \qquad \text{where} \quad \nu_t^m \sim \mathcal{N}\left(\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{i,m}^2 & 0 & 0 \\ 0 & \sigma_{x,m}^2 & 0 \\ 0 & 0 & \sigma_{\pi,m}^2 \end{pmatrix} \right) \tag{D.31}$$

In full matrix notation:

$$\begin{pmatrix} m_{i,t} \\ m_{x,t} \\ m_{\pi,t} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} i_t^* \\ x_t \\ \pi_t \end{pmatrix} + \begin{pmatrix} \nu_{i,t}^m \\ \nu_{x,t}^m \\ \nu_{\pi,t}^m \end{pmatrix} = \begin{pmatrix} i_t^* + \nu_{i,t}^m \\ x_t + \nu_{x,t}^m \\ \pi_t + \nu_{\pi,t}^m \end{pmatrix} \tag{D.32}$$

E.3.2 Evolution of Market Belief Before Fed Meeting.

Using the Kalman filter, we can obtain the Market's expectation about the current underlying state s_t at time t^-, i.e. before the FOMC meeting,

$$\mathbb{E}_{t^-}^M [s_t] = P\mathbb{E}_{t-1^+}^M [s_{t-1}] + \Sigma_+^M (\Sigma_+^M + \Sigma_m)^{-1} \cdot (m_t - P\mathbb{E}_{t-1^+}^M [s_{t-1}]). \tag{D.33}$$

E.3.3 Evolution of Fed Belief.

The Fed observes the signals f_t and m_t. Thus, the measurement equation with two signals is given by

$$\begin{pmatrix} m_t \\ f_t \end{pmatrix} = \begin{pmatrix} \mathbf{I} \\ \mathbf{I} \end{pmatrix} s_t + \begin{pmatrix} \nu_t^f \\ \nu_t^m \end{pmatrix}, \text{ where } \begin{pmatrix} \nu_t^f \\ \nu_t^m \end{pmatrix} \sim \mathcal{N}\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \Sigma_m & 0 \\ 0 & \Sigma_f \end{pmatrix} \right) \tag{D.34}$$

Translating into the notation of Section E.1, we can set $y_t = \begin{pmatrix} m_t \\ f_t \end{pmatrix}$, $G = \begin{pmatrix} \mathbf{I} \\ \mathbf{I} \end{pmatrix}$ and $\Sigma_y = \begin{pmatrix} \Sigma_m & 0 \\ 0 & \Sigma_f \end{pmatrix}$.

We can determine the Kalman gain according to

$$\begin{aligned} K^F = \begin{pmatrix} K_f^F & K_m^F \end{pmatrix} &= \begin{pmatrix} \Sigma^F & \Sigma^F \end{pmatrix} \left[\begin{pmatrix} \Sigma^F & \Sigma^F \\ \Sigma^F & \Sigma^F \end{pmatrix} + \begin{pmatrix} \Sigma_f & 0 \\ 0 & \Sigma_m \end{pmatrix} \right]^{-1} \\ &= \begin{pmatrix} \Sigma^F & \Sigma^F \end{pmatrix} \cdot \begin{pmatrix} \Sigma^F + \Sigma_f & \Sigma^F \\ \Sigma^F & \Sigma^F + \Sigma_m \end{pmatrix}^{-1}. \end{aligned} \tag{D.35}$$

This means the Fed update its belief according to

$$\begin{aligned}
\mathbb{E}_t^F[s_t] &= P\mathbb{E}_{t-1}^F[s_{t-1}] + K^F\left[\begin{pmatrix} f_t \\ m_t \end{pmatrix} - \begin{pmatrix} \mathbf{I} \\ \mathbf{I} \end{pmatrix} P\mathbb{E}_{t-1}^F[s_{t-1}]\right] \\
&= P\mathbb{E}_{t-1}^F[s_{t-1}] + K^F\begin{pmatrix} f_t - P\mathbb{E}_{t-1}^F[s_{t-1}] \\ m_t - P\mathbb{E}_{t-1}^F[s_{t-1}] \end{pmatrix} \\
&= P\mathbb{E}_{t-1}^F[s_{t-1}] + K_f^F\left(f_t - P\mathbb{E}_{t-1}^F[s_{t-1}]\right) + K_m^F\left(m_t - P\mathbb{E}_{t-1}^F[s_{t-1}]\right) \\
&= \left(\mathbf{I} - K_f^F - K_m^F\right)P\mathbb{E}_{t-1}^F[s_{t-1}] + \left(K_f^F + K_m^F\right)s_t + K_f^F\nu_t^f + K_m^F\nu_t^m.
\end{aligned} \tag{D.36}$$

Moreover, the steady-state belief uncertainty is given by

$$\Sigma^F = \Sigma_\epsilon + K^F\begin{pmatrix} \Sigma_m & 0 \\ 0 & \Sigma_f \end{pmatrix}K^{F\prime} + \left(P - K^F\begin{pmatrix} \mathbf{I} \\ \mathbf{I} \end{pmatrix}\right)\Sigma^F\left(P - K^F\begin{pmatrix} \mathbf{I} \\ \mathbf{I} \end{pmatrix}\right)^{\prime}. \tag{D.37}$$

E.3.4 Evolution of Market Belief after Fed Meeting

Case I - without dot plot release.

Then we can write the short-rate $y_{1,t}$ that the Fed sets as

$$\begin{aligned}
y_{1,t} &= \Phi'\mathbb{E}_t^F[s_t] = \Phi'\left[\left(\mathbf{I} - K_f^F - K_m^F\right)P\mathbb{E}_{t-1}^F[s_{t-1}] + \left(K_f^F + K_m^F\right)s_t + K_f^F\nu_t^f + K_m^F\nu_t^m\right] \\
&= \Phi'\left(\mathbf{I} - K_f^F - K_m^F\right)P\mathbb{E}_{t-1}^F[s_{t-1}] + \Phi'\left(K_f^F + K_m^F\right)s_t + \Phi'K_f^F\nu_t^f + \Phi'K_m^F\nu_t^m.
\end{aligned} \tag{D.38}$$

We can then express the measurement equation of the Market

$$\begin{pmatrix} m_t \\ y_{1,t} \end{pmatrix} = \begin{pmatrix} 0 & \mathbf{I} & \mathbf{I} & 0 \\ \Phi'\left(\mathbf{I} - K_f^F - K_m^F\right)P & \Phi'\left(K_f^F + K_m^F\right) & \Phi'K_m^F & \Phi'K_f^F \end{pmatrix} \cdot \begin{pmatrix} \mathbb{E}_{t-1}^F[s_{t-1}] \\ s_t \\ \nu_t^m \\ \nu_t^f \end{pmatrix} \tag{D.39}$$

and rewrite the state space system as:

$$\begin{pmatrix} \mathbb{E}_t^F[s_t] \\ s_{t+1} \\ \nu_{t+1}^m \\ \nu_{t+1}^f \end{pmatrix} = \begin{pmatrix} \left(\mathbf{I} - K_m^F - K_f^F\right)P & \left(K_f^F + K_m^F\right) & K_m^F & K_f^F \\ 0 & P & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} \mathbb{E}_{t-1}^F[s_{t-1}] \\ s_t \\ \nu_t^m \\ \nu_t^f \end{pmatrix} + \begin{pmatrix} 0 \\ \epsilon_{t+1} \\ \nu_{t+1}^m \\ \nu_{t+1}^f \end{pmatrix}, \tag{D.40}$$

where the variance of the shocks is given by

$$\mathbb{V}\begin{pmatrix} 0 \\ \epsilon_{t+1} \\ \nu_{t+1}^m \\ \nu_{t+1}^f \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & \Sigma_\epsilon & 0 & 0 \\ 0 & 0 & \Sigma_m & 0 \\ 0 & 0 & 0 & \Sigma_f \end{pmatrix}. \tag{D.41}$$

Applying the Kalman filter to this system yields $\mathbb{E}^M_{t^+}[i^*_t]$ and Σ^M_+.

Case II - with dot plot release.
We can rewrite the dot plot $\mathbb{E}^F_t[i^*_t]$ as

$$\begin{aligned}\mathbb{E}^F_t[i^*_t] &= (1,0,0)\ \mathbb{E}^F_t[s_t] = (1,0,0)\ \left[\left(\mathbf{I}-K^F_f-K^F_m\right)P\mathbb{E}^F_{t-1}[s_{t-1}] + \left(K^F_f+K^F_m\right)s_t + K^F_f\nu^f_t + K^F_m\nu^m_t\right] \\ &= (1,0,0)\ \left(\mathbf{I}-K^F_f-K^F_m\right)P\mathbb{E}^F_{t-1}[s_{t-1}] + (1,0,0)\ \left(K^F_f+K^F_m\right)s_t + (1,0,0)\ K^F_f\nu^f_t + (1,0,0)\ K^F_m\nu^m_t.\end{aligned} \tag{D.42}$$

Thus, if the Fed releases the dot plot $\mathbb{E}^F_t[i^*_t]$, then the measurement equation of the Market changes to

$$\begin{pmatrix} m_t \\ y_{1,t} \\ \mathbb{E}^F_t[i^*_t]\end{pmatrix} = \begin{pmatrix} 0 & \mathbf{I} & \mathbf{I} & 0 \\ \Phi'\left(\mathbf{I}-K^F_f-K^F_m\right)P & \Phi'\left(K^F_f+K^F_m\right) & \Phi' K^F_m & \Phi' K^F_f \\ (1,0,0)\ \left(\mathbf{I}-K^F_f-K^F_m\right)P & (1,0,0)\ \left(K^F_f+K^F_m\right) & (1,0,0)\ K^F_m & (1,0,0)\ K^F_f \end{pmatrix}. \\ \cdot\begin{pmatrix} \mathbb{E}^F_{t-1}[s_{t-1}] \\ s_t \\ \nu^m_t \\ \nu^f_t. \end{pmatrix} \tag{D.43}$$

The state-space system is the same in equation (D.40) and (D.41).

Applying the Kalman filter to this system yields $\mathbb{E}^M_{t^+}[i^*_t]$ and Σ^M_+.

E.4 Recursive Bond Pricing At Time t^-

The full model assumes that bonds are priced by the market in the Euler equation. Drawing on the affine term structure literature (Duffie and Kan, 1996; Duffee, 2002, e.g.), I assume that the stochastic discount factor is an affine function of the shocks to the Market's belief about the macroeconomic states. More specifically, the stochastic discount factor (sdf) at time t^-, i.e. *before* the FOMC meeting in period t, pricing cash flows or interest proceeds that are realized in the next period at time $t+1^-$ as

$$\mathcal{M}_{t^-,t+1^-} = \exp\left\{-\mathbb{E}^M_{t^-}[y_{1,t}] - \Lambda'_{t^-}\left(\mathbb{E}^M_{t+1^-}[s_{t+1}] - \mathbb{E}^M_{t^-}\left[\mathbb{E}^M_{t+1^-}[s_{t+1}]\right]\right) - \frac{1}{2}\Lambda'_{t^-}\widetilde{\Sigma}^M_-\Lambda_{t^-}\right\}, \tag{D.44}$$

where the price of risk is $\Lambda_{t^-} = \Lambda_0 + \Lambda_1\mathbb{E}^M_{t^-}[s_t]$ and $\widetilde{\Sigma}^M_- = \mathbb{V}^M_{t^-}\left(\mathbb{E}^M_{t+1^-}[s_{t+1}]\right)$ is the Market's conditional uncertainty about its own belief in the next period. $\widetilde{\Sigma}^M_-$ can be shown to equal $\Sigma^M_- - (P')^{-1}\left(\Sigma^M_- - \Sigma_\epsilon\right)P^{-1}$. The same relation also holds for $\widetilde{\Sigma}^M_+$ (following below).

Bond prices and yields follow the usual recursion in affine term structure models. Again, what is different in this model is that the term structure state variable is the Market's expectation of the unobserved economic state vector, $\mathbb{E}^M_{t^-}[s_t]$, instead of the unobserved state s_t. As, I will shows below, bond yields before the FOMC meeting follow the recursion

$$\begin{aligned} y_{k,t^-} &= -\frac{A_k^-}{k} - \frac{B_k^{-\prime}}{k}\mathbb{E}_{t^-}^M\left[s_t\right] \\ A_k^- &= A_{k-1}^- + \frac{1}{2}B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M B_{k-1}^- - B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M\Lambda_0 \\ B_k^{-\prime} &= -\Phi' + B_{k-1}^{-\prime}P - B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M\Lambda_1, \end{aligned} \tag{D.45}$$

where the $-$ sign in the notation of the term structure coefficients A_k^- and B_k^- illustrates that these are the bond pricing coefficients before the FOMC meeting. Iterating on $B_{k-1}^{-\prime}$, we find

$$B_k^{-\prime} = -\frac{1}{k}\Phi'\left[\mathbf{I} - \left(P - \widetilde{\Sigma}_-^M\Lambda_1\right)^k\right]\left[\mathbf{I} - \left(P - \widetilde{\Sigma}_-^M\Lambda_1\right)\right]^{-1}. \tag{D.46}$$

I now derive equation (D.45) recursively, starting with the one-period bond.

1-period bond: The price of a one-period that pays out 1 in period $t+1^-$ (before the FOMC meeting) in period t before the FOMC meeting is

$$\begin{aligned} P_{1,t^-} &= \mathbb{E}_{t^-}^M\left[\mathcal{M}_{t^-,t+1^-}\cdot 1\right] \\ &= \mathbb{E}_{t^-}^M\left[\exp\left\{m_{t^-,t+1^-}\right\}\right] \\ &= \mathbb{E}_{t^-}^M\left[\exp\left\{-\mathbb{E}_{t^-}^M\left[y_{1,t}\right] - \Lambda_{t^-}'\left(\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right] - \mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right]\right) - \frac{1}{2}\Lambda_{t^-}'\widetilde{\Sigma}_-^M\Lambda_{t^-}\right\}\right] \\ &= \exp\left\{\mathbb{E}_{t^-}^M\left[-y_{1,t} - \Lambda_{t^-}'\left(\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right] - \mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right]\right) - \frac{1}{2}\Lambda_{t^-}'\widetilde{\Sigma}_-^M\Lambda_{t^-}\right] + \frac{1}{2}\mathbb{V}_{t^-}^M\left(-\Lambda_{t^-}'\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right)\right\} \\ &= \exp\left\{-\mathbb{E}_{t^-}^M\left[y_{1,t}\right] - \Lambda_{t^-}'\left(\mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right] - \mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right]\right) - \frac{1}{2}\Lambda_{t^-}'\widetilde{\Sigma}_-^M\Lambda_{t^-} + \frac{1}{2}\Lambda_{t^-}'\widetilde{\Sigma}_-^M\Lambda_{t^-}\right\} \\ &= \exp\left\{-\mathbb{E}_{t^-}^M\left[y_{1,t}\right]\right\} = \exp\left\{-\Phi'\mathbb{E}_{t^-}^M\left[\mathbb{E}_t^F\left[s_t\right]\right]\right\}, \end{aligned} \tag{D.47}$$

where the last line follows from the monetary policy according to which the Fed sets the short rate, i.e. $y_{1,t} = \Phi'\mathbb{E}_t^F\left[s_t\right]$.

In addition, if the Market conjectures that the Fed perfectly observes the Market signal, i.e. yields are "invertible", then $\mathbb{E}_{t^-}^M\left[\mathbb{E}_t^F\left[s_t\right]\right] = \mathbb{E}_{t^-}^M\left[s_t\right]$ (this follows from the tower property of the conditional expectation).

We can therefore write the price of the one-period bond as

$$P_{1,t^-} = \exp\left\{-\Phi'\mathbb{E}_{t^-}^M\left[s_t\right]\right\} = \exp\left\{A_1^- + B_1^{-\prime}\mathbb{E}_{t^-}^M\left[s_t\right]\right\} \tag{D.48}$$

where

$$A_1^- = 0 \text{ and } B_1^{-\prime} = -\Phi'. \tag{D.49}$$

Therefore the one-period interest rate before the FOMC meeting is

$$\begin{aligned} y_{1,t^-} &= -\log(P_{1,t^-}) = -A_1^- - B_1^{-\prime}\mathbb{E}_{t^-}^M[s_t] = \Phi'\mathbb{E}_{t^-}^M[s_t] \\ &= \mathbb{E}_{t^-}^M[i_t^*] + \phi_x\mathbb{E}_{t^-}^M[\hat{x}_t] + \phi_\pi\mathbb{E}_{t^-}^M[\hat{\pi}_t] = \mathbb{E}_{t^-}^M[y_{1,t}] \end{aligned} \tag{D.50}$$

<u>*k-period bond:*</u> I now show that bond prices follow a recursion (ordinary differential equation). Suppose the price of a $k-1$-maturity bond at time $t+1^-$ before the FOMC meeting is $P_{k-1,t+1^-} = \exp\left\{A_{k-1}^- + B_{k-1}^{-\prime}\mathbb{E}_{t+1^-}^M[s_{t+1}]\right\}$, then we want to show that $P_{k,t^-} = \exp\left\{A_k^- + B_k^{-\prime}\mathbb{E}_{t^-}^M[s_t]\right\}$.

$$\begin{aligned} P_{k,t^-} &= \mathbb{E}_{t^-}^M\left[\mathcal{M}_{t^-,t+1^-}\cdot P_{k-1,t+1^-}\right] \\ &= \mathbb{E}_{t^-}^M\Big[\exp\left\{-\mathbb{E}_{t^-}^M[y_{1,t}] - \Lambda_{t^-}'\left(\mathbb{E}_{t+1^-}^M[s_{t+1}] - \mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+1^-}^M[s_{t+1}]\right]\right) - \frac{1}{2}\Lambda_{t^-}'\widetilde{\Sigma}_-^M\Lambda_{t^-}\right\} \\ &\qquad \cdot\exp\left\{A_{k-1}^- + B_{k-1}^{-\prime}\mathbb{E}_{t+1^-}^M[s_{t+1}]\right\}\Big] \\ &= \exp\Bigg\{\mathbb{E}_{t^-}^M\left[-y_{1,t} - \Lambda_{t^-}'\left(\mathbb{E}_{t+1^-}^M[s_{t+1}] - \mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+1^-}^M[s_{t+1}]\right]\right) - \frac{1}{2}\Lambda_{t^-}'\widetilde{\Sigma}_-^M\Lambda_{t^-} + A_{k-1}^- + B_{k-1}^{-\prime}\mathbb{E}_{t+1^-}^M[s_{t+1}]\right] \\ &\qquad + \frac{1}{2}\mathbb{V}_{t^-}^M\left(-\Lambda_{t^-}'\mathbb{E}_{t+1^-}^M[s_{t+1}] + B_{k-1}'\mathbb{E}_{t+1^-}^M[s_{t+1}]\right)\Bigg\} \\ &= \exp\Bigg\{A_1^- + B_1^{-\prime}\mathbb{E}_{t^-}^M[s_t] - \Lambda_{t^-}'\left(\mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+1^-}^M[s_{t+1}]\right] - \mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+1^-}^M[s_{t+1}]\right]\right) - \frac{1}{2}\Lambda_{t^-}'\widetilde{\Sigma}_-^M\Lambda_{t^-} + A_{k-1}^- \\ &\qquad + B_{k-1}^{-\prime}P\mathbb{E}_{t^-}^M[s_t] + \frac{1}{2}\Lambda_{t^-}'\widetilde{\Sigma}_-^M\Lambda_{t^-} + \frac{1}{2}B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M B_{k-1}^- - Co\mathbb{V}_{t^-}^M\left(\Lambda_{t^-}'\mathbb{E}_{t+1^-}^M[s_{t+1}], B_{k-1}^{-\prime}\mathbb{E}_{t+1^-}^M[s_{t+1}]\right)\Bigg\} \\ &= \exp\Bigg\{A_1^- + B_1^{-\prime}\mathbb{E}_{t^-}^M[s_t] + A_{k-1}^- + B_{k-1}'P\mathbb{E}_{t^-}^M[s_t] + \frac{1}{2}B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M B_{k-1}^- - B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M\underbrace{\left(\Lambda_0 + \Lambda_1\mathbb{E}_{t^-}^M[s_t]\right)}_{\Lambda_{t^-}}\Bigg\} \\ &= \exp\Bigg\{\underbrace{A_1^- + A_{k-1}^- + \frac{1}{2}B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M B_{k-1}^- - B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M\Lambda_0}_{A_k^-} + \underbrace{B_1^{-\prime}\mathbb{E}_{t^-}^M[s_t] + B_{k-1}^{-\prime}P\mathbb{E}_{t^-}^M[s_t] - B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M\Lambda_1\mathbb{E}_{t^-}^M[s_t]}_{B_k^{-\prime}\mathbb{E}_{t^-}^M[s_t]}\Bigg\}. \end{aligned} \tag{D.51}$$

where the fourth line uses the fact that (tower property of the conditional expectation)

$$\mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+1^-}^M[s_{t+1}]\right] = \mathbb{E}_{t^-}^M\left[\mathbb{E}_{t+1^-}^M[s_{t+1}]\right] = \mathbb{E}_{t^-}^M[s_{t+1}] = \mathbb{E}_{t^-}^M[Ps_t + \epsilon_t] = P\mathbb{E}_{t^-}^M[s_t] = P\mathbb{E}_{t^-}^M[s_t]. \tag{D.52}$$

This means that the k-period bond price is given by

$$\begin{aligned} P_{k,t^-} &= \exp\left\{A_k^- + B_k^{-\prime}\mathbb{E}_{t^-}^M[s_t]\right\} \\ A_k^- &= A_{k-1}^- + \frac{1}{2}B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M B_{k-1}^- - B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M\Lambda_0 \\ B_k^{-\prime} &= -\Phi' + B_{k-1}^{-\prime}P - B_{k-1}^{-\prime}\widetilde{\Sigma}_-^M\Lambda_1. \end{aligned} \tag{D.53}$$

Similarly, yields are given by

$$\begin{aligned} y_{k,t^-} &= -\frac{1}{k}\log\left(P_{k,t^-}\right) = -\frac{A_k^-}{k} - \frac{B_k^{-\prime}}{k}\mathbb{E}_{t^-}^M\left[s_t\right] \\ &= -\frac{A_k^-}{k} - \frac{1}{k}\left[B_{i,k}^-\mathbb{E}_{t^-}^M\left[i_t^*\right] - B_{x,k}^-\mathbb{E}_{t^-}^M\left[\hat{x}_t\right] - B_{\pi,k}^-\mathbb{E}_{t^-}^M\left[\hat{\pi}_t\right]\right]. \end{aligned} \tag{D.54}$$

Verification of equilibrium: Given equation (D.54), the Fed can back out the Market's expectation using the system

$$\begin{pmatrix} k_1 \cdot y_{k_1,t^-} \\ k_2 \cdot y_{k_2,t^-} \\ k_3 \cdot y_{k_3,t^-} \end{pmatrix} = -\begin{pmatrix} A_{k_1}^- \\ A_{k_2}^- \\ A_{k_3}^- \end{pmatrix} - \begin{pmatrix} B_{i,k_1}^- & B_{x,k_1}^- & B_{\pi,k_1}^- \\ B_{i,k_2}^- & B_{x,k_2}^- & B_{\pi,k_2}^- \\ B_{i,k_3}^- & B_{x,k_3}^- & B_{\pi,k_3}^- \end{pmatrix} \cdot \begin{pmatrix} \mathbb{E}_{t^-}^M\left[i_t^*\right] \\ \mathbb{E}_{t^-}^M\left[\hat{x}_t\right] \\ \mathbb{E}_{t^-}^M\left[\hat{\pi}_t\right] \end{pmatrix}. \tag{D.55}$$

Doing the same at the end of period $t-1^+$ means the Fed is able to perfectly back out the market signal m_t using equation (D.33).

E.5 Recursive Bond Pricing At Time t^+

The sdf after the FOMC meeting is defined analogously. Therefore, the sdf *after* the FOMC meeting at time t pricing interest rate proceeds that are realized in the next period at time $t+1^-$ is defined as

$$\mathcal{M}_{t^+,t+1^-} = \exp\left\{-y_{1,t} - \Lambda_{t^+}'\left(\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right] - \mathbb{E}_{t^+}^M\left[\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right]\right) - \frac{1}{2}\Lambda_{t^+}\widetilde{\Sigma}_+^M\Lambda_{t^+}'.\right\}, \tag{D.56}$$

where the price of risk is $\Lambda_{t^+} = \Lambda_0 + \Lambda_1\mathbb{E}_{t^+}^M\left[s_t\right]$ and $\widetilde{\Sigma}_+^M = \mathbb{V}_{t^+}^M\left(\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right)$. Note that because the short rate $y_{1,t}$ is already known to the Market, the Market does no longer need to form an expectation about it.

Again, as for time t^-, let us derive bond prices and yields recursively, starting with the one-period bond.

<u>*1-period bond:*</u> The price of a one-period that pays out 1 in period $t+1^-$ (before the FOMC meeting) in period t after the FOMC meeting is

$$\begin{aligned} P_{1,t^+} &= \mathbb{E}_{t^+}^M\left[\mathcal{M}_{t^+,t+1^-}\cdot 1\right] \\ &= \mathbb{E}_{t^+}^M\left[\exp\left\{-y_{1,t} - \Lambda_{t^+}'\left(\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right] - \mathbb{E}_{t^+}^M\left[\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right]\right) - \frac{1}{2}\Lambda_{t^+}\widetilde{\Sigma}_+^M\Lambda_{t^+}'\right\}1\right] \\ &= \exp\left\{\mathbb{E}_{t^+}^M\left[-y_{1,t} - \Lambda_{t^-}'\left(\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right] - \mathbb{E}_{t^+}^M\left[\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right]\right) - \frac{1}{2}\Lambda_{t^+}\widetilde{\Sigma}_+^M\Lambda_{t^+}'\right] + \frac{1}{2}\mathbb{V}_t^M\left(-\Lambda_{t^-}'\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right)\right\} \\ &= \exp\left\{-\mathbb{E}_{t^+}^M\left[y_{1,t}\right] - \Lambda_{t^-}'\left(\mathbb{E}_{t^+}^M\left[\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right] - \mathbb{E}_{t^+}^M\left[\mathbb{E}_{t+1^-}^M\left[s_{t+1}\right]\right]\right) - \frac{1}{2}\Lambda_{t^+}\widetilde{\Sigma}_+^M\Lambda_{t^+}' + \frac{1}{2}\Lambda_{t^+}\widetilde{\Sigma}_+^M\Lambda_{t^+}'\right\} \\ &= \exp\left\{-\mathbb{E}_{t^+}^M\left[y_{1,t}\right]\right\} = \exp\left\{-\Phi'\mathbb{E}_{t^+}^M\left[\mathbb{E}_t^F\left[s_t\right]\right]\right\}, \end{aligned} \tag{D.57}$$

where the last line follows from the monetary policy according to which the Fed sets the short rate, i.e. $y_{1,t} = \Phi'\mathbb{E}_t^F\left[s_t\right]$. In addition, if the Market conjectures that the Fed perfectly observes the Market signal, i.e. yields are "invertible" (I later show that this conjecture is correct), then $\mathbb{E}_{t^+}^M\left[\mathbb{E}_t^F\left[s_t\right]\right] = \mathbb{E}_{t^+}^M\left[s_t\right]$ (this follows from the tower property of the conditional expectation).

We can therefore write the price of the one-period bond (consistent with the short rate) as

$$P_{1,t^+} = \exp\left\{-\Phi' \mathbb{E}^M_{t^+}\left[s_t\right]\right\} = \exp\left\{A_1 + B_1' \mathbb{E}^M_{t^+}\left[s_t\right]\right\} \tag{D.58}$$

where

$$A_1 = A_1^- = 0 \quad \text{and} \quad B_1' = B_1^{-\prime} = -\Phi'. \tag{D.59}$$

Therefore the one-period interest rate after the FOMC meeting is

$$y_{1,t^+} = -\log(P_{1,t^+}) = -A_1 - B_1' \mathbb{E}^M_{t^+}\left[s_t\right]. \tag{D.60}$$

Ultimately, the one-period short rate is set by the Fed and not the Market. Therefore, it is required $\Phi' \mathbb{E}^M_{t^+}[s_t] = y_{1,t^+} = y_{1,t} = \Phi' \mathbb{E}^F_t[s_t]$. However, this requirement is fulfilled, because the Market observes the short rate set by the Fed and adjusts its belief accordingly (Simon, 2010).

k-period bond: We know that the $k-1$ period bond at time $t+1$ before the FOMC meeting will be $P_{k-1,t+1^-} = \exp\left\{A^-_{k-1} + B^{-\prime}_{k-1} \mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]\right\}$. We can use this to derive the k-period bond at time t after the FOMC meeting as

$$
\begin{aligned}
P_{k,t^+} &= \mathbb{E}^M_{t^+}\left[\mathcal{M}_{t,t+1^-}\cdot P_{k-1,t+1^-}\right]\\
&= \mathbb{E}^M_{t^+}\Bigg[\exp\left\{-y_{1,t}-\Lambda'_{t^+}\left(\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]-\mathbb{E}^M_{t^+}\left[\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]\right]\right)-\frac{1}{2}\Lambda_{t^+}\widetilde{\Sigma}^M_+\Lambda'_{t^+}\right\}\\
&\qquad\cdot\exp\left\{A^-_{k-1}+B^{-\prime}_{k-1}\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]\right\}\Bigg]\\
&= \exp\Bigg\{\mathbb{E}^M_{t^+}\left[-y_{1,t}-\Lambda'_{t^+}\left(\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]-\mathbb{E}^M_{t^+}\left[\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]\right]\right)-\frac{1}{2}\Lambda_{t^+}\widetilde{\Sigma}^M_+\Lambda'_{t^+}+A^-_{k-1}+B^{-\prime}_{k-1}\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]\right]\\
&\qquad+\frac{1}{2}\mathbb{V}^M_{t^+}\left(-\Lambda'_{t^+}\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]+B^{-\prime}_{k-1}\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]\right)\Bigg\}\\
&= \exp\Bigg\{A_1+B'_1\mathbb{E}^M_{t^+}\left[s_t\right]-\frac{1}{2}\Lambda_{t^+}\widetilde{\Sigma}^M_+\Lambda'_{t^+}+A^-_{k-1}+B^{-\prime}_{k-1}P\mathbb{E}^M_{t^+}\left[s_t\right]+\frac{1}{2}\mathbb{V}^M_{t^+}\left(y_{1,t}\right)+\frac{1}{2}\Lambda'_{t^+}\widetilde{\Sigma}^M_+\Lambda_{t^+}\\
&\qquad+\frac{1}{2}B^{-\prime}_{k-1}\widetilde{\Sigma}^M_+B^-_{k-1}-Co\mathbb{V}^M_{t^+}\left(\Lambda'_t\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right],B^{-\prime}_{k-1}\mathbb{E}^M_{t+1^-}\left[s_{t+1}\right]\right)\Bigg\}\\
&= \exp\Bigg\{A_1+B'_1\mathbb{E}^M_{t^+}\left[s_t\right]+A^-_{k-1}+B^{-\prime}_{k-1}P\mathbb{E}^M_{t^+}\left[s_t\right]+\frac{1}{2}B^{-\prime}_{k-1}\widetilde{\Sigma}^M_+B^-_{k-1}-B^{-\prime}_{k-1}\widetilde{\Sigma}^M_+\underbrace{\left(\Lambda_0+\Lambda_1\mathbb{E}^M_{t^+}\left[s_t\right]\right)}_{\Lambda_t}\Bigg\}\\
&= \exp\Bigg\{\underbrace{A_1+A^-_{k-1}+\frac{1}{2}B^{-\prime}_{k-1}\widetilde{\Sigma}^M_+B^-_{k-1}-B^{-\prime}_{k-1}\widetilde{\Sigma}^M_+\Lambda_0}_{A'_k}+\underbrace{B'_1\mathbb{E}^M_{t^+}\left[s_t\right]+B^{-\prime}_{k-1}P\mathbb{E}^M_{t^+}\left[s_t\right]-B^{-\prime}_{k-1}\widetilde{\Sigma}^M_+\Lambda_1\mathbb{E}^M_{t^+}\left[s_t\right]}_{B'_k\mathbb{E}^M_{t^+}\left[s_t\right]}\Bigg\}.
\end{aligned}
\tag{D.61}
$$

We can write

$$
\begin{aligned}
P_{k,t^+} &= \exp\left\{A^+_k+B^{+\prime}_k\mathbb{E}^M_{t^+}\left[s_t\right]\right\}\\
A^+_k &= A^-_{k-1}+\frac{1}{2}B^{-\prime}_{k-1}\widetilde{\Sigma}^M_+B^-_{k-1}-B^{-\prime}_{k-1}\widetilde{\Sigma}^M_+\Lambda_0\\
B^{+\prime}_k &= -\Phi'+B^{-\prime}_{k-1}P-B^{-\prime}_{k-1}\widetilde{\Sigma}^M_+\Lambda_1.
\end{aligned}
\tag{D.62}
$$

This means that yields are given by

$$
y_{k,t^+}=-\frac{1}{k}\log\left(P_{k,t}\right)=-\frac{A_k}{k}-\frac{B'_k}{k}\mathbb{E}^M_{t^+}\left[s_t\right].
\tag{D.63}
$$

There are some key difference between yields before and after the FOMC meeting. First, Market beliefs change from $\mathbb{E}^M_{t^-}\left[s_t\right]$ before the meeting to $\mathbb{E}^M_{t^+}\left[s_t\right]$ after the meeting as a result of the Fed information. Second, the Market's uncertainty about its own belief in the next period decreases from $\widetilde{\Sigma}^M_-$ to $\widetilde{\Sigma}^M_+$ also as a result of the Fed information. This uncertainty reduction is

$$
\widetilde{\Sigma}^M_- - \widetilde{\Sigma}^M_+ = P'\mathbb{V}^M_{t^-}\left(\mathbb{E}^M_{t^+}\left[s_t\right]\right)P.
\tag{D.64}
$$

E.6 Estimation of the Term Structure Parameters

The model specifies bond yields as a function of the Market's belief about three macroeconomic states: the long-run rate, the output gap, the inflation gap. The translation of Market beliefs into bond yields thereby depends on several term structure parameters: (i) the lag-dependence matrix P, (ii) the variance-covariance matrix of the fundamental shocks Σ_ϵ, (iii) the Taylor rule coefficients Φ, and (iv) the prices of risk $\Lambda = (\Lambda_1 \quad \Lambda_0)$. Note that this translation does not depend on the signal precision of either the Market or the Fed – by contrast, the signal precision terms govern the belief evolution of the agents.

Accordingly, conditional on having proxies for the Market's belief about the macro-states, we can estimate the aforementioned term structure parameters. To do so, I obtain data on a quarterly frequency from 1989Q2 to 2020Q1. To proxy for the Market's belief about the nominal long-run rate, I collect the r^* estimates from Laubach and Williams (2003) and add to them survey forecasts for inflation over the next 10 years.[8] To proxy for the Market's expectation about the inflation gap, I obtain the survey forecasts over the next year from the Survey of Professional Forecasters. I then subtract from these short-term inflation forecasts the long-term inflation forecasts to get a measure of the perceived inflation gap. Finally, to get a measure of the Market's perception of the output gap, I obtain the actual real GDP (series: GDPC1) and the potential real GDP (series: GDPPOT) from FRED and compute the output gap as the difference between realized and potential GDP scaled by potential GDP. Finally, bond yields are obtained from Gürkaynak et al. (2007) and I include all maturities from 1 quarter to 40 quarters (10 years) in the estimation.

I then estimate the model parameters in two steps following Ang et al. (2006). In the first step, the state dynamics and Taylor rule coefficients are estimated via simple OLS.[9] To reduce the dimensionality of the parameter space and to avoid overfitting, I assume that the states evolve independently, i.e. P and Σ_ϵ are diagonal. In the second step, the prices of risk are estimated by minimizing the distance between model-implied yields and yields as observed in the data. In the second step, the prices of risk Λ_0 and Λ_1 are estimated. Note that equation (D.45) states the yield of maturity k as a closed-form function y_k of the Market beliefs $\mathbb{E}^M_{t^+}[s_t]$ and the parameters that govern the economy Λ, P, Σ_ϵ, and Φ. Using the estimates for the latter parameters obtained in step 1, we can get an estimate for Λ by numerically minimizing the squared distance between observed yields y^o_{k,t^+} and model-implied yields. Thus, we obtain the estimates $\widehat{\Lambda}$ as

$$\underset{\Lambda}{\operatorname{argmin}} \sum_t \sum_k \left[y^o_{k,t^+} - y_k \left(\mathbb{E}^M_{t^+}[s_t], \Lambda, \widehat{P}, \widehat{\Sigma_\epsilon}, \widehat{\Phi} \right) \right]^2. \tag{D.65}$$

The parameter estimates are reported in Table D.1. The Taylor rule coefficients indicate that the long-run rate enters the Taylor rule with a coefficient of close to 1. I therefore impose this coefficient to

[8] I use the average of the forecasts taken from the Survey of Professional Forecasters (available since 1991Q4), the Livingston survey (available since 1991Q1) and the Blue Chip survey (available until 1991Q4). These forecasts are available on the website of the Philadelphia Fed: `https://www.philadelphiafed.org/surveys-and-data/real-time-data-research/inflation-forecasts`.

[9] I make the approximating assumption that the dynamics of the underlying (unobserved) states are the same as the dynamics of the Market beliefs.

Table D.1: Estimates of Term Structure Parameters

	Long-run rate	Output gap	Inflation gap
First Step:			
Taylor rule coefficient - ϕ	1.02	0.37	2.08
	(0.09)	(0.10)	(0.75)
AR(1) coefficient - ρ	0.96	0.79	0.01
	(0.01)	(0.04)	(0.18)
Innovation standard deviation (in %) - σ_ϵ	0.37%	1.30%	1.09%
Second Step:			
Constant Price of Risk - Λ_0	-0.007	-0.002	-0.002
Time-varying Price of Risk - Λ_1	-0.007	0.025	-0.105
	-0.036	0.035	-0.886
	-0.021	-0.012	-0.386
Average Pricing Errors:			
1-quarter yield:	0.77 bps		
2-year yield:	0.75 bps		
5-year yield:	0.68 bps		
10-year yield:	0.59 bps		

Note: The table reports the estimates for the term structure parameters. The Taylor rule coefficients are obtained by regressing the 1-quarter Treasury yield on the three proxies for the Market beliefs. The AR(1) coefficient and innovation variance of every variable is obtained by regressing the variable on its 4-quarters-lagged value. The standard errors (in brackets) are adjusted for heteroskedasticity and autocorrelation. The data runs on a quarterly frequency from 1989Q3 to 2020Q1.

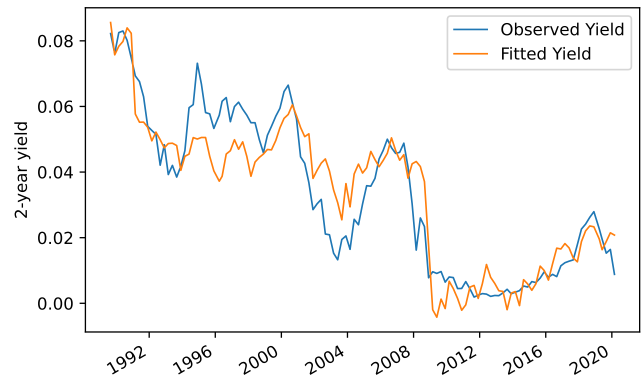
be 1 (after the estimation). The short rate is also responsive to the output gap and the inflation gap. A 1% higher output gap means that the short rate was higher by 0.37%. The estimated short rate rule also fulfills the Taylor principle as the responsiveness to inflation is larger than 1 (Taylor, 1993). In general, the three Market belief proxies are able to explain the behavior of the short rate quite well as illustrated in Panel A of Figure D.1. With regards to the state dynamics, the long-run rate is quite persistent in the data – with an annual persistence parameter of 0.96 –, while the output gap and the inflation gap are less persistent as we would expect from cyclical variables. The annual volatility of the long-run rate is lowest compared to the other two variables consistent with the notion that it is a slowly-moving variable.

Considering that the model is estimated mostly with macro variables and survey forecasts, it does a decent job at fitting yields (Figure D.1). It is important to consider that the main purpose of the model is not to fit the quarterly movements in yields, but to make predictions about how the term structure changes around FOMC meetings. In principle, one could use more variables to fit the yield curve, but for the purpose of my analysis, this would then also require an assumption on how any such variable would move in response to monetary policy.

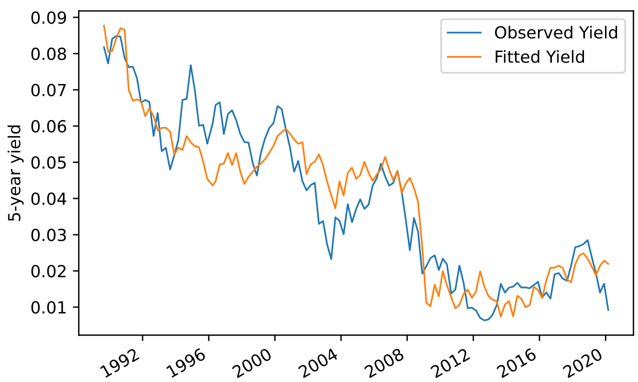
Figure D.1: Term Structure Fit

(A) Short rate (1-quarter)

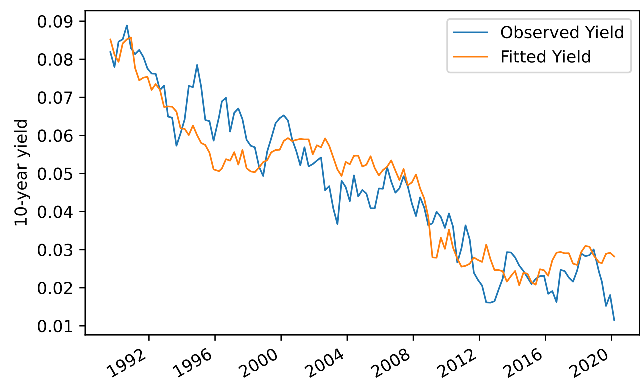
(B) 2-year yield



(C) 5-year yield



(D) 10-year yield



Note: The figure illustrates the model fit for yields of various maturities.