Monetary Policy Surprises and the Yield Curve: Evidence from the U.S.

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Abstract

I study how U.S. monetary policy surprises affect the Treasury yield curve by decomposing high-frequency yield changes around 257 FOMC announcements from 1995 to 2024 into anticipated and surprise components across level, slope, and curvature factors. I document a shift in monetary policy transmission over time: prior to the Zero Lower Bound period, policy surprises primarily affected short- and long-term yields, whereas in the post-crisis period, transmission operates predominantly through medium-term yields. This pattern is consistent with the increasing importance of communication-based policy, including forward guidance, in shaping market expectations. I further show that policy communications can generate yield responses comparable to conventional rate changes, even when policy rates remain unchanged.

JEL Classification: C32, C5, E4, E52, E58, G1

Keywords: Monetary policy surprises, monetary policy transmission, forward guidance, yield curve, Zero Lower Bound (ZLB), state-space model

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1. Introduction

This paper studies how U.S. monetary policy surprises are transmitted across the Treasury yield curve and how that transmission has changed over time. Using daily yield movements around 257 FOMC announcements from 1995 to 2024, I decompose the yield curve into anticipated and surprise changes in level, slope, and curvature factors.

I document a shift in the channels of monetary policy transmission: Prior to the Zero Lower Bound (ZLB) period, monetary policy surprises primarily affected short- and long-term yields through slope and level factors. In contrast, during and after the ZLB period, transmission operates predominantly through medium-term yields, captured by curvature surprise. This pattern is consistent with the increasing importance of communication-based policy, including forward guidance, in shaping market expectations.

A central contribution of the paper is the identification of the U.S. monetary policy surprises. Because I use daily rather than intraday yield data, surprise movements on FOMC announcement days may also reflect other same-day news. I address this in two steps: First, I estimate a state-space model of the U.S. Treasury yield curve and decompose daily yield changes into anticipated and surprise components across latent level, slope, and curvature factors. Second, I compare announcement-day surprises with nearby non-announcement days using nonparametric tests to isolate the component most plausibly attributable to FOMC announcements. This yields a factor-based measure of monetary policy surprises that can be linked to different segments of the yield curve.

My empirical strategy relates to the literature on high-frequency identification of monetary policy shocks and on forward guidance as a tool of monetary transmission. Relative to studies such as Nakamura and Steinsson (2018), Miranda-Agrippino and Ricco (2021), I focus on how monetary policy surprises are transmitted across the Treasury yield curve, and how this transmission varies across policy regimes. To quantify the role of different policy tools, I estimate the sensitivity of yield curve factors to monetary policy surprises across subsamples of announcements and combine these with the empirical distribution of the surprises to construct distribution-weighted responses across maturities.

This paper makes three contribution: First, I provide a factor-based decomposition of monetary policy surprises that links policy tools—interest rate changes, forward guidance, and large-scale asset purchases—to movements in different segments of the yield curve. Second, I document that forward guidance plays an important role not only during easing periods but also during tightening cycles, where it significantly shapes market expectations even in the absence of immediate policy rate changes. Third, I show that monetary policy transmission is time-varying, with a structural shift from short- and long-term yields toward medium-term yields in the post-ZLB period. Taken together, these results highlight the importance of expectations management as a central channel of modern monetary policy and suggest that models of policy transmission should account for time variation in communication strategies.

This paper is organized as follows: Section 2 provides an overview of the current literature on identifying monetary policy shocks and how my empirical methodology fits within it. Section 3 details the payoffs of my two-step empirical strategy to isolate the surprise component of the daily change in the US Treasury yield curve and the identification of these daily surprises as US monetary policy surprises. Section 4 details the features of the surprises and maps the identified daily monetary policy surprises in Section 3 to the Fed's conventional and unconventional monetary policy tools based on narrative evidence. Section 5 details the stylized impact of the Fed's monetary policy tools on the US Treasury yield curve within the estimated state-space model in Section 3 and estimates the possible impact of each monetary policy tool based on the identified daily US monetary surprises. Section 6 concludes the paper with a summary of the key findings.

2. Contact with Literature

This paper relates to three strands of the literature: high-frequency identification of monetary policy shocks, the role of forward guidance and unconventional policy tools, and term structure models of the yield curve.

First, a large literature identifies monetary policy surprises using high-frequency asset price movements around policy announcements (Nakamura and Steinsson (2018); Miranda-Agrippino and Ricco (2021); Inoue and Rossi (2021)). These studies emphasize the importance of disentangling different components of policy shocks, including information effects and forward guidance. However, they typically do not explicitly map these components into yield curve factors or allow for time variation in transmission across policy regimes.

A related literature emphasizes the role of information effects in monetary policy announcements. Central bank communications may convey information about economic fundamentals in addition to policy intentions (Romer and Romer (2000); Nakamura and Steinsson (2018); Bauer and Swanson (2023)). A number of recent studies distinguish between information effects and policy shocks using high-frequency comovement of asset prices (Jarociński and Karadi (2020); Miranda-Agrippino and Ricco (2021)). While my approach does not separately identify information effects, it captures the overall impact of policy communication on the yield curve and allows for a factor-based interpretation across maturities.

Second, a growing literature studies forward guidance and unconventional monetary policy (Swanson (2021); Campbell, et al. (2012)). This work shows that forward guidance plays a central role during periods when conventional policy is constrained, particularly at the Zero Lower Bound. However, most of this literature focuses on easing cycles and does not examine the role of forward guidance during tightening episodes or its interaction with conventional policy tools outside the ZLB period.

Third, I build on term structure models that represent the yield curve using a small number of factors (Nelson and Siegel (1987); Diebold, Rudebusch and Aruoba (2006)). While this framework is widely used to study yield curve dynamics, it has been less commonly used to decompose high-frequency monetary policy surprises across maturities.

This paper contributes to these literatures in three ways. First, I provide a factor-based decomposition of monetary policy surprises that links policy tools—interest rate changes, forward guidance, and large-scale asset purchases—to movements in different segments of the yield curve. Second, I document that forward guidance plays an important role not only during easing periods but also during tightening cycles, where it significantly shapes market expectations even in the absence of immediate policy rate changes. Third, I show that monetary policy transmission is time-varying, with a structural shift from short- and long-term yields toward medium-term yields in the post-ZLB period. These findings highlight the importance of expectations management as a central channel of modern monetary policy.

3. Empirical Strategy

My US monetary policy surprise represents the change in the whole US Treasury yield curve due to unexpected aspects of 257 FOMC announcements from February 1st, 1995 to January 31st, 2024. It is a 257×3 matrix $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}} = (\eta_{i,\bar{t}})$ for $\bar{t} = 1, \ldots, 257$ announcements where the latent factors $i = L, S, C$ are the level (L), slope (S) and curvature (C) factors that summarize the yield curve following Nelson and Siegel (1987). Each $\eta_{L,\bar{t}}$, $\eta_{S,\bar{t}}$ and $\eta_{C,\bar{t}}$ is the unexpected change in the latent factors on day $\bar{t}$ that is identified as the change due to FOMC announcement on $\bar{t}$ and not due to any other event or announcement on the same day.

The estimated and identified US monetary policy surprise maps to different parts of the US Treasury yield curve that allows us to gauge market reaction to FOMC statements from the US Treasury yield curve as a whole. This is because by the design in Nelson and Siegel (1987) the level factor is responsible for the movement on the long end of the yield curve, while the slope factor largely captures the shortest end of the yield curve and the curvature factor captures the middle part of the yield curve.

My empirical strategy is summarized in two consecutive steps: First, I extract the surprise daily change of the US Treasury yield curve for $t = 1, \ldots, 7295$ days from the 1st of January 1995 to 9th of March 2024, $\mathbf{\Delta}_{t}^{\text{Surprise}}$, then I take a subset of these surprises that occur on FOMC announcement days during this period, $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ for $\bar{t} = 1, \ldots, 257$ starting from announcement on the 1st of February 1995 to the 31st of January 2024. The second and last step is to identify $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ as surprises that occurred due to FOMC announcement on day $\bar{t}$ only and not due to any other event and announcement occurring on day $\bar{t}$. Only if this is the case that $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ is identified

as US monetary policy surprise. The first step is detailed in Section 3.1 while the second step is elaborated in Section 3.2. Section 3.3 describes the three advantages of deploying this empirical strategy.

3.1. Decomposition of the 1-day Change in the US Treasury Yield Curve

First, I fit the US Treasury yield curve for each day $t = 1, \dots 7295$ from the January 1st, 1995 to March 9th, 2024 into a state-space model following Diebold, Rudebusch and Aruoba (2006) using the zero-coupon bond yield data from Gürkaynak, Sack and Wright (2007). The bond yield at each maturity $\tau = 3, 6, 12, \dots, 360$ months at the end of each day $t = 1, \dots, 7295$, is a 7295×32 matrix $\mathbf{y_t} = (y_{t,\tau}) = (y_t(\tau))$ and is represented by the observation equation 3.1. The 7295×3 matrix of unobserved state variables $\mathbf{i_t} = (L_t, S_t, C_t)$ are the three latent factors - the level factor L_t, slope factor S_t and the curvature factor C_t of which law of motion depicted in the state equation 3.2.

$$\mathbf{y_t} = \mathbf{\Lambda i_t} + \boldsymbol{\epsilon_t} \tag{3.1}$$

$$\mathbf{i_t} - \boldsymbol{\mu} = \mathbf{A}(\mathbf{i_{t-1}} - \boldsymbol{\mu}) + \boldsymbol{\eta_t} \tag{3.2}$$

The measurement disturbance $\boldsymbol{\epsilon_t}$ in the observation equation 3.1 is orthogonal to the innovation $\boldsymbol{\eta_t} = (\eta_{L,t}, \eta_{S,t}, \eta_{C,t})$ in the state equation 3.2. At each maturity $\tau = 3, 6, 12, \dots, 360$ months, $y_t(\tau)$ follows Nelson and Siegel (1987) representation of the yield curve in equation 3.3 [1]:

$$\begin{aligned} y_t(\tau) &= L_t + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau}\right) S_t + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right) C_t \\ &= \sum_{i=L,S,C} l_i i_t \end{aligned} \tag{3.3}$$

where the latent factors of the yield curve i_t for $i = L, S, C$ follows the state equation 3.2 where $i_t = \mathbb{E}_{t-1} i_t + \eta_{i,t}$. The advantage of estimating the state-space model represented by equation 3.1 and 3.2 lies in the inclusion of the state equation 3.2 in the state-space model. The in-built Kalman filter updates the estimation of the three latent factors as soon as new information comes, which allows for a decomposition of the change of the US Treasury yield curve into its expected and unexpected components.

Using equation 3.3, the 1-day change in the US Treasury yield curve at each maturity τ is

[1] Whereas λ is a fixed parameter in the two-step methodology used by Inoue and Rossi (2021), the state-space methodology instead estimates the λ based on the data. The estimated λ ranges between $0.0349 - 0.0405$ depending on the sample when using the state-space methodology, while it is fixed at 0.0609 for all samples in the replication using the two-step methodology.

$$\Delta y_t(\tau) = \sum_{i=L,S,C} l_i \Delta i_t \tag{3.4}$$

where Δi_t is the 1-day change in the latent factors: the level, slope and curvature factors such that

$$\begin{aligned}
\Delta i_t &= i_t - i_{t-1} \\
&= (\mathbb{E}_{t-1} i_t - \eta_{i,t}) - (\mathbb{E}_{t-2} i_{t-1} - \eta_{i,t-1}) \\
&= \eta_{i,t} + \mathbb{E}_{t-1} i_t - (\mathbb{E}_{t-2} i_{t-1} - \eta_{i,t-1}) \\
&= \underbrace{\eta_{i,t}}_{\Delta i_t^{\text{Surprise}}} + \underbrace{\mathbb{E}_{t-1} i_t - i_{t-1}}_{\Delta i_t^{\text{Anticipated}}}
\end{aligned} \tag{3.5}$$

where the surprise and the anticipated components of the 1-day change in the latent factors of the yield curve are represented by $\Delta i_t^{\text{Surprise}} = \eta_{i,t}$ and $\Delta i_t^{\text{Anticipated}} = \mathbb{E}_{t-1} i_t - i_{t-1}$ respectively in equation 3.5.

Using equation 3.5 in equation 3.4, I can further decompose the daily change of the US Treasury yield curve $\Delta y_t(\tau)$ for each day $t = 1, \ldots 7295$ into

$$\begin{aligned}
\Delta y_t(\tau) &= \sum_{i=L,S,C} l_i \Delta i_t \\
&= \sum_{i=L,S,C} l_i \Delta i_t^{\text{Surprise}} + \sum_{i=L,S,C} l_i \Delta i_t^{\text{Anticipated}} \\
&= \underbrace{\Delta y_t(\tau)^{\text{Surprise}}}_{F(\Delta i_t^{\text{Surprise}})} + \underbrace{\Delta y_t(\tau)^{\text{Anticipated}}}_{F(\Delta i_t^{\text{Anticipated}})}
\end{aligned} \tag{3.6}$$

and thereby extracting the 1-day change of the yield curve due to new information on day t, $\Delta y_t(\tau)^{\text{Surprise}}$ for $t = 1, \ldots 7295$.

Each $\Delta y_t(\tau)^{\text{Surprise}}$ in the equation 3.6 is a linear combination $F(.)$ of the surprise change of the three latent factors $\Delta i_t^{\text{Surprise}}$ and it follows that

$$\begin{aligned}
\mathbf{\Delta y_t} &= \mathbf{\Delta y_t}^{\text{Surprise}} + \mathbf{\Delta y_t}^{\text{Anticipated}} \\
&= F(\mathbf{\Delta}_t^{\text{Surprise}}) + F(\mathbf{\Delta}_t^{\text{Anticipated}}).
\end{aligned} \tag{3.7}$$

Therefore, the unexpected daily change of the yield curve in the whole sample is represented by the 7295×3 matrix $\mathbf{\Delta}_t^{\text{Surprise}} = \{\Delta i_t^{\text{Surprise}}\} = \{\eta_{i,t}\}$ of factor $i = L, S, C$ of the yield curve on each day $t = 1, \ldots 7295$. The anticipated 1-day change in the US Treasury yield curve on day t is summarized by the anticipated change of the latent factors based on information a day before t,

$$\mathbf{\Delta}_t^{\text{Anticipated}} = \mathbf{\Delta}_t - \mathbf{\Delta}_t^{\text{Surprise}}, \text{where}$$

$$\boldsymbol{\Delta}_t = (\Delta L_t, \Delta S_t, \Delta C_t) \text{ and}$$

$$\boldsymbol{\Delta}_t^{\text{Surprise}} = (\eta_{L,t}, \eta_{S,t}, \eta_{C,t})$$

$t = 1, \ldots 7295$ where the 7295×3 matrix $\boldsymbol{\Delta}_t = (\Delta i_t)$ is the overall daily change of the latent factor $i = L, S, C$ of the yield curve on each day $t = 1, \ldots 7295$.

The 257×3 matrix of surprises $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}} = \{\Delta i_{\bar{t}}^{\text{Surprise}}\} = \{\eta_{i,\bar{t}}\}$ are a subset of $\boldsymbol{\Delta}_t^{\text{Surprise}}$ that occurs on a subset of days $\bar{t} = 1, \ldots, 257$ for each $i = L, S, C$ on which FOMC announcement took place from February 1st, 1995 to the January 31st 2024. This matrix $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ will later be identified as US monetary policy surprises in Section 3.2. In a similar manner, a subset of $\boldsymbol{\Delta}_t^{\text{Anticipated}}$, $\boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}}$ that occurs on a subset of days on which FOMC announcement took place from February 1st, 1995 to the January 31st, 2024 is the anticipated change of the yield curve based on the day before the announcement

$$\boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}} = \boldsymbol{\Delta}_{\bar{t}} - \boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}, \text{where}$$

$$\boldsymbol{\Delta}_{\bar{t}} = (\Delta L_{\bar{t}}, \Delta S_{\bar{t}}, \Delta C_{\bar{t}}) \text{ and}$$

$$\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}} = (\eta_{L,\bar{t}}, \eta_{S,\bar{t}}, \eta_{C,\bar{t}})$$

for each announcement day $\bar{t} = 1, \ldots, 257$.

3.2. Identification of US Monetary Policy Surprise

Although the Kalman filter ensures that the surprise change $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ is orthogonal to the anticipated change $\boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}}$ of the US Treasury yield curve on $\bar{t}$, but using daily data implies the possibility that $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ will also capture the surprise change due the other events occurring on the same day as the announcement. Thus, the second step after extracting the surprise $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ following $\bar{t} = 1, \ldots, 257$ announcements from February 1st, 1995 to the January 31st 2024 is to identify it as the matrix containing surprises occurring *solely* due to FOMC announcement and not due to other event or announcement on $\bar{t}$.

I did this by conducting a non-parametric pairwise Wilcoxon signed rank test to establish three results: First, FOMC announcement on $\bar{t}$ is the only event that people anticipate within k days to $\bar{t}$. Second, for each announcement $\bar{t} = 1, \ldots, 257$ from February 1st, 1995 to January 31st 2024, $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ are distinct to surprises on "normal" days $\boldsymbol{\Delta}_{\bar{t}-k}^{\text{Surprise}}$ which occur k days prior to FOMC announcement on $\bar{t}$. Third, if the first and second results hold, $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ are the unexpected change of the yield curve due to FOMC announcement and hence it is the US monetary policy surprise. That is when both Condition 3.8 and Condition 3.9 below hypothetically hold for all FOMC announcements on $\bar{t}$ in the sample, $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ can then be identified as US monetary policy surprise.

$$\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}} \neq \boldsymbol{\Delta}_{\bar{t}-k}^{\text{Surprise}} \tag{3.8}$$

and

$$\begin{aligned} &\boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}} \neq 0 \text{ while} \\ &\boldsymbol{\Delta}_{\bar{t}-k}^{\text{Anticipated}} \neq \boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}} \text{ and} \\ &\boldsymbol{\Delta}_{(\bar{t}-1)-k}^{\text{Anticipated}} = \boldsymbol{\Delta}_{\bar{t}-1}^{\text{Anticipated}} \end{aligned} \tag{3.9}$$

The first Condition 3.8 is straightforward: if the unexpected movement of the yield curve after the FOMC press release on $\bar{t}$, $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ is identical to any unexpected movement on another day before $\bar{t}$, $\boldsymbol{\Delta}_{\bar{t}-k}^{\text{Surprise}}$, then $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ cannot be precisely identified as monetary policy surprise following announcement on $\bar{t}$. The second condition 3.9 ensures that the scheduled FOMC announcement on $\bar{t}$ is the main event that drives the 1-day change of yield curve at the end of the day $\bar{t}$. When this is true, by the orthogonality of $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ to $\boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}}$ we can conclude that $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ is the monetary policy surprise capturing the surprise component of the 1-day change of the US Treasury yield curve on day $\bar{t}$ due to the release of US monetary policy stance by the FOMC. If 3.9 is violated, $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ cannot be identified as monetary policy surprise since it is orthogonal to the anticipated 1-day change that does not necessarily, or majorly driven by the result of anticipation to the scheduled FOMC announcement.

To see how the second Condition 3.9 works, suppose that there is no FOMC announcement on the day $\bar{t}$ then any unexpected movement in the latent factors of the US Treasury yield curve $\boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}}$ is not a monetary policy surprise. Further assuming that there are no scheduled events on the same day then it is also the case that $\boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}} = 0$ as the market do not expect any change in the US Treasury yield curve following the absence of any events on $\bar{t}$. By this assumption, if there is an FOMC announcement on the day $\bar{t}$ then $\boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}} \neq 0$ as FOMC announcement will move the yield curve. At the same time, if FOMC announcement is the main driver that moves the US Treasury yield curve on $\bar{t}$ regardless of another event on the same day, it ought to be the case that $\boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}}$ along with $\boldsymbol{\Delta}_{\bar{t}-k}^{\text{Anticipated}}$ represents the anticipated 1-day change in the US Treasury yield curve due to the scheduled FOMC announcement within a sufficiently close period k days to $\bar{t}$. This is possible if the anticipated 1-day change of the US Treasury yield curve $\boldsymbol{\Delta}_{\bar{t}-k}^{\text{Anticipated}}$ is distinct to $\boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}}$ but indistinguishable to the anticipated change of the yield curve on any days prior to it.

To check for Condition 3.8 and Condition 3.9, I conduct pairwise nonparametric Wilcoxon signed rank tests on the following null hypotheses for $\bar{t} = 1, \ldots, 257$ FOMC announcement days from February 1st, 1995 to January 31st, 2024:

$$H_0 : \boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}} = 0. \tag{3.10}$$

$$H_0 : \boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}} - \boldsymbol{\Delta}_{\bar{t}-k}^{\text{Surprise}} = 0, \tag{3.11}$$

$$H_0 : \mathbf{\Delta}_{\bar{t}}^{\text{Anticipated}} - \mathbf{\Delta}_{\bar{t}-k}^{\text{Anticipated}} = 0, \tag{3.12}$$

$$H_0 : \mathbf{\Delta}_{(\bar{t}-1)-k}^{\text{Anticipated}} - \mathbf{\Delta}_{\bar{t}-1}^{\text{Anticipated}} = 0, \tag{3.13}$$

The null hypothesis 3.11 corresponds to Condition 3.8, while the null hypotheses 3.10, 3.12 and 3.13 corresponds to Condition 3.9. I do not test whether or not $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}} = 0$ because it is of less importance since one FOMC decision could be as much as a surprise as a set expectation based on the previous announcement.

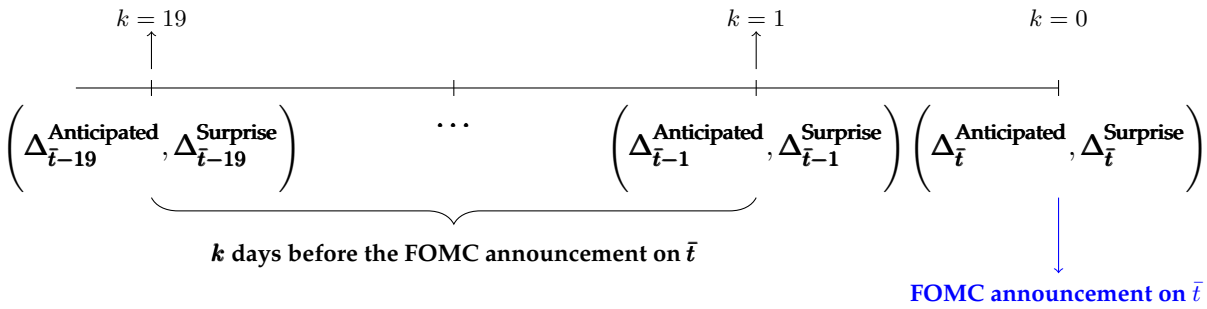
I test the null hypothesis 3.11 to establish whether $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ resembles any other 1-day surprise k days prior to announcement day $\bar{t}$. If we accept the null hypothesis 3.11, then we conclude that the 1-day surprise on announcement day $\bar{t}$, $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ is indistinguishable from the 1-day surprise that occur k days before the announcement on day $\bar{t}$, $\mathbf{\Delta}_{\bar{t}-k}^{\text{Surprise}}$ and consequently it cannot be a monetary policy surprise on $\bar{t}$. On the other hand, if we can reject the null hypothesis 3.11, then we can conclude that $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ is distinct from any surprise k days before $\bar{t}$ and could be identified as a monetary policy surprise as it satisfies Condition 3.8.

If the null hypothesis 3.10 is rejected then $\mathbf{\Delta}_{\bar{t}}^{\text{Anticipated}} \neq 0$, which implies that there is anticipation of the result from the scheduled announcement of US monetary policy decision on $\bar{t}$. Suppose we can further reject the null hypothesis 3.12 and accept null hypothesis 3.13, we can also conclude that the FOMC announcement on $\bar{t}$ dominates any other events k days before day $\bar{t}$. Since this means Condition 3.9 is satisfied, if $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ is also distinct from surprise k days before $\bar{t}$ I can then identify $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ as the monetary policy surprise.

I test the null hypotheses 3.10, 3.11, 3.12 and 3.13 on my data which consists of both the estimates of anticipated and surprise components of the 1-day change in the US Treasury yield curve $(\mathbf{\Delta}_{\bar{t}}^{\text{Anticipated}}, \mathbf{\Delta}_{\bar{t}}^{\text{Surprise}})$ on $\bar{t} = 1, \ldots, 257$ FOMC announcement days from February 1995 to January 31st, 2024, paired with the anticipated and surprise components of the 1-day change in the US Treasury yield curve k days before each announcement, $(\mathbf{\Delta}_{\bar{t}-k}^{\text{Anticipated}}, \mathbf{\Delta}_{\bar{t}-k}^{\text{Surprise}})$. By doing so, I contrast the 1-day change in the US Treasury yield curve on days with FOMC announcements versus on normal days. Figure 1 shows the data for an FOMC announcement on $\bar{t}$.

I chose to compare the median of each surprise and anticipated components of the daily change of the yield curve's latent factors instead of the means as they are in general the closer representation of the typical values of each surprise and anticipated components of the daily change of the latent factors.

Figure 1: Data for an announcement on $\bar{t} = 1, \ldots, 257$ and up to k days before $\bar{t}$

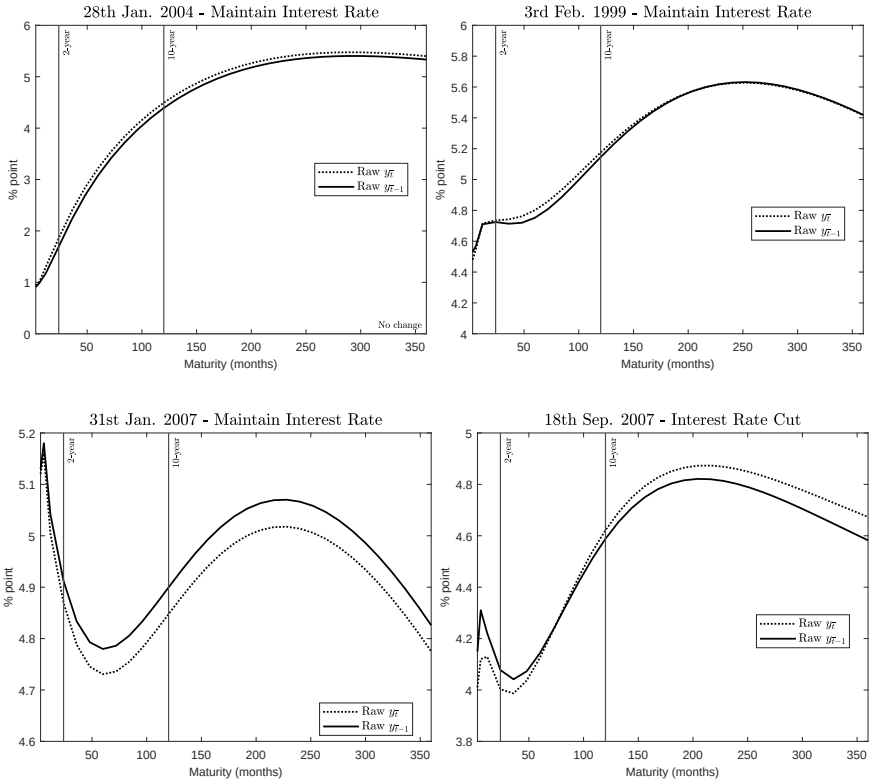


3.3. The Three Payoffs of the Empirical Strategy

There are three advantages in deploying the empirical strategy in Section 3.1 followed by Section 3.2. First, decomposing the US Treasury yield curve in Section 3.1 allows narratives surrounding market reaction surrounding FOMC announcements to be established based on past expectations and reaction to new information as illustrated on select dates in Figure 2. Second, the decomposition clarifies what is often perceived as misleading yield curve movements throughout the years as illustrated on select dates in Figure 4. This motivates how different monetary policy tools map to different parts of the yield by the factors they influence in different eras. Third, by identifying the US monetary policy surprise via pairwise nonparametric Wilcoxon signed rank test in Section 3.2, I establish that these surprises are indeed the market reaction to FOMC announcement and thus can quantify the sensitivity of the US Treasury yield curve to FOMC announcements surprise obtained in Section 3.1.

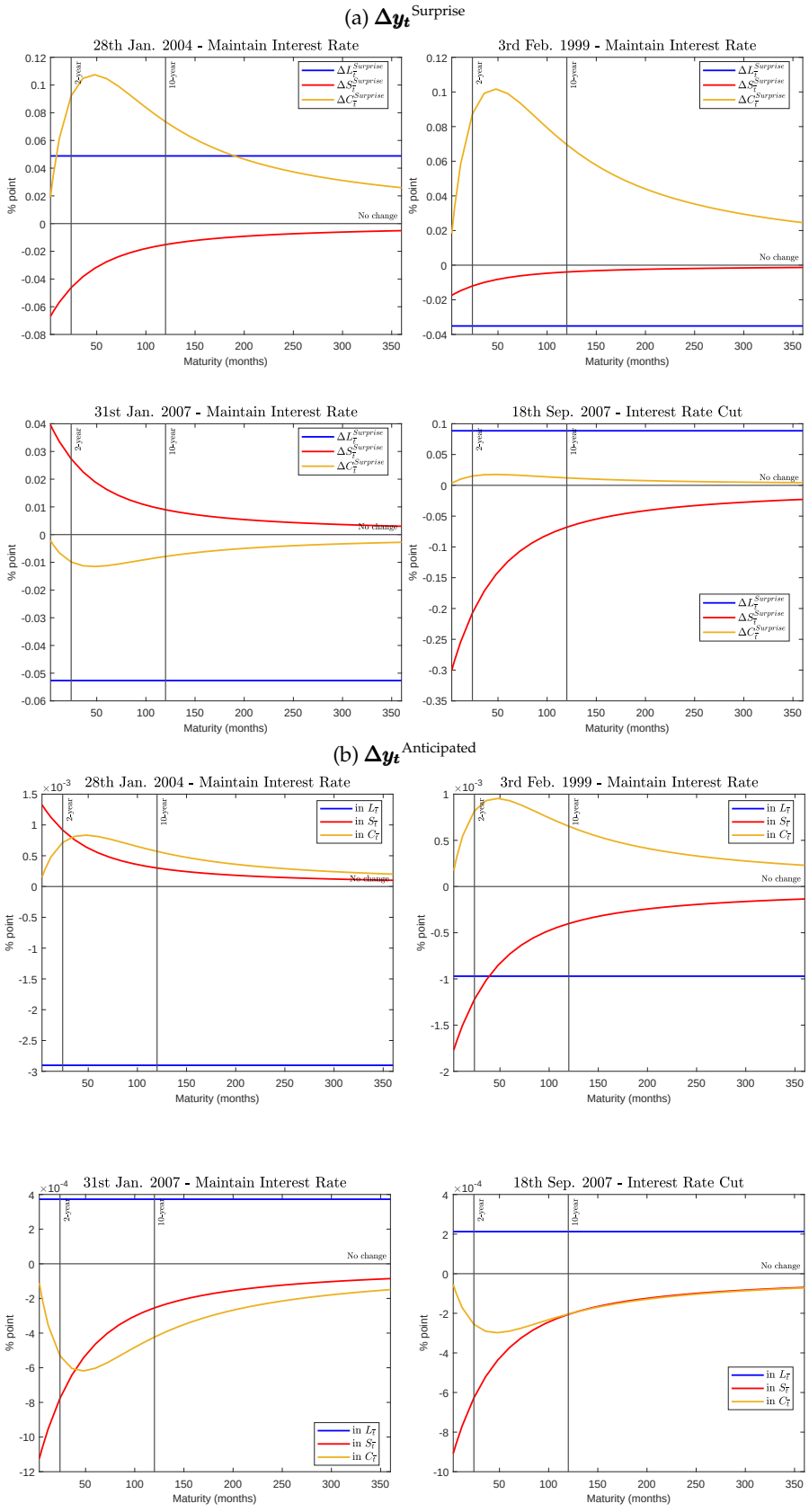
The decomposition of the US Treasury yield curve into the surprise and anticipated components shown in Figure 3 establishes narratives surrounding four FOMC announcements before the Zero Lower Bound period (ZLB) on select dates depicted in Figure 2: when the Fed maintained interest rates on the 3rd of February 1999 amid the global currency crisis, on 28th January 2004 amid low inflation period and on the 31st January 2007 right before cutting interest rate due to the housing market crash on the 18th of September 2007.

Figure 2: US Treasury yield curve following FOMC announcements on select dates



Source: The zero-coupon bond yield data was from Gürkaynak, Sack and Wright (2007).

Figure 3: $\Delta y_t^{\text{Surprise}}$ and $\Delta y_t^{\text{Anticipated}}$ by each factor for each date in Figure 2



Source: Own calculation following the decomposition of the daily change of the US Treasury yield curve in equation 3.6.

After three consecutive cuts during the global currency crisis that started in 1998 the US had since maintained expansionary monetary policy by the 3rd of February 1999 and it is evidenced by the decline of the short end of the yield curve in Figure 2 that is due to the negative surprise to the slope factor in Panel (a) in Figure 3. By the 3rd of February 1999, the market anticipated further easing in what they perceived as a slowing down economy as evidenced by the negative anticipated change in the level factor as evidenced from the negative anticipated change in the slope and level factors respectively in Panel (b) in Figure 3.

Similarly, the FOMC maintained interest rate at the same level amid a brief period of easing during the low inflation period on 28th January 2004 but instead, it lifted the yield curve (Figure 2). Panel (a) in Figure 3 nevertheless shows that there was a negative surprise to the slope factor following the FOMC announcement; What drove the yield curve up in a parallel manner are the shifts in the Fed's statement on their policy: instead of keeping its promise to keep rates on hold for a *"... considerable period"* , the FOMC stated it could be *"... patient"* with rates. This causes a positive surprise to the curvature and slope factors in Panel (a) in Figure 3 given negative anticipated change on the level factor in Panel (b) in Figure 3.

By the 31st of January 2007, the FOMC had held the interest rate constant for the fifth consecutive meeting after 17 previous increases during the housing market boom from 2004, and this shifted the yield curve downward (Figure 2). Panel (a) in Figure 3 indicates that while this action was viewed as a removal of the ongoing contractionary monetary policy (positive surprise to the slope factor), the expectation of a much more accommodative monetary policy from the Fed shown in Panel (b) in Figure 3 (negative anticipated change in the slope and curvature factor) also puts additional downward pressure on the yield curve. This announcement preceded the eventual interest rate cut by the Fed on the 18th of September 2007 due to the housing market crash.

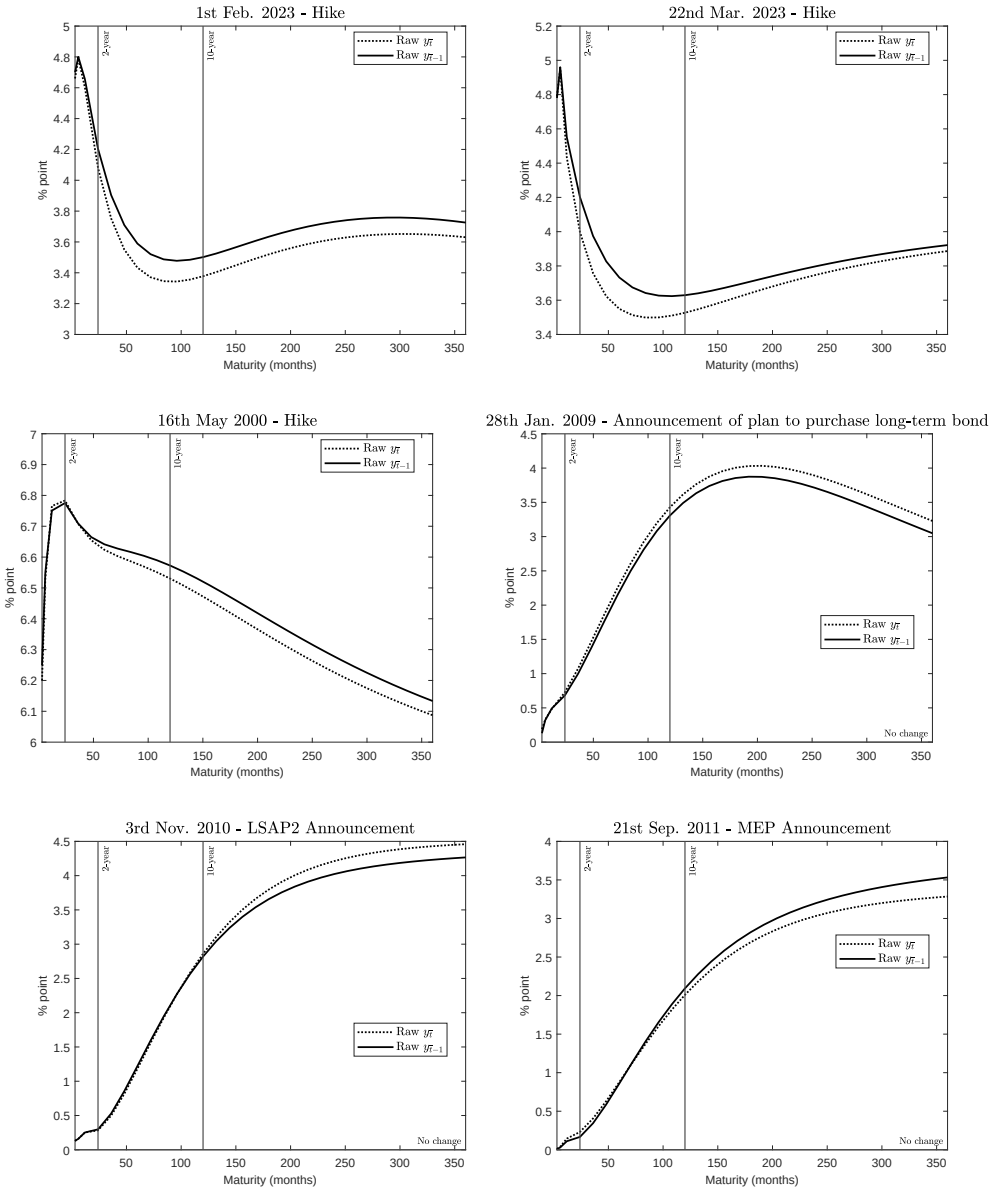
Figure 2 shows several announcements with fitting narratives but in some cases, the change in the US Treasury yield curve could be misleading. Figure 4 shows that the movements of the yield curve following select FOMC announcements of hikes and cuts throughout the years were misleading before and during the ZLB period: the rate hikes before the ZLB period on the 16th of May 2000 and the recent rate hikes on the 1st February 2023 and the 22nd of March 2023, and the announcement of balance sheet policies during the ZLB period. Nevertheless, the decomposition of the yield curve surprise into its level, slope and curvature factors allows for clarification of the corresponding monetary policy tool and market reaction to it as shown in Figure 5.

Ideally, when the Fed hikes interest rate it should stimulate the demand for short-term bonds and increase their yields. However, the rate hikes on the 1st of February 2023 and the 22nd of March 2023 are followed by a decrease in bond yields at all maturities (Figure 4). This is not a new occurrence since the rate hike on the 16th of May 2000 was also followed by an overall decline in bond yields (Figure 4). Figure 5 nevertheless shows that following these three announcements, the surprises to the slope factor following the announcements on the 16th of May 2000, 1st of February 2023 and the 22nd of March are positive.

Figure 4 shows that during the ZLB period, the Maturity Extension Program on the 21st of

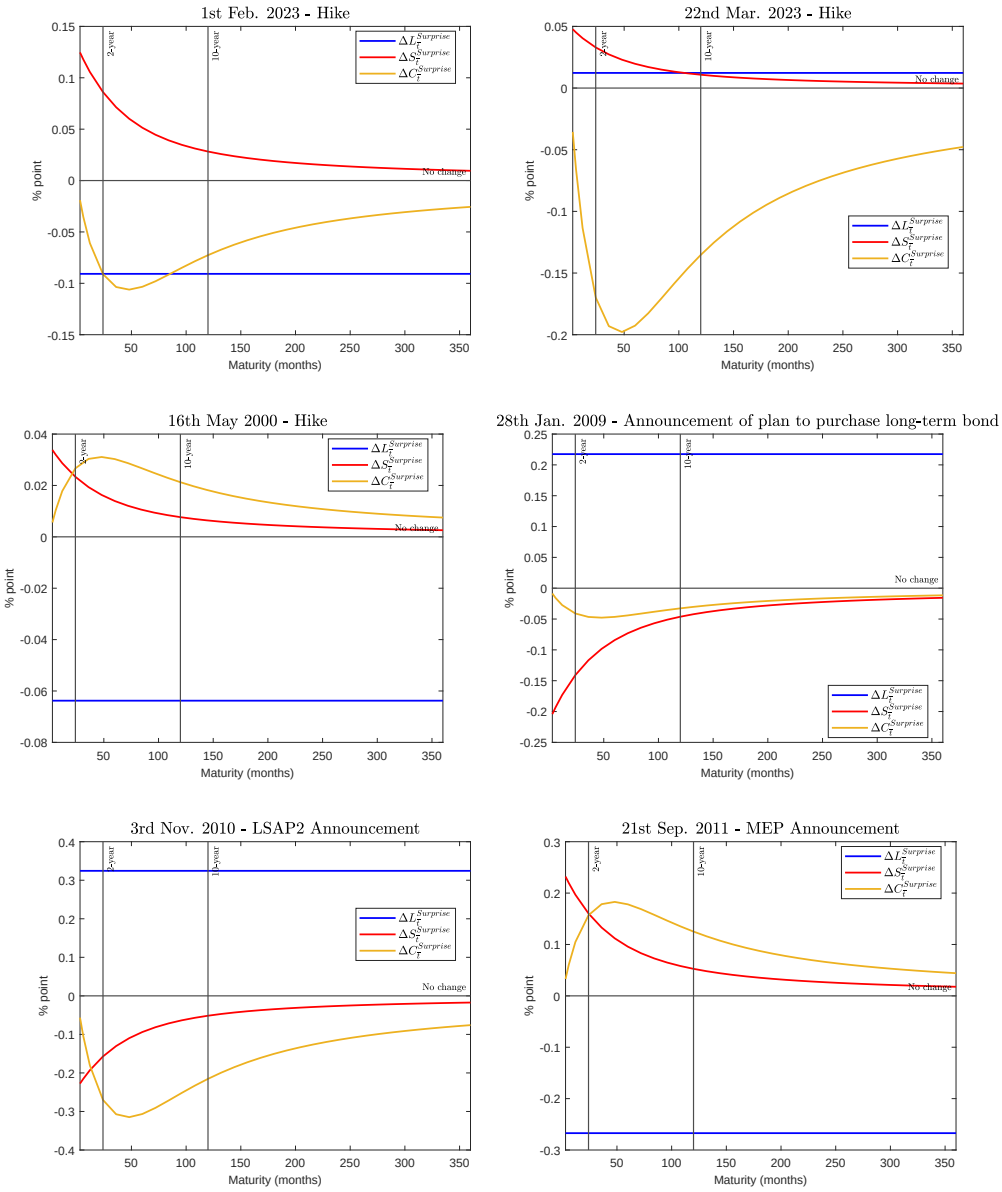
September 2011 was instead followed by a decline in the yield of long-term bonds, while other announcements of monetary policy easing or at least the intention of further easing during the Zero Lower Bound (ZLB) period on the 28th of January 2009 and the 3rd of November 2010 instead lifted the long end of the yield curve at the end of the day. Nevertheless, Figure 5 clarifies that the announcement of further easing during the ZLB period on the 28th of January 2009 and the 3rd of November 2010 causes negative surprise on the slope and curvature factors while the announcement of the Maturity Extension Program results in positive surprise on the slope and curvature factors.

Figure 4: Misleading movements of the US Treasury yield curve following FOMC announcements on select dates



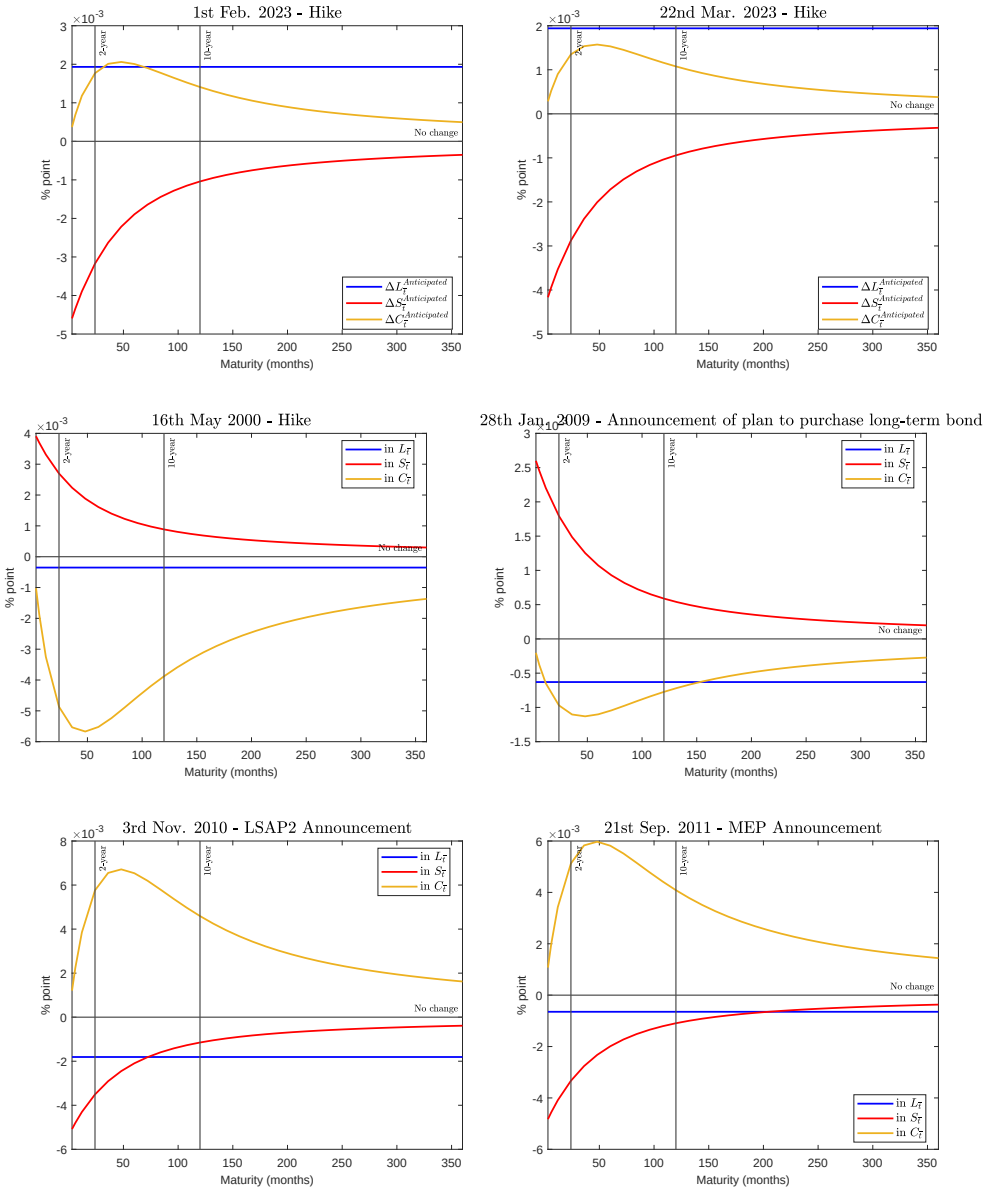
Source: The zero-coupon bond yield data was from Gürkaynak, Sack and Wright (2007).

Figure 5: $\Delta \boldsymbol{y_t}^{\text{Surprise}}$ by each factor for select dates in Figure 4



Source: Own calculation following the decomposition of the daily change of the US Treasury yield curve in equation 3.6.

Figure 6: $\Delta \boldsymbol{y_t}^{\text{Anticipated}}$ by each factor for select dates in Figure 4



Source: Own calculation following the decomposition of the daily change of the US Treasury yield curve in equation 3.6.

Figure 5 and Panel (a) in Figure 3 indicate that the surprise component of the daily change in the US Treasury yield curve captured the FOMC announcement effect and provides motivation of how the monetary policy tools by the Fed affects different parts of the yield curve via the surprise change to each of the level, slope and curvature factors following the announcement. While Panel (a) in Figure 3 shows that the hikes and cuts are reflected in the surprises to the slope factors that drive the change in the short-term bond yields before the ZLB period, Figure 5 shows that during the ZLB period intention for further easing as well as quantitative easing and the operation twist were all captured by the slope and curvature factors that drive the movement of both short- and medium-term bond yields.

To map each of the surprises to the relevant monetary policy tool by the Fed, each element of the yield curve surprise $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}} = (\eta_{L,\bar{t}}, \eta_{S,\bar{t}}, \eta_{C,\bar{t}})$ for $\bar{t} = 1, \ldots, 257$ has to be identified as monetary policy surprise that capture solely the effect of FOMC announcement and not any other event on a similar day and corresponds to a particular monetary policy tool. Thus I test the null hypotheses 3.10, 3.11, 3.12 and 3.13 to check for Condition 3.8 and Condition 3.9 in Section 3.2 using the Wilcoxon signed rank test.

The result for testing the null hypothesis 3.10 suggests that if the market is anticipating the FOMC announcements on day $\bar{t}$, they are expecting movement on the medium-term bond yields: the p-values from this test are well below the significance level of 1% before and during the Zero Lower Bound (ZLB) period for the case of the anticipated change in the curvature factor. In contrast, the p-values in the case of the anticipated change in the slope and level factors are significant only before the ZLB period. I tested the null hypothesis 3.10 of whether $\mathbf{\Delta}_{\bar{t}}^{\text{Anticipated}} = 0$, where $\mathbf{\Delta}_{\bar{t}}^{\text{Anticipated}} = \{\Delta i_{\bar{t}}^{\text{Anticipated}}\}$ for $\bar{t} = 1, \ldots, 257$ FOMC announcements from the 1st of February 1995 to the 31st of August 2024. The Wilcoxon signed rank test was conducted for the period of observations before the ZLB period from February 1st, 1995 to the 16th of December 2008 (124 FOMC announcements) and during the ZLB period from the 16th of January 2009 to the 28th of October 2015 (61 FOMC announcements).

Figure 7 also shows the p-values from testing the null hypotheses 3.11, 3.12 and 3.13. There were $m = 7$ pairwise comparisons to test for null hypotheses 3.11 and 3.12, and $m = 6$ pairwise comparisons to test for null hypothesis 3.13. Because the daily zero-coupon bond yield data from Gürkaynak, Sack and Wright (2007) are not available during weekends and public holidays the m pairwise comparisons between announcement day $\bar{t}$ and normal days $t - k$ are pairwise comparisons between announcement day $\bar{t}$ to the available $m = 7$ observations before $\bar{t}$ that are k days before $\bar{t}$. As such, the pairwise comparisons compare announcement day t to normal days ranging from $k = 1, \ldots, 13$ days before $\bar{t}$. Nevertheless, m pairwise comparisons imply the Bonferroni adjustment for the significance level is done for m tests and thus the p-values are significant (at 10%) if it is within $[\frac{10}{m}\%, 10\%]$. The distance between one FOMC announcement and the next FOMC announcement cannot be more than 58 days in this sample and as such, 13 days before any announcement are roughly halfway to the next announcement.

Panel (b) in Figure 7 serves as evidence that anticipations k days before FOMC announcement

on $\bar{t}$ are mostly directed towards FOMC announcement on $\bar{t}$ as the anticipated component of the daily change in the latent factors on any normal days k days before $\bar{t}$ is identical to the anticipated component of the daily change in the latent factors on the day before FOMC announcement on $\bar{t}$. The p-values for testing null hypothesis 3.13 are not significant in most cases before and after the ZLB as seen in Panel (b) in Figure 7, and hence I accept null hypothesis 3.13 for all anticipated components of the latent factors at the significance level ranging from $\frac{10}{6}\%$ to 10%.

Furthermore, Panel (a) in Figure 7 indicates that if FOMC announcement is anticipated on day $\bar{t}$ it is captured by the curvature and level factor before the ZLB period, and only by the curvature factor during the ZLB period. The p-values for testing the null hypothesis 3.12 is only significant for the anticipated components of the slope and curvature factors before the ZLB and hence we reject the null for the anticipated components of these two factors. During the ZLB, The p-values for testing the null hypothesis 3.12 are only significant for the anticipated component of the curvature factor, and hence we only reject the null for this component.

The p-values from testing the null hypothesis 3.11 shown in Panel (c) in Figure 7 indicate that the surprise in the level factor following FOMC announcements are distinct from its counterpart on normal days before the ZLB period as the p-values for testing $H_0 : \eta_{L,\bar{t}} = \eta_{L,\bar{t}-k}$ fell within the range of the significance level before the ZLB only and thus we reject null hypothesis 3.11 for the surprise in the level factor. The surprise to the slope factor following FOMC announcements before the ZLB period is distinct from its counterpart on normal days at roughly 7-11 days before $\bar{t}$. Meanwhile, the surprise to the curvature factor following the FOMC announcements before the ZLB period is indistinguishable from its counterparts during normal days before the ZLB period for any day beyond 4 days before any FOMC announcements before the ZLB period. However, during the ZLB period the the p-values for testing $H0 : \eta_{C,\bar{t}} = \eta_{C,\bar{t}-k}$ are significant for $k = 5$ days before announcement on day $\bar{t}$, and as such the surprise to curvature factor following FOMC announcements are distinct to its counterparts on normal days during the ZLB period. In contrast, the surprise to slope and level factors are indistinguishable from their counterparts on normal days during the ZLB period.

Based on the hypothesis test results in Figure 7, the market anticipates changes in the medium- and long-term bond yields following FOMC announcements before the ZLB period and anticipates changes mostly in the medium-term bond yields following FOMC announcements during the ZLB period. The unexpected aspects of FOMC decisions are nevertheless captured by the slope and level factors responsible for the movement of the short- and long-term bond yields before ZLB respectively, and by the curvature factor during the ZLB. This indicates that $\Delta_{\bar{t}}^{\text{Surprise}}$ captures the unexpected aspects of FOMC decisions for all $\bar{t}$ with each of its elements corresponding to different monetary policy tools.

Therefore, I identify the matrix $\Delta_{\bar{t}}^{\text{surprise}} = (\eta_{i,\bar{t}})$ for $\bar{t} = 1, \ldots, 124$ FOMC announcements as monetary policy surprise before the ZLB period. The FOMC statements before the ZLB period drew anticipation from the public that was felt on the medium- and long-term bond yield, with any unanticipated aspects of the statements reflected on the whole yield curve. Meanwhile, the

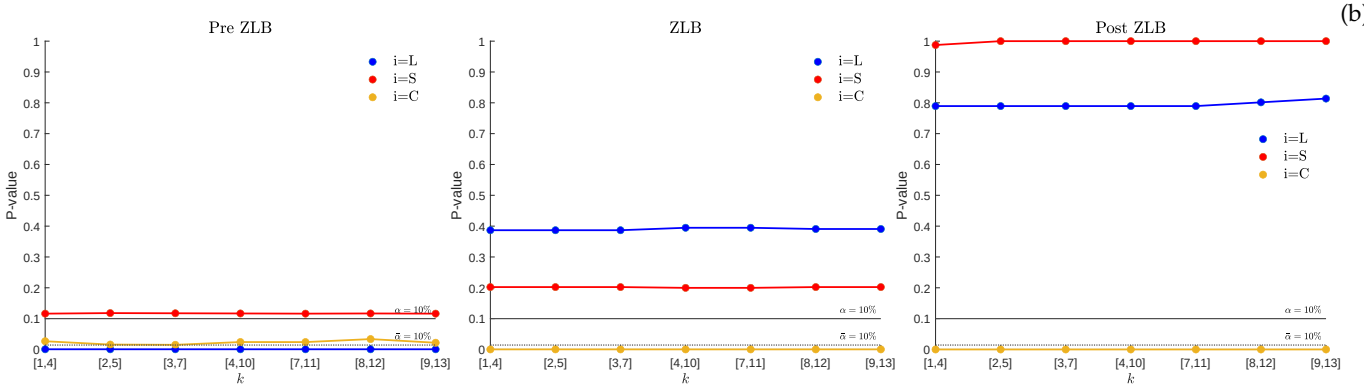
decomposition results suggested that the conventional interest rate policy by the Fed influenced the yield curve following the FOMC announcement via the surprise to the short-end of the yield curve before the ZLB and the hypothesis test identifies the surprise to the level factors to contain the most impact of the FOMC announcement on day $\bar{t}$.

Although the matrix $\Delta_{\bar{t}}^{\text{Surprise}} = (\eta_{i,\bar{t}})$ for $\bar{t} = 125, \ldots, 185$ still represents the whole yield curve movements following FOMC announcements during the ZLB period, it is less clear if the surprise to factors other than curvature factors respond to any particular monetary policy tool during this period. The most dominant monetary policy tools are reflected in the movement of the curvature factor during the ZLB period; be it anticipated or surprise movements: during the ZLB period when the FOMC announced LSAP, MEP and a set of forward guidance in the absence of conventional interest rate policy the impact of FOMC announcement was captured mostly by the medium-term bond yields as both the decomposition in Section 3.1 and the identification in Section 3.2 agrees that the surprise to curvature factor captures the FOMC announcement effect during the ZLB.

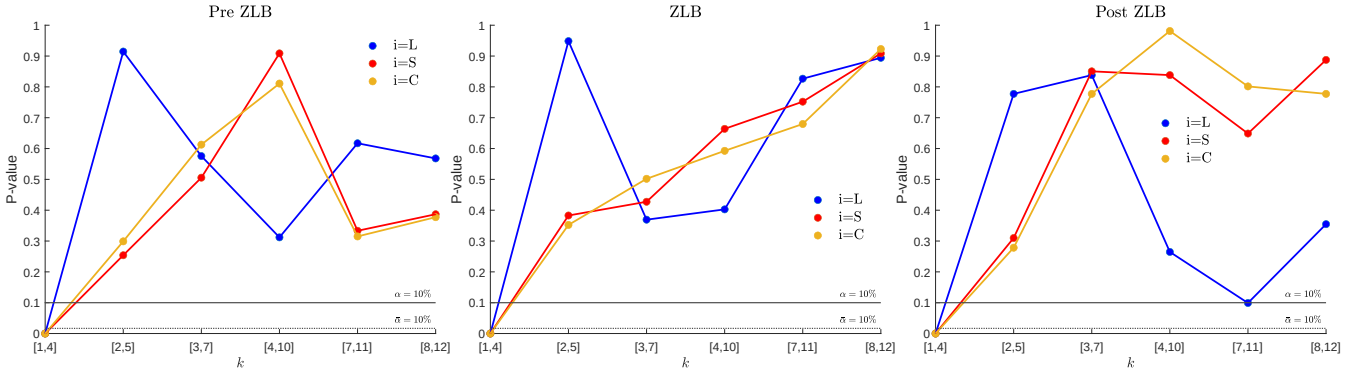
Figure 7: P-values for null hypotheses 3.11, 3.12 and 3.13: Before and during the 2008-2015 Zero Lower Bound (ZLB) period

(a) $H_0 : \boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}} - \boldsymbol{\Delta}_{\bar{t}-k}^{\text{Anticipated}} = 0$

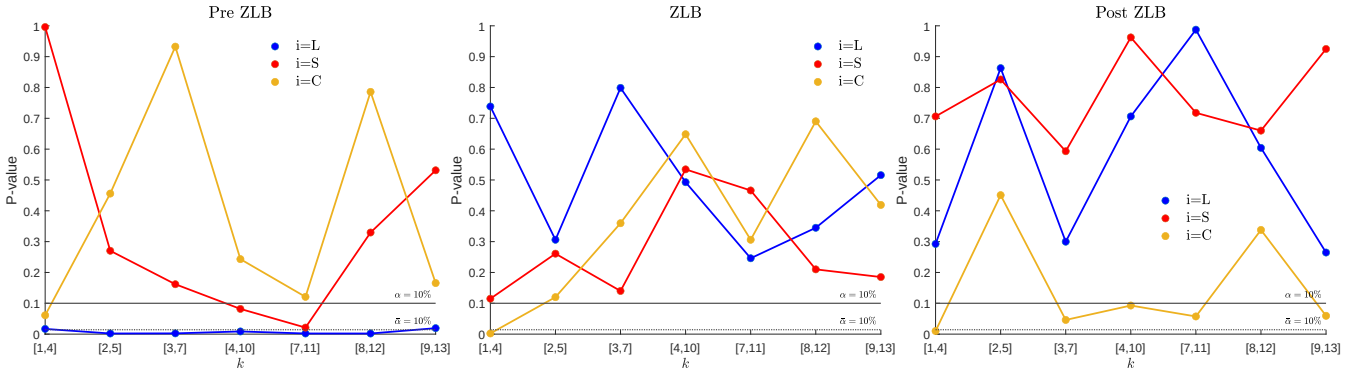
(b)



$H_0 : \boldsymbol{\Delta}_{(\bar{t}-1)-k}^{\text{Anticipated}} - \boldsymbol{\Delta}_{\bar{t}-1}^{\text{Anticipated}} = 0$



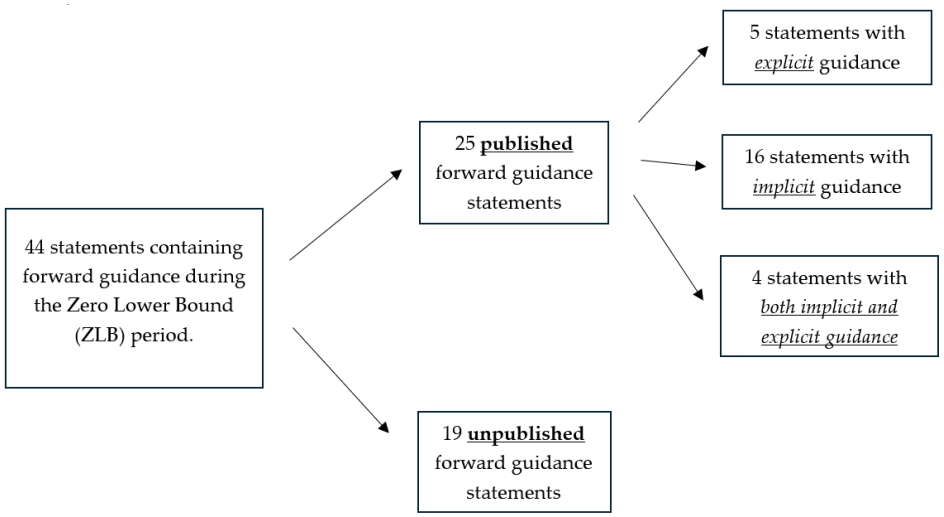
(c) $H_0 : \boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}} - \boldsymbol{\Delta}_{\bar{t}-k}^{\text{Surprise}} = 0$



Notes: The x-axis in Figure 7 depicts $k = 1, \ldots, 13$ days prior to $\bar{t}$, categorized into $m = 1, \ldots, 7$ groups, eg. at $m = 1$ the 1st observation prior to $\bar{t}$ ranges from 1 to 4 days before announcement on $\bar{t}$. The significance level at 10% is $[\bar{\alpha}, \alpha] = [0.1/\max(m), 0.1]$.

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Figure 8: FOMC statements containing forward guidance during the Zero Lower Bound (ZLB) period



Notes: Figure 8 depicts the breakdown of the forward guidance statements inside the 44 press releases following FOMC announcements from the 16th of January 2009 to the 28th of October 2015. Days on which FOMC makes LSAP announcement alongside their forward guidance, eg. 18 March 2009 are not counted in the forward guidance observed in Figure 8. Explicit forward guidance which are direct statements in the press releases acknowledged by the Fed and published on their website:
https://www.federalreserve.gov/monetarypolicy/timeline-forward-guidance-about-the-federal-funds-rate.htm.

Again, I test the null hypotheses 3.11, 3.12 and 3.13 to check for Condition 3.8 and Condition 3.9 in Section 3.2 using the Wilcoxon signed rank test only for announcements containing forward guidance during the 2008-2015 ZLB period depicted in Figure 8. Forty-four out of 61 FOMC announcements spanning from the 16th of December 2008 (when the Fed Funds rate fell to zero) to the 18th of October 2015 during the Zero Lower Bound (ZLB) period contain forward guidance of the Fed's future action and the future environment of which the Fed will have to react to. I categorized the forward guidance in these 44 announcements as either **published** or **unpublished**. The **unpublished** forward guidance statements are acknowledged as forward guidance by recent studies such as Sablik (2022) and Sutherland (2023) but not by the Fed. **Published** forward guidance statements on the other hand are acknowledged publicly by the Fed as their forward guidance statements. Figure 8 depicts this distinction.

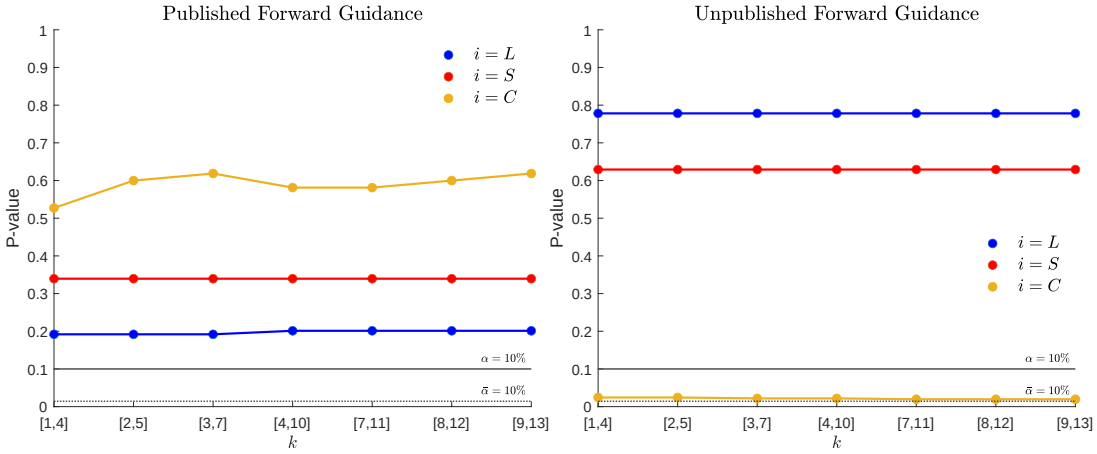
I further categorized **published** forward guidance into two categories: *implicit* guidance such as the announcement of the Summary of Economic Projection (SEP) and *explicit* guidance which are direct statements in the press release acknowledged by the Fed as their forward guidance and published on their website as depicted in Figure 8. Among these forty-seven forward guidance statements, there are 25 **published** forward guidance, 5 of them being explicit and 16 being implicit forward guidance while the remaining 4 statements contain both explicit and implicit forward guidance. Based on Sablik (2022) and Sutherland (2023), there are 19 FOMC statements containing

unpublished forward guidance. Figure 8 depicts these distinctions.

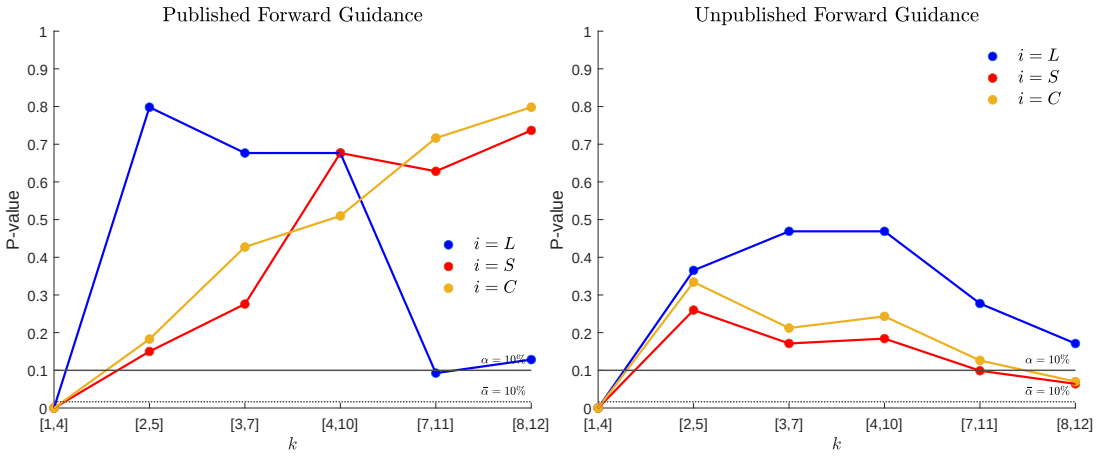
My hypothesis test result in Figure 9 shows that the surprise to curvature factor corresponds to the forward guidance surprise which was the most dominant tool during the 2008-2015 ZLB. Figure 9 shows the results of the hypothesis tests for the null hypotheses 3.11, 3.12 and 3.13. Panel (a) in Figure 9 shows that the market does not anticipate **published** forward guidance from the Fed, but anticipates surprises on the medium-term bond yields on the sample with **unpublished** forward guidance. Panel (c) in Figure 9 shows that the unanticipated forward guidance from the Fed has its impact through the surprise on the curvature factor during the 2008-2015 ZLB period. Panel (c) in Figure 9 also shows that the results for **unpublished** forward guidance are weaker compared to the results for **published** forward guidance.

Figure 9: The impact of forward guidance during the 2008-2015 Zero Lower Bound Period (ZLB)

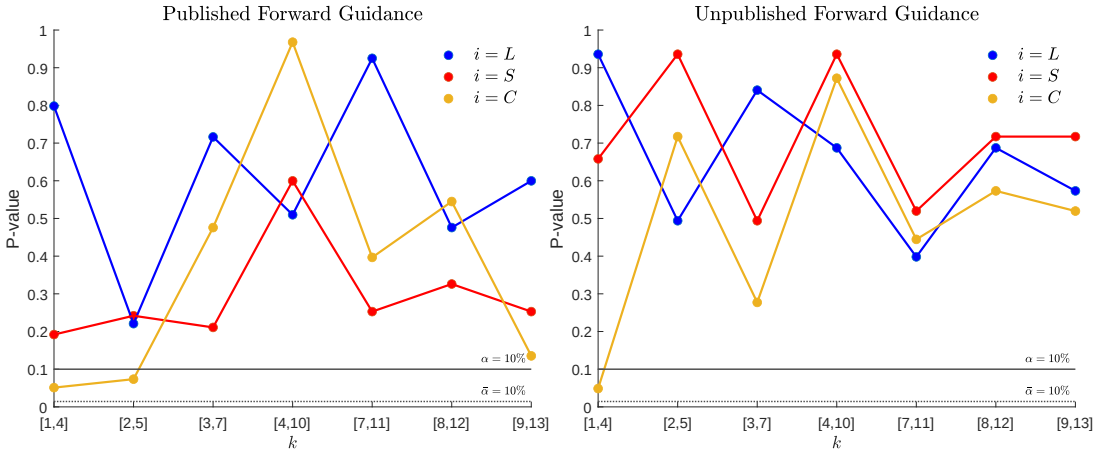
(a) $H_0 : \boldsymbol{\Delta}_{\bar{t}}^{\text{Anticipated}} - \boldsymbol{\Delta}_{\bar{t}-k}^{\text{Anticipated}} = 0$



(b) $H_0 : \boldsymbol{\Delta}_{(\bar{t}-1)-k}^{\text{Anticipated}} - \boldsymbol{\Delta}_{\bar{t}-1}^{\text{Anticipated}} = 0$



(c) $H_0 : \boldsymbol{\Delta}_{\bar{t}}^{\text{Surprise}} - \boldsymbol{\Delta}_{\bar{t}-k}^{\text{Surprise}} = 0$



Notes: The x-axis in Figure 9 depicts $k = 1, \ldots, 13$ days prior to $\bar{t}$, categorized into $m = 1, \ldots, 7$ groups, eg. at $m = 1$ the 1st observation prior to $\bar{t}$ ranges from 1 to 4 days before announcement on $\bar{t}$. The significance level at 10% is $[\bar{\alpha}, \alpha] = [0.1/\max(m), 0.1]$.

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4. Mapping the Daily Monetary Policy Surprise to the Federal Reserve's Monetary Policy Tools

There are three features of the daily monetary policy surprise identified in Section 3 that suggest unique mapping of each $\eta_{L,\bar{t}}$, $\eta_{S,\bar{t}}$ and $\eta_{C,\bar{t}}$ to different monetary policy tools deployed by the Federal Reserve.

Feature 1. FOMC announcements drive surprise changes in the level, slope, and curvature factors, with the curvature surprise becoming dominant post-2008–2015 ZLB.

I showed in Section 3 that FOMC announcements affect the whole yield curve through their influence on the surprise change of each level, slope and curvature factor following FOMC announcement. Table 1 indeed showed that the influence of unanticipated FOMC decisions reflected on $\mathbf{\Delta}_{\bar{t}}$ have a larger influence on the daily change of the yield curve compared to normal days via $\mathbf{\Delta}_t$.

To see this, I calculated the overall magnitude of the daily change of each factor as the the sum of the absolute magnitude of the daily change of the anticipated level of the factors on day t and the absolute magnitude of the surprise to the factor on day t,

$$\mathbf{\Delta}_t^{\text{Overall}} = |\mathbf{\Delta}_t^{\text{Surprise}}| + |\mathbf{\Delta}_t^{\text{Anticipated}}| \tag{4.1}$$

and the influence of unexpected events on the daily change of the yield curve $\mathbf{\Delta y_t}$ is

$$\%\eta_{i,t}^{\Delta} = \frac{|\eta_{i,\bar{t}}|}{\Delta i_t^{\text{Overall}}} \text{ for } i = L, S, C. \tag{4.2}$$

Table 1 shows the distinction between $\%\eta_{i,t}^{\Delta}$ versus $\%\eta_{i,\bar{t}}^{\Delta}$ in different monetary policy regimes.

Panel (a) in Table 1 presents the interquartile range (IQR) of $\%\eta_{i,t}^{\Delta}$ for $i = L, S, C$. The lower IQR on FOMC days indicates that surprises contribute more consistently to yield curve changes, suggesting that market participants anticipate FOMC announcements as key events. In contrast, the higher IQR on non-FOMC days reflects greater variability, where yield movements are driven by macroeconomic data releases, speeches, or geopolitical events.

This lower IQR on FOMC days highlights the role of FOMC announcements as a coordination mechanism, anchoring market expectations and leading to more structured responses. Conversely, on non-FOMC days, the absence of a central policy signal results in more dispersed yield curve movements. Two key patterns emerge from Panel (a) in Table 1: First, after the 2008-2015 ZLB period, the IQR of $\%\eta_{L,t}^{\Delta}$ is lower on FOMC days, whereas outside ZLB periods, the IQR of $\%\eta_{S,t}^{\Delta}$ is lower instead. Second, since the 2008–2015 ZLB period, the IQR of $\%\eta_{C,t}^{\Delta}$ has remained lower on FOMC days, reinforcing the growing role of the curvature factor in monetary policy transmission.

Table 1: Interquartile range of $\%\eta^{\Delta}_{i,t}$ and $\%\eta_{i,t}$ on days with (*Ann.*) and without (*Nonann.*) FOMC announcements (%)

(a) Interquartile range of $\%\eta^{\Delta}_{i,t}$

	$i = L$		$i = S$		$i = C$	
	Ann.	*Nonann.*	*Ann.*	*Nonann.*	*Ann.*	*Nonann.*
Pre ZLB	8.57	7.56	5.54	8.35	9.26	9.41
ZLB	3.66	3.95	5.95	9.42	11.99	16.67
Post ZLB	4.52	7.91	8.94	8.56	8.85	11.82
CoVid ZLB	7.02	6.49	7.49	6.97	6.15	11.14
Post CoVid ZLB	5.08	5.43	7.01	11.97	2.16	9.70

(b) Interquartile range of $\%\eta_{i,t}$

	$i = L$		$i = S$		$i = C$	
	Ann.	*Nonann.*	*Ann.*	*Nonann.*	*Ann.*	*Nonann.*
Pre ZLB	0.545	0.623	6.46	4.12	6.33	7.65
ZLB	1.195	1.16	1.66	1.4	8.83	4.58
Post ZLB	2.738	1.12	3.04	3.48	9.55	6.82
CoVid ZLB	1.12	2.08	7.68	2.22	10.11	4.31
Post CoVid ZLB	1.32	1.54	3.42	6.9	9.4	11.49

Note: For the 257 FOMC announcement days from February 1995 to January 2024, 124 occurred before the 2008–2015 ZLB, 60 during it, 36 between the 2008-2015 ZLB and the CoViD ZLB periods, 21 during the COVID ZLB, and 16 after. For the 7,037 non-announcement days from February 1995 to January 2024, 3,361 were before the 2008-2015 ZLB, 1,691 during it, 1,024 between the end of 2008-2015 ZLB and CoViD ZLB periods, 448 during the CoViD ZLB, and 513 after.

These findings confirm that FOMC announcements drive changes in the US Treasury yield curve and highlight a shift in monetary policy transmission. Before the 2008–2015 ZLB period, slope surprises were the dominant channel, whereas post-ZLB, curvature surprises have become the primary driver. This is consistent with the identification results in Section 3: Before the 2008-2015 ZLB period the level and slope surprises were distinct from normal days, while curvature surprises were not. After the 2008-2015 ZLB period, curvature surprises became distinct, while level and slope surprises resembled those on normal days.

The influence of unexpected FOMC decisions on daily yield curve changes, $\%\eta^{\Delta}_{i,\bar{t}}$, is at least 29% for each factor ($i = L, S, C$) in all periods except for the slope factor before the 2008-2015 ZLB peirod. In contrast, on normal days, the influence of unexpected events can be as low as 0.04% and never exceeds 9.31%. Since the 2008–2015 ZLB period, the influence of FOMC announcements on the curvature factor has grown significantly, while unexpected events on normal days have had a consistent but limited effect. Post-CoVid ZLB, at least 93.67% of the surprise change in the curvature factor on FOMC days was driven by unexpected aspects of the Fed's statements. In contrast, the lower bounds of $\%\eta^{\Delta}_{L,\bar{t}}$ and $\%\eta^{\Delta}_{S,\bar{t}}$ remain significantly lower, confirming that in recent

periods, FOMC announcements primarily impact the yield curve through the curvature factor. On normal days, the lower bound of $\%\eta^{\Delta}_{C,t}$ remains significantly lower across all regimes, never exceeding 7.74%.

Feature 2. The slope factor captured economic regime shifts in the US before the 2008–2015 ZLB period, but after the ZLB, no single factor explicitly captures changes in economic episodes.

While Section 3 shows that the FOMC announcement effect before the 2008-2015 Zero Lower Bound (ZLB) period was identified on the whole yield curve, the dominant effect was identified on the surprise to the level factor. The decomposition in 3 nevertheless indicates that the slope factor captures the change in US economic episodes and the subsequent monetary policy strategy before the ZLB period.

To show this more clearly, I quantify the influence of FOMC announcements on the overall magnitude and daily change of the level, slope and curvature factors. I describe the overall magnitude of each factor as the sum of the absolute magnitude of the expected level of the factors on day t and the absolute magnitude of the unexpected deviation from this expected level on day t,

$$\boldsymbol{i}_t^{\text{Overall}} = |\mathbb{E}_{t-1}\boldsymbol{i}_t| + |\boldsymbol{\Delta}_t^{\text{Surprise}}| \tag{4.3}$$

where $\boldsymbol{\Delta}_t^{\text{Surprise}} = (\eta_{i,t})$ for $i = L, S, C$. The influence of unexpected events on the yield curve $\boldsymbol{y_t}$ is then

$$\%\eta_{i,t} = \frac{|\eta_{i,t}|}{i_t^{\text{Overall}}} \text{ for } i = L, S, C. \tag{4.4}$$

Figure 10 plots the extent to which each latent factor on the day $\bar{t}$ is driven by unexpected aspects of FOMC decisions announced on that day following equation 4.4. The figure showing the Zero Lower Bound (ZLB) period was plotted sometime before the ZLB period, starting from the announcement on the 31st of October 2007 when the Fed first announced the Summary of Economic Projections (SEP) along with their monetary policy decision until the announcement on the 30th January 2019 on which the last published forward guidance was announced[2].

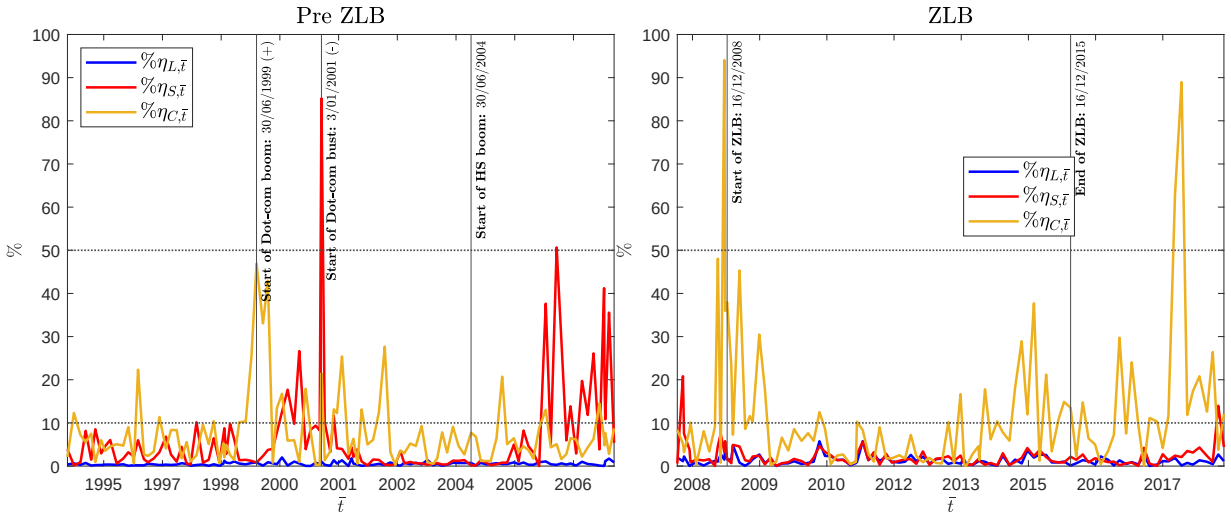
Before the 2008-2015 ZLB period, surprises to the slope factor drove up to 85% of its magnitude, often linked to pivotal shifts in the US economy. For example, the unexpected interest rate cut on January 3, 2001, during the dot-com bust, accounted for 85% of the slope factor's impact, as shown in Panel (b) of Figure 10. Similarly, as the economy transitioned into the 2008 financial crisis, nearly 50% of the slope factor's changes from March 28, 2006, to January 22, 2008, were driven by surprises, later amplified in the days following FOMC announcements, as depicted in Figure 10. While the surprises to the curvature factor are prominent after the 2008-2015 ZLB, it does not explicitly capture changes in US economics episodes.

[2] https://www.federalreserve.gov/monetarypolicy/timeline-forward-guidance-about-the-federal-funds-rate.htm

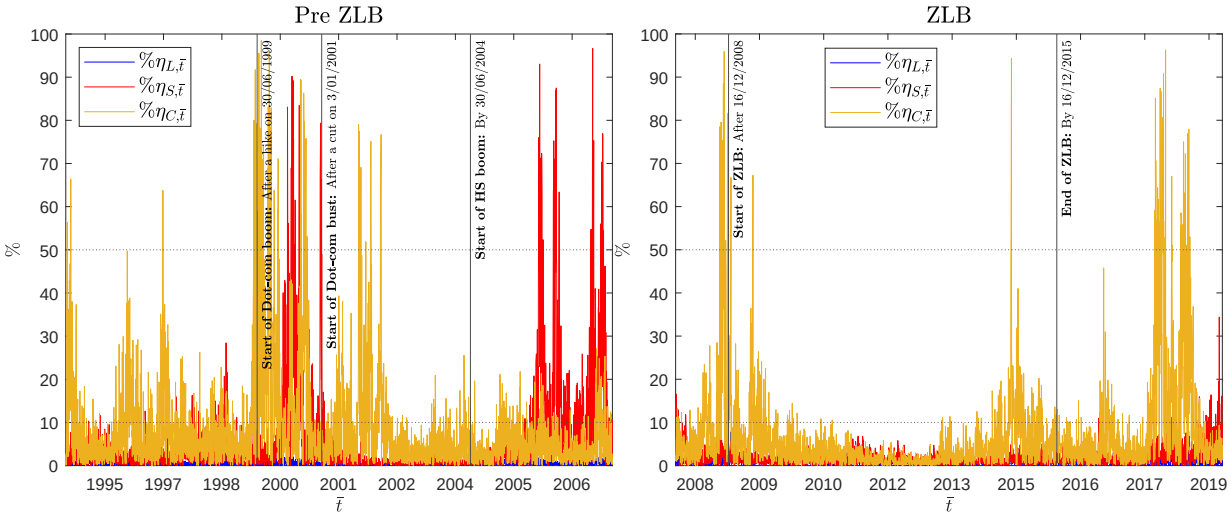
Figure 10 show that after the ZLB, the curvature factor captures most of the market deviation, even on non-FOMC days. While my identification strategy confirms that the Fed drives yield curve changes on FOMC days, this broader pattern suggests that medium-term yields continuously adjust to evolving policy expectations and macroeconomic conditions. Future research could explore whether specific news or financial conditions explain yield movements on non-FOMC days, shedding further light on the extended role of forward guidance.

Figure 10: % influence of unexpected events on the $\boldsymbol{y_t}$.

(a) % influence of unexpected FOMC decisions.



(b) % influence of unexpected events on days without FOMC announcements.



Notes: Panel (a) shows the extent to which factor $L_{\bar{t}}$, $S_{\bar{t}}$ and $C_{\bar{t}}$ are driven by the unexpected aspects of FOMC decision announced on day $\bar{t} = 1, \ldots, 185$ before and during the ZLB period, which is calculated as $\%\eta_{i,\bar{t}} = 100\% \times \frac{|\eta_{i,\bar{t}}|}{|\mathbb{E}_{\bar{t}-1} i_{\bar{t}}|+|\eta_{i,\bar{t}}|}$ for $i = L, S, C$. Panel (b) shows the extent to which factor L_t, S_t and C_t are driven by the unexpected events on non FOMC announcement day, or "normal" day $t = 1, \ldots, 7012$ before and during the ZLB period starting from January 4th, 1995 to February 1st, 2024, which is calculated as $\%\eta_{i,t} = 100\% \times \frac{|\eta_{i,t}|}{|\mathbb{E}_{t-1} i_t|+|\eta_{i,t}|}$ for $i = L, S, C$. This figure is produced using sample D1.

Feature 3. Surprise to the level factor is associated with the most dominant effect of the conventional monetary policy tool before the 2008-2015 ZLB period, while the surprise to the curvature factor maps to the most dominant unconventional monetary policy tool during the 2008-2015 ZLB period.

The FOMC announcement effects during the 2008-2015 ZLB period instead are identified only on the surprise change of the medium-term bond yields via the surprise change to the curvature factor in Section 3. Furthermore, I also showed that the surprise to the curvature factor during the 2008-2015 ZLB period captured the forward guidance surprise.

Panel (a) and Panel (b) of Figure 10 show that before and during the ZLB period, at most 45–48% of the overall magnitude of the curvature factor was driven by its surprise component. In contrast, while only 4–5% of the overall magnitude of the level factor was attributable to surprises, at least 29% of the overall change in the level factor following an FOMC announcement was unexpected, compared to just 0.09% for the slope factor before the ZLB. Additionally, during the ZLB period, as the Fed shifted toward forward guidance and balance sheet policies, merely 5.65% of the overall magnitude of the slope factor was driven by surprises.

Notably, while surprises to the level, slope, and curvature factors typically drive most daily yield curve changes (Equation 4.2), they remain minor deviations from market expectations (Equation 4.4). However, in rare instances, monetary policy surprises lead to significant deviations, disproportionately impacting the yield curve's short- and medium-term segments. This suggests that while FOMC announcements generally anchor market expectations, unexpected policy guidance, or economic conditions, shifts can lead to sharp adjustments, particularly in these maturities.

Two rare but significant instances - March 21, 2018, and January 26, 2022 - saw the surprise component drive significant deviations in the yield curve, coinciding with monetary policy shifts and economic uncertainty. On March 21, 2018, Jerome Powell's debut FOMC meeting saw markets underestimate the Fed's commitment to tightening, leading to a sharp repricing of medium-term yields. This forward guidance surprise forced investors to adjust expectations more drastically than usual, highlighting the market's sensitivity to leadership transitions. Similarly, the January 26, 2022 announcement on ending asset purchases and imminent rate hikes forced a rapid adjustment in expectations. These episodes reveal a key limitation of forward guidance: while it typically anchors expectations, its effectiveness weakens during leadership changes and policy transitions, as markets struggle to interpret shifts in direction.

These three features suggest that the surprise component of each latent factor, rather than their linear combinations maps to different monetary policy tools by the Fed. More importantly, they also suggest the growing importance of forward guidance identified on the surprise to the medium-term curvature factor, $\eta_{C,\bar{t}}$ in influencing the change in the US Treasury yield curve above other monetary policy tools in different regimes.

Part of the identification of the US monetary policy surprise has to do with the different effects it has on the US Treasury yield curve through the expectation of future interest rates and term

premia before and during the ZLB period. It is well documented that the response of the yield curve to the policy rate and forward guidance surprises during conventional and unconventional time is determined by the change in the expectation of future interest rates as well as term premium (Lane (2019)). I do not investigate how monetary policy surprise affects each of the expectation and term premium components of the US Treasury yield curve. I instead collect the different findings on the effects of monetary policy surprises on the expectation and term premium components of the US Treasury yield curve and identify the daily monetary surprise according to this evidence.

Altavilla et al. (2019) documents that before the ZLB period, an interest rate cut mainly affects the short end of the yield curve (steepening the yield curve) while communication from the central bank about future rates (forward guidance surprise) has a large impact on the intermediate maturities. Hanson and Stein (2015) postulates that "yield-oriented investors" are the rationale behind the strong reaction of long-term forward rates to a change in policy rate before the ZLB period: a standard rate cut consequently lowers the term premium. A more recent study, Bundick et al. (2022) however shows that forward guidance lowers the uncertainty surrounding future policy path and thus drives down term-premia in longer-term bond markets before the ZLB period.

Meanwhile, documentation of the effect of LSAP and forward guidance during the ZLB period indicates mixed results on the effect of monetary policy surprises on the expectation and term premium components of the yield curve. A conventional view during the ZLB period is that forward guidance surprise affects the yield curve via the expectation component while LSAP works through the term premium component of the yield curve: Bernanke (2013) states that *"Forward rate guidance affects longer-term interest rates primarily by influencing investors' expectations of future short-term interest rates. LSAPs, in contrast, most directly affect term premiums."*. It is generally agreed upon that LSAP flattens the US Treasury yield curve as the long end of the yield curve declines more than the short end[3]. The impact of LSAP on term premium and expectation component of the yield curve is largely examined through two broad lenses, the signaling versus portfolio rebalancing channel. Notably, Bauer and Rudebusch (2014) presents evidence for the signaling channel of monetary policy that the news about asset purchases by the Fed compresses the expectation component of the yield curve as LSAP announcements translate into a commitment by the Fed to keep interest rates low in the future. A large body of literature suggests that as investors rebalance their portfolios, the LSAP compresses the term premium (portfolio rebalancing channel, Joyce et al. (2011) and Gagnon et al. (2011)). Meanwhile, Rudebusch and Swanson (2012) and Andreasen (2012) show that a change in monetary policy stance has a negligible effect on term premia in estimated macro-finance models, which highlights the gap between theory and practice.

Despite the mixed results from the literature, Figure 11 and Figure 12 show that the identification of $\eta_{L,t}$, $\eta_{S,t}$ and $\eta_{C,t}$ in Section 3 fits the narrative of Fed's policy actions until now. Figure 11 and Figure 12[4] show the three features that support my identification in Section 3: First, Panel

[3]Bauer and Rudebusch(2014), D'Amico and King (2013), Gagnon et al. (2011), Hamilton and Wu (2012), Krishnamurthy and Vissing-Jorgensen (2011), Neely (2011) and Woodford (2012).

[4]There are three well-known papers that decompose the US Treasury yield curve into the unobservable term

(a) in Figure 12 shows that as the surprise component of the slope factor $\eta_{S,\bar{t}}$ moved the shortest end of the yield curve before the 2008-2015 ZLB period, it served as both policy tools and signals that moved market expectation and thus has much larger correlation to the daily change in the expectation component of the yield curve compared to during the 2008-2015 ZLB period in Panel (b) in Figure 12. Panel (b) in Figure 12 shows that the correlation of the standard monetary policy surprise $\eta_{S,\bar{t}}$ on the daily change in the expectation component of the yield curve is close to zero during the 2008-2015 ZLB, capturing the change in monetary policy tool as the Fed was constrained at the zero lower bound.

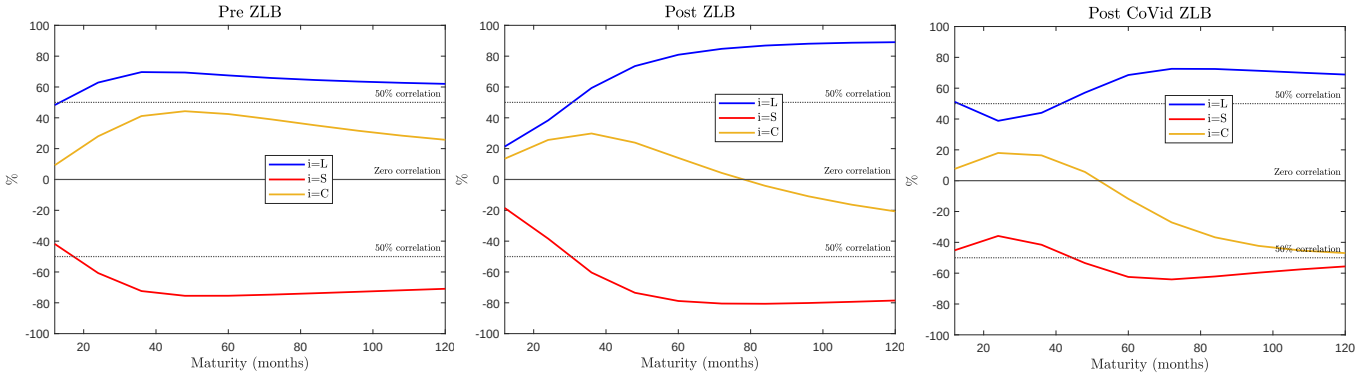
Second, the forward guidance surprise $\eta_{C,\bar{t}}$ has stronger positive correlation at larger than 50% in most cases with the change in the expectation component of the yield curve in Figure 12 as rather than with the term premium in Figure 11 in all periods, confirming the traditional view that forward guidance influences expectations more so than term premium. This supports my argument that forward guidance has always been the dominant tool by the Fed that drives a large portion of the 1-day change in the US Treasury yield curve following FOMC announcements.

Lastly, the correlation between $\eta_{L,\bar{t}}$ and the change in the term premium component in Figure 11 has been growing after the 2008-2015 ZLB period, reflecting the completion of the asset purchase program. The correlation between the term premium component and $\eta_{L,\bar{t}}$ in Figure 11 reached the highest during the CoVid ZLB period in 2020-2022 and went down afterward, reflecting the same pattern. Meanwhile, Figure 12 also shows that the correlation between the change in the expectation component of the yield curve with $\eta_{L,\bar{t}}$ was initially near zero before the 2008-2015 ZLB, but it became negative during the 2008-2015 ZLB period and stayed mostly negative afterward. This suggests that $\eta_{L,\bar{t}}$ captures the balance sheet policy such as asset purchase and sales when the Fed was constrained at the zero lower bound.

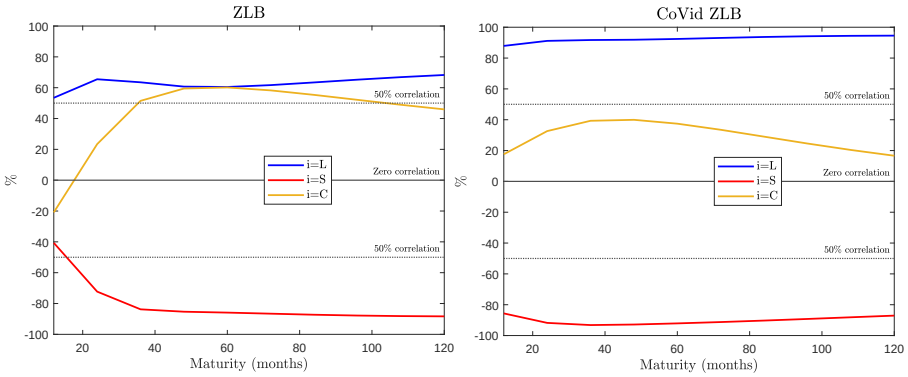
premium and expectation components, namely Kim and Wright (2005) (Kim-Wright decomposition), Adrian, Crump and Moench (2013) (ACM model) and D'Amico, Kim and Wei (2014) (DKW model). However, I choose the decomposition of Adrian, Crump and Moench (2013) as it is referenced in recent newspaper article: https://www.reuters.com/markets/rates-bonds/market-us-bond-market-signals-end-an-era-2023-10-02/. The three models has been shown to be consistent with each other by Wu (2014).

Figure 11: Correlation with the term premium component of the US Treasury yield curve

(a) Unconstrained



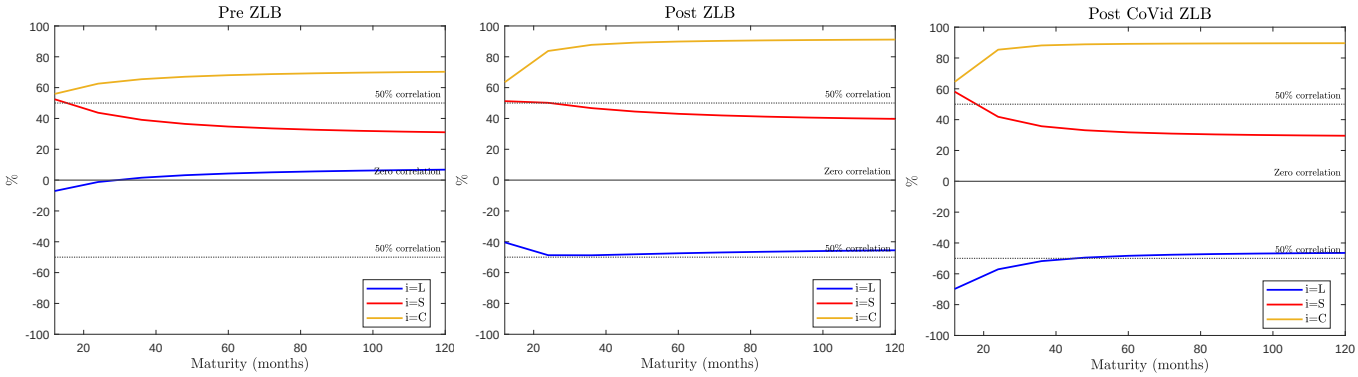
(b) Constrained



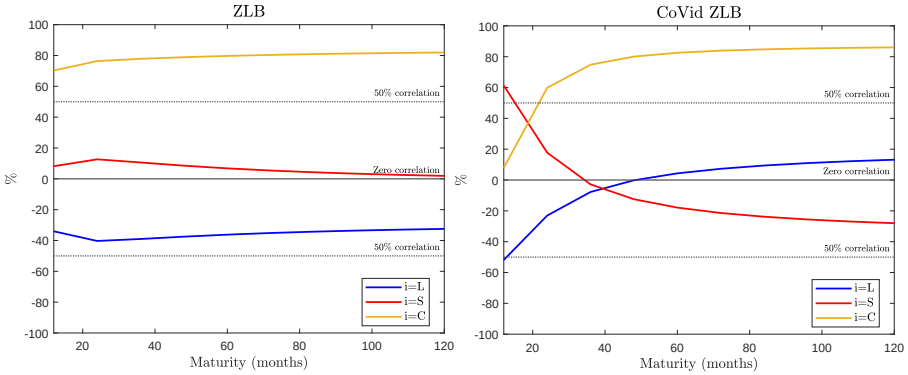
Source: The term premium and expectation components of $\Delta y_t(\tau)$ are estimated by Adrian, Crump and Moench (2013)

Figure 12: Correlation with the expectation component of the US Treasury yield curve

(a) Unconstrained



(b) Constrained

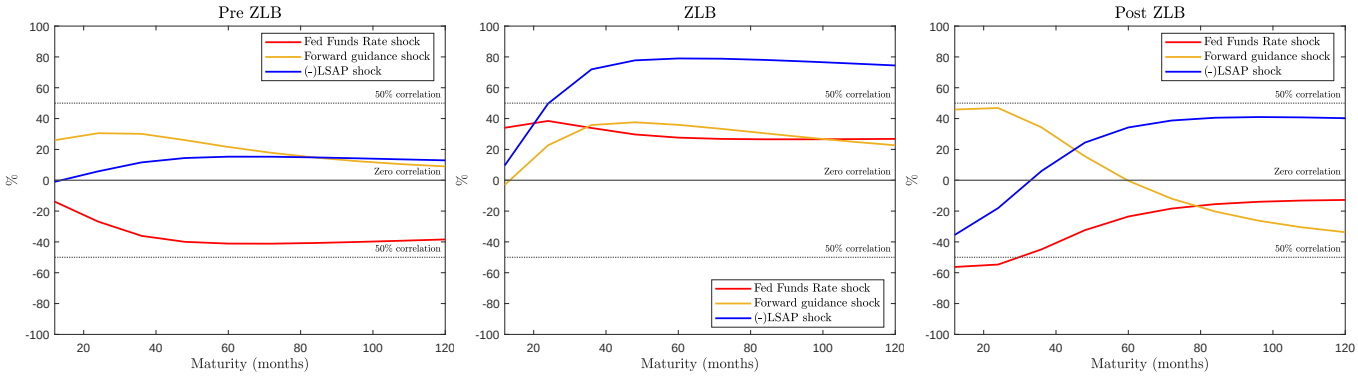


Source: The term premium and expectation components of $\Delta y_t(\tau)$ are estimated by Adrian, Crump and Moench (2013)

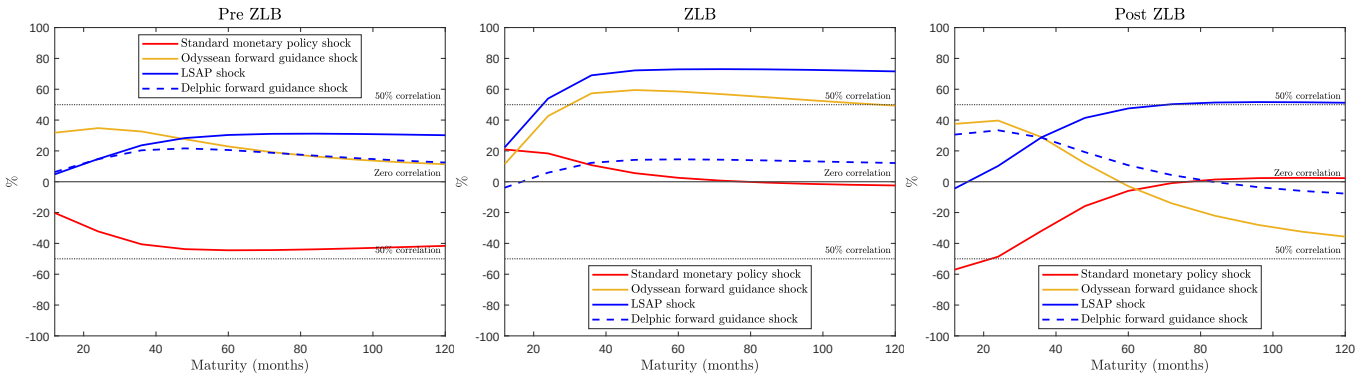
The distinct interpretation of $\eta_{L,\bar{t}}$, $\eta_{S,\bar{t}}$ and $\eta_{C,\bar{t}}$ representing different dimensions of US monetary policy actions shown in Figure 11 and Figure 12 are consistent with notable estimated intraday surprises in the literature. Figure 13 and Figure 14 shows that the standard monetary policy shock before the 2008-2015 ZLB period estimated by Swanson (2021) and Jarociński (2021) also has significantly lower correlation with the change in the expectation component of the yield curve during the 2008-2015 ZLB period. Their forward guidance shock has a much larger positive correlation with the expectation component of the yield curve during and after the 2008-2015 ZLB period in Figure 14 compared to their standard monetary policy shock and LSAP shocks, which is an evidence of the growing influence of forward guidance on the yield curve after the 2008-2015 ZLB period. Meanwhile, their LSAP shock has significantly positive correlations with the change in the term premium component of the yield curve shown in Figure 13.

Figure 13: Correlation between intraday surprises with the term premium component of the US Treasury yield curve

(a) Swanson (2021)



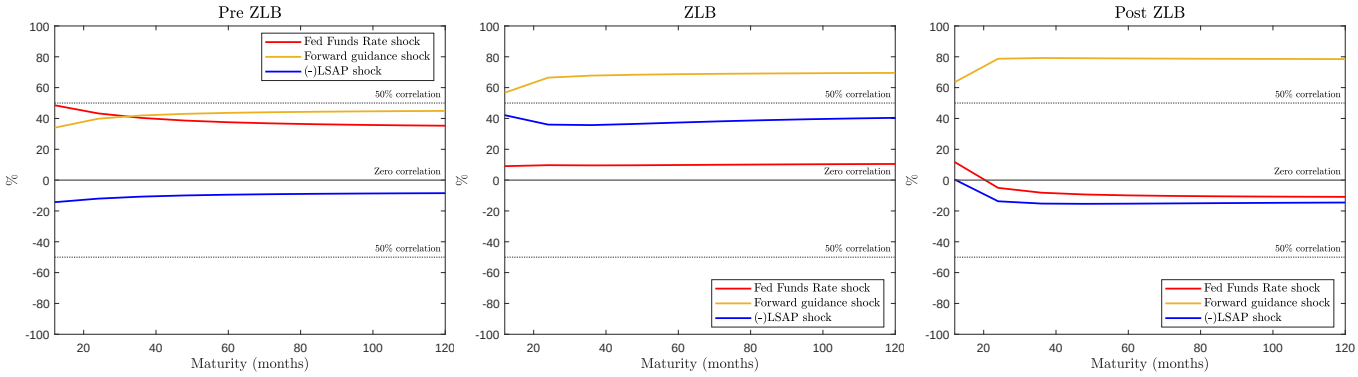
(b) Jarociński (2021)



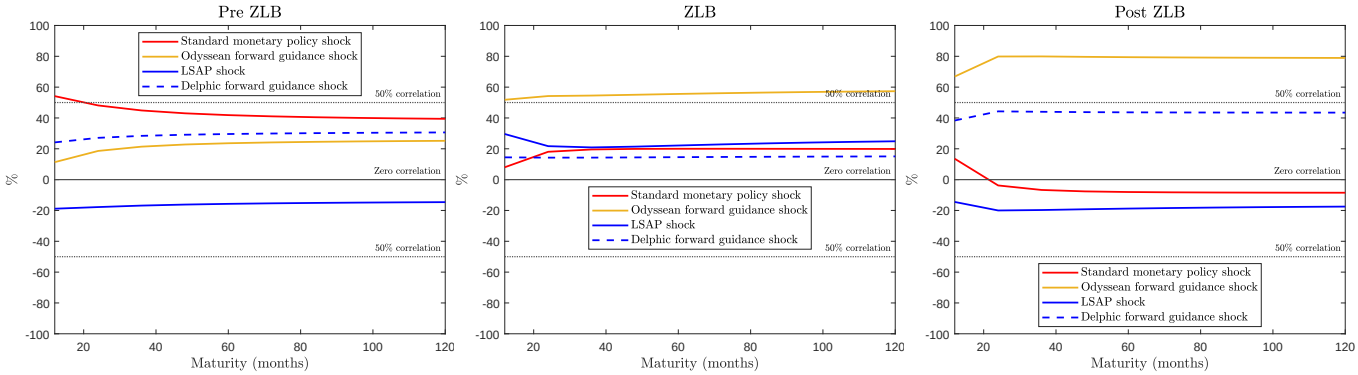
Source: The shocks are published material of Swanson (2021) and Jarociński (2021). The term premium and expectation components of $\Delta y_t(\tau)$ are estimated by Adrian, Crump and Moench (2013).

Figure 14: Correlation between intraday surprises with the expectation component of the US Treasury yield curve

(a) Swanson (2021)



(b) Jarociński (2021)



Source: The shocks are published material of Swanson (2021) and Jarociński (2021). The term premium and expectation components of $\Delta y_t(\tau)$ are estimated by Adrian, Crump and Moench (2013).

My daily surprise seems to be an improvement to other intraday surprises estimated by Nakamura and Steinsson (2018), Jarociński and Karadi (2020), Swanson (2021) and Jarociński (2021). There were 11 FOMC announcement dates before the 2008-2015 ZLB period when the intraday standard monetary policy shocks estimated in all four papers do not have the correct signs, namely the 29th September 1998, the 30th of June 199, the 2nd of February 200, the 31st of January 2001, the 27th of June 2001, the 21st of August 2001, the 25th of June 2003, the 30th of June 2004, the 29th of June 2006, the 11th December 2007 and the 18th of March 2008. My decomposition in Section 3.1 resolves the misleading signs of the intraday standard monetary policy surprise on 7 out of these 11 problematic dates, leaving only the 25th of June 2003, the 30th of June 2004, the 30th of June 1999 and the 29th of June 2006 as problematic dates.

5. The Efficacy of the Federal Reserve's Monetary Policy Tool(s)

Starting from the 1st of February 1995 until now the Federal Reserve (Fed) has deployed several monetary policy tools: conventional interest rate targets, balance sheet policies (asset purchase and sales) as well as forward guidance. I have established in Section 3 and Section 4 that each surprise to the slope, level and curvature factors can be uniquely mapped to each of these tools and corresponds to different parts of the yield curve. More importantly, I also documented the increasing influence of forward guidance on the daily change of the US Treasury yield curve after the 2008-2015 Zero Lower Bound (ZLB) period via its influence on the curvature factor in Section 3 and Section 4.

In this section, I examine the role of different monetary policy tools. To do so, I classify announcements based on the primary policy instrument emphasized in FOMC communication, including interest rate changes, forward guidance, and large-scale asset purchases[5]. I then estimate the sensitivity of yield curve factors to monetary policy surprises within each subsample and combine these sensitivities with the empirical distribution of shocks to construct distribution-weighted responses across maturities. While this approach is reduced-form and does not fully isolate causal effects of individual tools, it provides a transparent framework to compare how different policy instruments are associated with yield curve movements across policy regimes.

I quantify the impact of each of the tools deployed by the Federal Reserve throughout the years in two cases: when the Fed was constrained at the Zero Lower Bound (ZLB) versus when the Fed was unconstrained. To obtain the impact of each monetary policy tool on the yield curve, I estimate $\Delta y_{\bar{t}}(\tau)$ in different samples representing the dominant usage of these tools both when the Fed was constrained at the ZLB and when they were unconstrained. I do so by regressing the daily change of the yield curve at each maturity on the identified daily surprises to obtain the sensitivity of the yield curve to FOMC announcements in each case for each tool. Since each surprises $\eta_{L,\bar{t}}$, $\eta_{S,\bar{t}}$ and $\eta_{C,\bar{t}}$ is uniquely mapped to different policy tools, I can estimate their likely value via kernel density estimation for the 257 announcements from February 1st, 1995 to January 31st, 2024 in all cases. I then use the kernel density estimate of these surprises and the sensitivity obtained from the regression to estimate $\Delta y_{\bar{t}}(\tau)$ in all cases.

I quantify the impact of each policy tool to understand how people receive different statements and communications from the Fed which is reflected in the magnitude and the direction of the surprise change in the US Treasury yield curve due to FOMC announcements from February 1st, 1995 to January 31st, 2024. Section 5.1 will detail the breakdown of the samples corresponding to each tool in both constrained and unconstrained cases while Section 5.2 presents the stylized

[5]In the empirical classification, I group forward guidance and communication associated with the Summary of Economic Projections (SEP) into a broader expectations-management category, as both channels influence market expectations about future policy. However, SEP releases may also convey information about the Federal Reserve's economic outlook, implying that this component may combine policy guidance with information effects. Accordingly, the estimates should be interpreted as capturing a communication-related channel of monetary policy rather than a pure measure of forward guidance.

impact of each policy tool on the yield curve based on the outcome of state-space model of the US Treasury yield curve. Section 5.3 presents the estimate of the possible impact of the Federal Reserve's monetary policy tools on the yield curve.

5.1. Federal Reserve's Monetary Policy Tools

Figure 15 depicts the monetary policy tools deployed by the Federal Reserve from February 1st, 1995 to January 31st, 2024. I analyzed 257 FOMC announcements during this period and observed FOMC monetary policy decisions under two conditions: constrained and unconstrained.

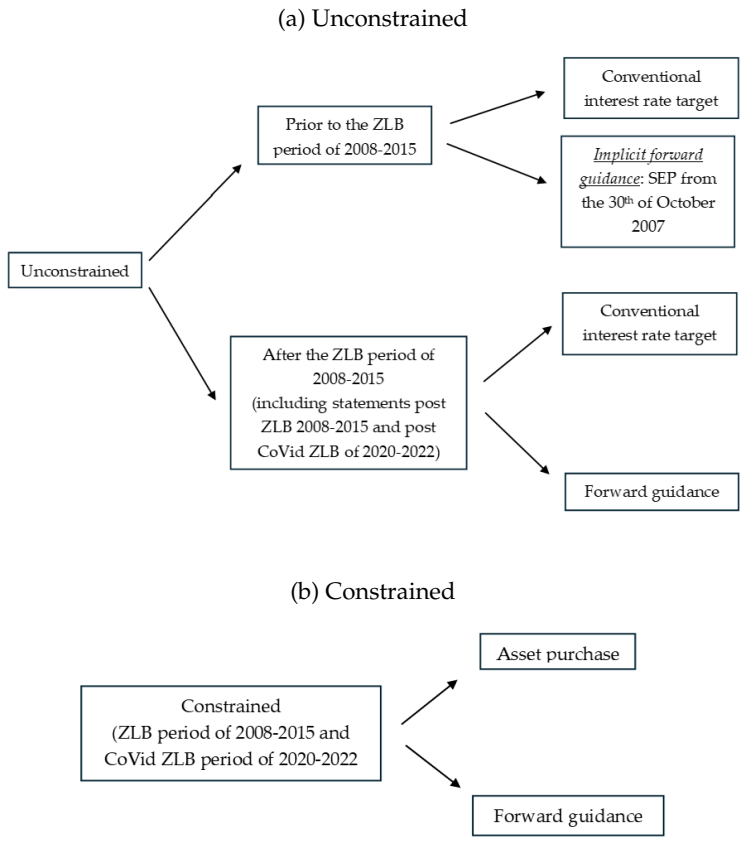
When the Fed was unconstrained they had the option to change interest rate targets, issue forward guidance statements, and complete their balance sheet policy such as asset purchases and sales. When the Fed was constrained (eg. during the period when the interest rate fell to zero), they utilized balance sheet policies such as Large Scale Asset Purchase (LSAP) and forward guidance. There are 176 announcements during the unconstrained period (124 announcements before the Great Recession in 2008 and 52 announcements after the conclusion of the 2008-2015 ZLB period) and 82 announcements during the constrained period (61 announcements from the 2008-2015 ZLB period and 21 announcements from the 2020-2022 CoVid ZLB period) in Figure 15. This adds up to 257 announcements from the 1st of February 1995 to the 31st of January 2024 since I include the rate cut on the 16th of December into both samples of constrained and unconstrained periods.

Recall that there were 44 announcements containing *solely* **published** or **unpublished** forward guidance (no LSAP announcements) depicted in Figure 8. The **unpublished** forward guidance statements are acknowledged as forward guidance by recent studies such as Sablik (2022) and Sutherland (2023) but not by the Fed. **Published** forward guidance statements on the other hand are acknowledged publicly by the Fed as their forward guidance statements. **Published** forward guidance fell into two categories: *implicit* guidance such as the announcements of the Summary of Economic Projections (SEP) and *explicit* guidance which are direct statements in the press release acknowledged by the Fed as their forward guidance and published on their website[6]. Among these forty-four forward guidance statements, there are 25 **published** forward guidance, 5 of them being explicit and 16 being implicit forward guidance while the remaining 4 statements contain both explicit and implicit forward guidance. Based on Sablik (2022) and Sutherland (2023), there are 19 FOMC statements containing **unpublished** forward guidance.

Table 16 shows the breakdown of the Federal Reserve's monetary policy tools during the unconstrained period: before the 2008-2015 ZLB period and after both the 2008-2015 and 2020-2022 CoVid ZLB periods. When unconstrained, the Fed hikes, cuts and maintains interest rates. The

[6]Explicit forward guidance are published in the Fed's website:
https://www.federalreserve.gov/monetarypolicy/timeline-forward-guidance-about-the-federal-funds-rate.htm.
Dates of LSAP announcements can be found in:
https://www.federalreserve.gov/monetarypolicy/timeline-balance-sheet-policies.htm

Figure 15: Fed's Monetary Policy Tools



Notes: Figure 15 depicts the monetary policy tools deployed by the Federal Reserve from February 1st, 1995 to January 31st, 2024. The periods outside the Zero Lower Bound (ZLB) periods includes periods before the 2008-2015 ZLB period, and period before and after the 2020-2022 CoVid ZLB period. There are 176 announcements during unconstrained period and 82 announcements during constrained period. I include the rate cut on the 16th of December 2008 into both samples of constrained and unconstrained periods.

introduction of the Summary of Economic Projections (SEP) in October 2007 serves as implicit forward guidance on top of the conventional interest rate policy before the 2008-2015 ZLB period.

I document 25 interest rate hikes, 24 interest rate cuts, as well as 32 and 37 instances when the Fed maintained interest rates amid tightening and easing episodes respectively without any additional influence of forward guidance, before the 2008-2015 ZLB period (Table 16). In the same period, the Fed introduced the SEP in October 2007, and there were 5 cases where interest rate cuts were accompanied by the announcement of SEP and 1 case when the Fed kept interest rate amid easing episodes while announcing its SEP in 2007.

After the 2008-2015 and 2020-2022 CoVid ZLB periods, the Fed deployed explicit and implicit forward guidance (SEP) as well as balance sheet normalization on top of the conventional interest rate tools. I document 6 interest rate hikes, 3 interest rate cuts, as well as 12 and 3 instances when the Fed maintained interest rates amid tightening and easing episodes respectively without

any additional influence of forward guidance post-2008-2015 and 2020-2022 CoVid ZLB periods (Table 16). Meanwhile, there were 14 interest rate hikes, 1 interest rate cut, and 9 and 4 instances when the Fed maintained interest rates amid tightening and easing episodes respectively with any additional influence of forward guidance post-2008-2015 and 2020-2022 CoVid ZLB periods (Table 16).

During constrained times, the Fed can only utilize implicit forward guidance (Summary of Economic Projections), explicit forward guidance, and balance sheet policies such as asset purchases and sales, and none of the conventional interest rate policy tools. Figure 17 and Figure 18 shows the breakdown of the Federal Reserve's monetary policy tools under constraint during the 2008-2015 and the 2020-2022 ZLB periods respectively.

I divided the 61 observations during the 2008-2015 ZLB period into two sub-periods: 39 announcements before the taper tantrum (16th of December 2008 to the 1st of May 2013) and 22 announcements after the taper tantrum (19th of June 2013 to the 28th of October 2015) in Figure 17. The observation before the taper tantrum ended at the FOMC meeting on May 1st, 2013 where they first introduced language in its policy statement regarding a potential change in the pace of asset purchases. The observation after the taper tantrum started after the FOMC meeting on June 19th, 2013 in which the following statement was interpreted as signaling the future tapering of the Federal Reserve's asset purchases.

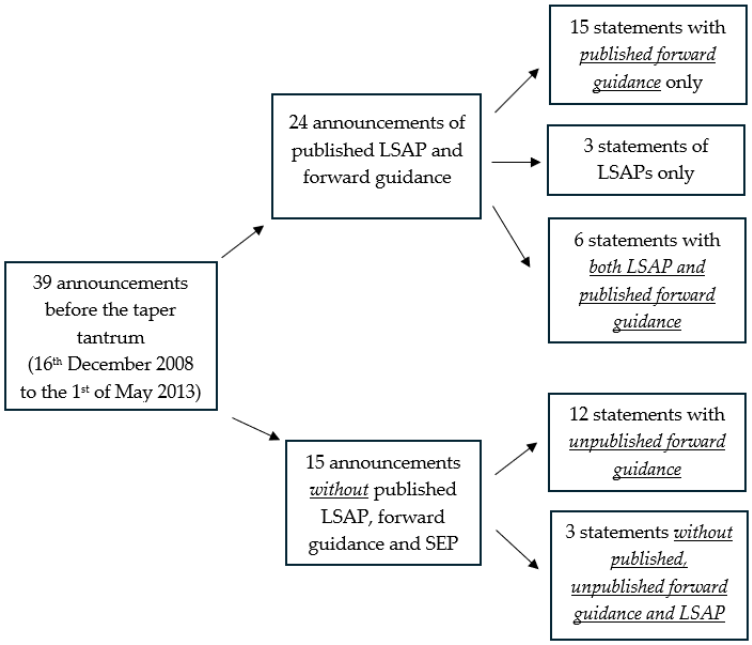
Figure 16: Fed's Monetary Policy Tools: Unconstrained

	Prior to 2008-2015 ZLB period		**Post 2008-2015 and 2020-2022 CoVid ZLB periods**	
	Without SEP	*With SEP*	*Without forward guidance and asset purchase/sale*	*With forward guidance and asset purchase/sale*
Hikes	25	-	6	14
Cuts	24	5	3	1
Maintain - amid tightening episodes	32	-	12	9
Maintain - amid easing episodes	27	1	3	4
Total announcements	118	6	24	28

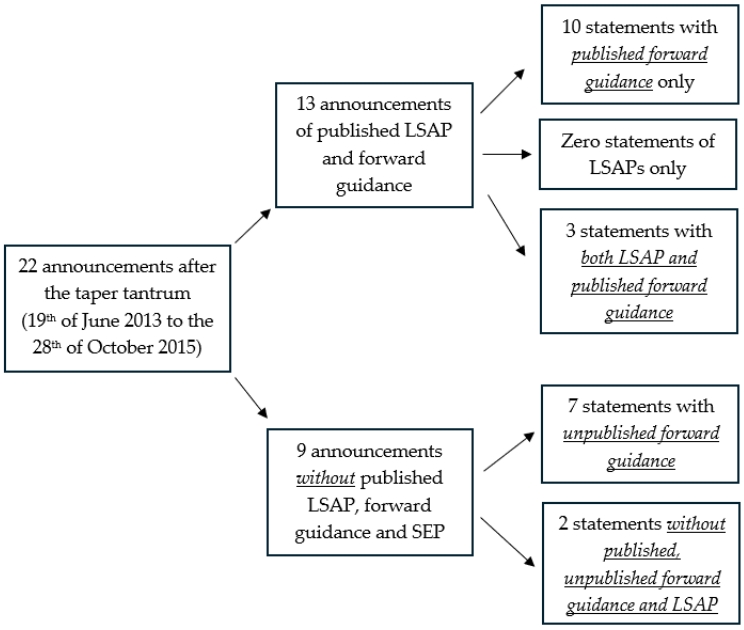
Notes: Table 16 depicts the monetary policy tools deployed by the Federal Reserve outside the 2008-2015 and the 2020-2022 CoVid ZLB periods when they are under no ZLB constraint. There are 176 announcements during this unconstrained period. I include the rate cut on the 16th of December 2008 in this set of announcements.

Figure 17: Monetary Policy Tools during the 2008-2015 Zero Lower Bound (ZLB) period

(a) Before the taper tantrum



(b) After the taper tantrum



Notes: Figure 17 depicts the breakdown of 61 FOMC announcements during the 2008-2015 ZLB period. The observation before the taper tantrum ends at the FOMC's meeting on May 1st, 2013 where they first introduced language in its policy statement regarding a potential change in the pace of asset purchases. The observation after the taper tantrum started after the FOMC meeting on June 19th, 2013 of which the following statement was interpreted as signaling the future tapering of the Federal Reserve's asset purchases.

I categorized each announcement before and after the taper tantrum in Figure 17 into two categories: ones that contain Large Scale Asset Purchase (LSAP) announcements and **published** forward guidance, and others that contain none of these two policies. I then further categorized announcements containing **published** forward guidance and LSAP statements into three categories: containing solely Large Scale Asset Purchase (LSAP) announcements only, solely **published** forward guidance, or a mixture of both. For announcements containing none of the LSAP and **published** forward guidance statements, I categorized them into two categories: ones containing **unpublished** forward guidance, and others with no specific policy announcements.

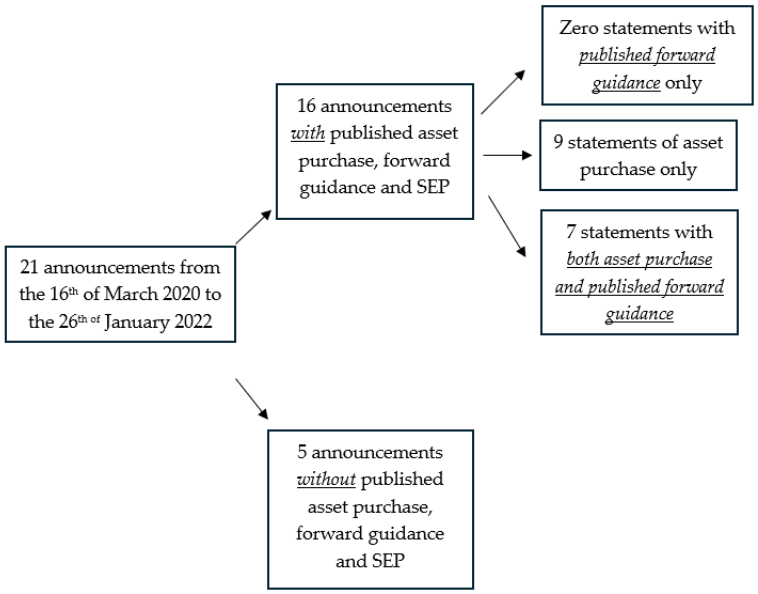
For the 2020-2022 CoVid ZLB period, I combine all 21 observations as one in Figure 18. FOMC actions during this period are mostly asset purchases combined with implicit forward guidance such as SEP announcements after their meetings. Different from the 2008-2015 ZLB period, the FOMC announced that they would reduce their purchase only during the last three meetings in this period, before finally hiking the interest rate on March 16th, 2022. There are 16 statements announcing asset purchases during this period, 7 of the 16 statements were announced together with the SEP. The remaining 5 statements contain no asset purchase announcement and were not announced with the SEP. There was no explicit forward guidance in this period, unlike during the 2008-2015 ZLB period.

5.2. Stylized Impact of the Federal Reserve's Monetary Policy Tools on the Yield Curve

Figure 19 and Figure 20 show the raw yield curve a day before FOMC announcement $y_{\bar{t}-1}$ and on the day of the FOMC announcement $y_{\bar{t}}$ in both cases when the Fed was constrained at the ZLB and when they were unconstrained respectively. There were only a handful of instances when the yield curve was inverted before the 2008-2015 ZLB period and recently, the yield curve inverted at the beginning of 2022. In the case when the yield curve was not inverted, the slope between 2-month to 360-month yield can reach 0.01, which is why the raw yield a day before the announcement $y_{\bar{t}-1}$ was shown to have a slope of 0.01 between 3-month to 360-month yield to mirror the real yield curve in both Figure 19 and Figure 20.

Figure 19 and Figure 20 show the stylized impact of US monetary policy surprises on the US Treasury yield curve. I use the kernel density estimates of the surprises in the Nelson-Siegel representation of the yield curve in each sample to produce $y_{\bar{t}}(\tau)$ in Figure 19 and Figure 20, assuming that the sensitivity of the yield curve to FOMC announcements remain the same for every monetary policy regime following the Nelson-Siegel representation in Section 3. Figure 19 illustrates the impact of two unconventional monetary policy tools by the Fed when they were constrained at the ZLB during both the Great Recession and the CoVid period: forward guidance and asset purchase. Figure 20 illustrates the impact of both conventional and unconventional tools deployed by the Fed when they were unconstrained, namely interest rate target and forward guidance. There was no (Summary of Economic Projections) SEP or other form of published forward guidance before

Figure 18: Monetary Policy Tools during the 2020-2022 CoVid Zero Lower Bound (ZLB) period



Notes: Figure 18 depicts the breakdown of 21 FOMC announcements during the 2020-2022 CoVid ZLB period. There are 16 statements announcing asset purchases during this period, 7 of the 16 statements were announced together with the SEP. The remaining 5 statements contain no asset purchase announcement and were not announced with a SEP. There was no explicit forward guidance during this period, unlike during the 2008-2015 ZLB period.

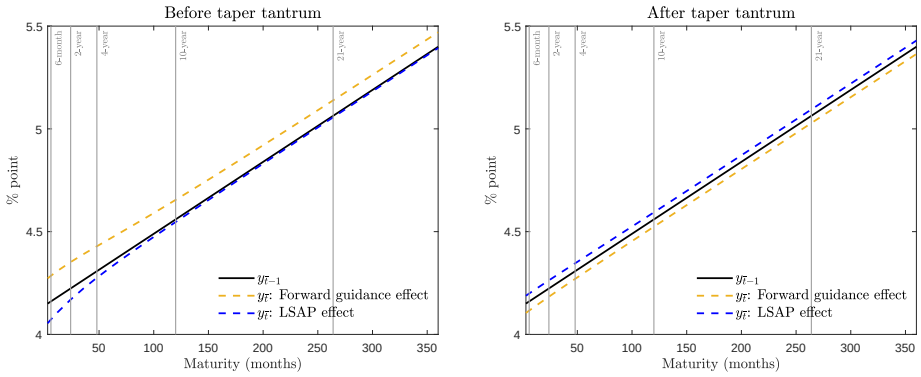
the 30th of October 2007, and hence only an interest rate target was deployed. By the 30th of October 2007, the Fed started to announce SEP and explicit statements which became forward guidance tools in the subsequent periods.

The stylized impact of unconventional monetary policy tools when the Fed was constrained at the ZLB is shown in Figure 19. Panel (a) and Panel (b) in Figure 19 show that the impact of asset purchases by the Fed before the taper tantrum during the 2008-2015 ZLB period and the CoVid ZLB period moved the shortest end of the yield curve downward by larger magnitude compared to the longest end of the yield curve. While this is analogous to what is widely perceived to be the impact of interest rate cuts, this result is counterintuitive: if LSAP was working as intended, it was to be reflected on the downward shift of the long end of the yield curve as it lowered the long-term interest rate. Notably, the impact of asset purchase before the taper tantrum was also overshadowed by forward guidance from the Fed that shifted the yield curve upwards which is shown in Panel (a) in Figure 19.

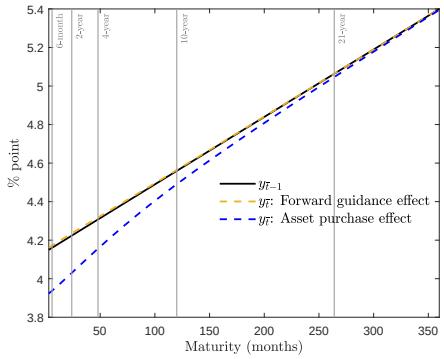
After the brief period of taper tantrum when the Fed signaled that they would scale down their asset purchase during the 2008-2015 ZLB period, the asset purchase announcement shifted the yield curve upward but was also offset by the forward guidance that shifted the yield curve downward by the same magnitude as shown in Panel (a) in Figure 19. Panel (b) in Figure 19 nev-

Figure 19: The impact of US monetary policy surprise on the US Treasury yield curve when the Fed was constrained

(a) 2008-2015 ZLB period



(b) 2020-2022 CoVid ZLB period



ertheless shows that the impact of forward guidance when the Fed was constrained diminishes after the 2008-2015 ZLB period: the impact of forward guidance was nearly zero and instead overshadowed by the impact of asset purchase during the 2020-2022 CoVid ZLB period. It is worth noting that this weak impact of forward guidance was perhaps attributed to the absence of *explicit* forward guidance statements from the Fed akin to those during the 2008-2015 ZLB period: there were only *implicit* forward guidance statements in the form of SEP announcements that always coincided with the asset purchase announcement during the 2020-2022 CoVid ZLB period.

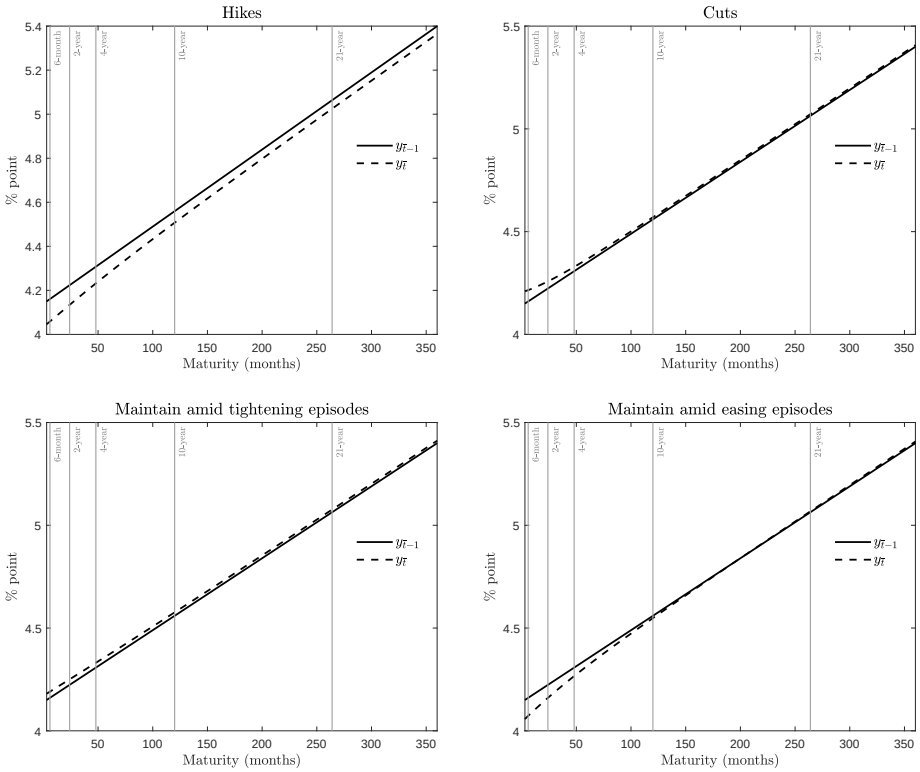
The stylized impact of both conventional interest rate targets and unconventional tools such as forward guidance when they were unconstrained are shown in Figure 20 are also counterintuitive. When the Fed hiked rates before the 2008-2015 ZLB period, the yield curve instead shifted downward with the largest magnitude on the shortest end as shown in Panel (a) in Figure 20. The impact of a rate cut during the same period is also counterintuitive as it pushes the shortest end of the yield curve upward albeit by a lesser magnitude compared to a rate hike.

Nevertheless, Panel (b) in Figure 20 shows the conventional monetary policy tools seemed more effective after the introduction of forward guidance on the 30th of October 2007. An interest

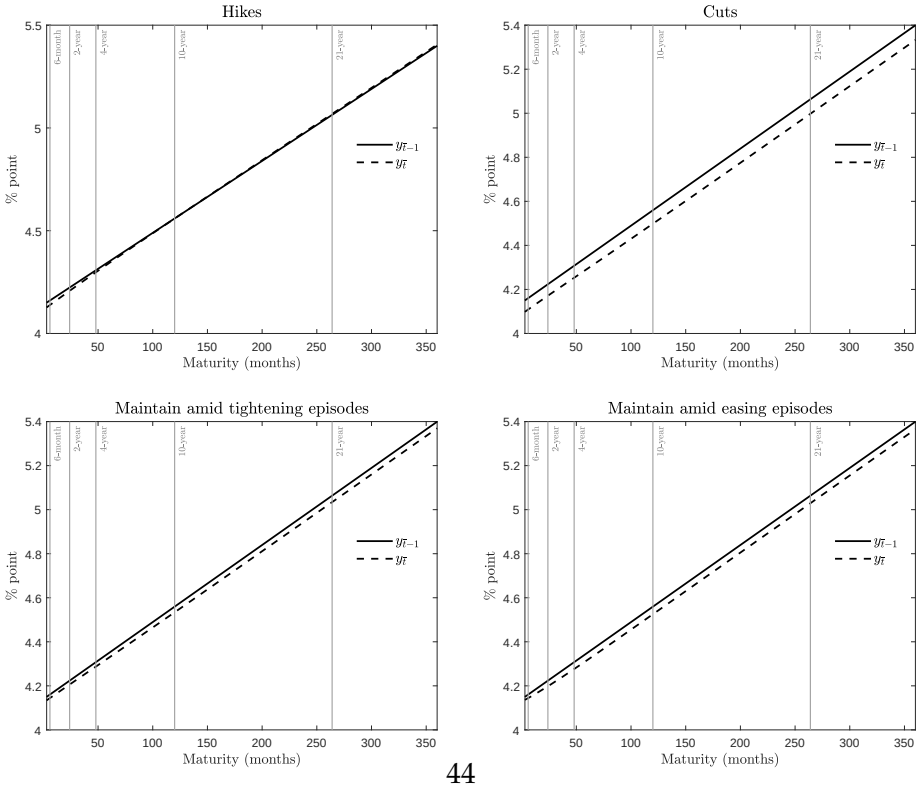
rate hike by the Fed lifts the longest end of the yield curve, while an interest rate cut shifts the yield curve downward by a much larger magnitude. Panel (a) in Figure 20 shows that the impact of maintaining interest rate amid tightening/easing episodes was identical to what is widely perceived as the impact of a rate cut/hike before the introduction of forward guidance on the 30th of October 2007: When the Fed maintained interest rate amid tightening/easing episode, it lifts/shifts down the shortest end of the yield curve leaving the longest end nearly unchanged. In contrast, the yield curve always shifts downward by the same magnitude when the Fed maintains interest rates at the same level after the 30th of October 2007 (Panel (b) in Figure 20).

Figure 20: The impact of US monetary policy surprise on the US Treasury yield curve when the Fed was unconstrained

(a) Prior to the 2008-2015 ZLB period



(b) After the 2008-2015 and the 2020-2022 CoVid ZLB periods



5.3. The Role of Forward Guidance in Transmitting Monetary Policy to the US Treasury Yield Curve

The stylized impact of FOMC announcements illustrated in Figure 19 and Figure 20 suggests three outcomes of forward guidance as monetary policy tools: First, when the Fed was unconstrained, utilizing forward guidance along with the conventional tool of interest rate target speeds up the transmission of the Fed's monetary policy to the long-end of the yield curve, especially in the case of a rate cut. Second, utilizing forward guidance whenever the Fed maintains interest rate is akin to monetary policy easing as it shifts the yield curve downward by roughly the same magnitude. Lastly, *explicit* forward guidance statements as opposed to *implicit* forward guidance in the form of SEP (Summary of Economic Projections) announcement has a larger impact on the yield curve during constrained times.

To estimate the possible impact of forward guidance when the Fed was unconstrained, I calculate the difference between the impact of conventional interest rate target on the yield curve before and after the introduction of forward guidance on the 20th of October when the Fed was unconstrained. I then compare this estimate to the estimate when the Fed was constrained. To do so, I first estimate the sensitivity $\beta^{\tau}_{i,\bar{t}}$ of the yield curve for each maturity $\tau = 3, \ldots, 360$ months in each of the sample representing each monetary policy tool and regime as detailed in Section 5.1 following individual (not panel) regression 5.1

$$\Delta y^{\tau}_{\bar{t}} = \sum_{i=L,S,C} \beta^{\tau}_{i,\bar{t}} \Delta i^{\text{Surprise}}_{\bar{t}} + X^{\tau}_{\bar{t}} + \epsilon^{\tau}_{\bar{t}} \tag{5.1}$$

where $X_{\bar{t},\tau}$ control for the anticipated change in the yield curve. The regression coefficient $\beta^{\tau}_{i,\bar{t}}$ is the sensitivity of bond yield at particular maturity τ to monetary policy surprise $\Delta i^{\text{Surprise}}_{\bar{t}} = \eta_{i,\bar{t}}$, where $i = L, S, C$ corresponds to the level, slope and curvature factors respectively. I then use the estimated sensitivity $\beta^{\tau}_{i,\bar{t}}$ the kernel density estimates of $\eta_{i,\bar{t}}$ in each of the sample representing each monetary policy tool and regime as detailed in Section 5.1 to calculate the possible impact of the surprises $\Delta y^{\tau}_{\bar{t}}$ corresponding to each monetary policy tool and regime as detailed in Section 5.1.

Figure 21 shows the possible impact of each monetary policy tool in different regimes to the yield curve, $\Delta y^{\tau}_{\bar{t}}$. Panel (a) in Figure 21 plots $\Delta y^{\tau}_{\bar{t}}$ calculated using the estimated $\beta^{\tau}_{i,\bar{t}}$ and kernel density estimates of $\eta_{i,\bar{t}}$ where $\bar{t}$ are the sets of days when the Fed were constrained and utilizes unconventional monetary policy tools such as *explicit*/*implicit* forward guidance and Large Scale Asset Purchase (LSAP) during the 2008-2015 ZLB period, as well as asset purchase and *implicit* forward guidance in the form of SEP announcement during the 2020-2022 CoVid ZLB period. Panel (b) in Figure 21 plots $\Delta y^{\tau}_{\bar{t}}$ calculated using the estimated $\beta^{\tau}_{i,\bar{t}}$ and kernel density estimates of $\eta_{i,\bar{t}}$ where $\bar{t}$ are the sets of days when the Fed was unconstrained outside both the 2008-2015 ZLB period and the 2020-2022 CoVid ZLb period. Before the 2008-2015 ZLB period, there was no forward guidance and the Fed relied mainly on the conventional interest rate target as a monetary

policy tool. Forward guidance was introduced on the 30th of October 2007, and ever since the Fed has deployed both the interest rate target and the forward guidance as monetary policy tools when unconstrained.

The results shown in Panel (a) in Figure 21 suggest that if constrained, both asset purchase and forward guidance have opposite impacts on the yield curve with the diminishing influence of forward guidance on the yield curve and that the asset purchase is the most effective tool to bring the long-term interest rate down when the Fed was constrained. Panel (a) in Figure 21 shows that before the taper tantrum during the 2008-2015 ZLB period, the effect of forward guidance dominates the effect of the LSAP on the US Treasury yield curve. Both *explicit/implicit* forward guidance shifts the yield curve upward by 0.079 percentage points on average at all maturities, and especially by 0.147 percentage points at 48-month maturity. On the other hand, the effect of LSAP is the largest at 6-month maturity as it shifts the yield curve downward by 0.088 percentage points, but diminishes afterward and averages around zero for bonds with maturities beyond 8 years. After the taper tantrum, the effect of forward guidance and asset purchase offset each other with both the *explicit/implicit* forward guidance shifts the yield curve down by 0.037 percentage points on average and the LSAP shifts the yield curve up by 0.034 percentage points on average. Notably, both forward guidance and LSAP have the largest effects on bond yields with maturities around 48 months after the taper tantrum.

In the case when the Fed was unconstrained in Panel (b) in Figure 21, there were only 4 interest rate cuts after the 2008-2015 ZLB period following the introduction of forward guidance on the 30th of October 2007, compared to 29 interest rate cuts before the 2008-2015 ZLB period. Therefore I calculate the yield curve's sensitivity to interest rate cuts after the introduction of forward guidance as

$$\frac{(33 \times \beta_{i,\bar{t}^{\text{All announcements}}}) - (29 \times \beta_{i,\bar{t}^{\text{All announcements with forward guidance}}})}{4},$$

where "All announcements" implies all announcements of interest rate cuts outside the period when the Fed was constrained. Similarly, there were only 7 instances when the Fed maintained interest rates amid easing episodes outside the 2008-2015 ZLB period and the CoVid ZLB periods after the introduction of forward guidance. Therefore I calculate the sensitivity of the yield curve to the Fed's decision to maintain the interest rate at the same level amid easing episodes after the introduction of forward guidance as

$$\frac{(45 \times \beta_{i,\bar{t}^{\text{All announcements}}}) - (38 \times \beta_{i,\bar{t}^{\text{All announcements with forward guidance}}})}{7},$$

where "All announcements" implies all announcements of the Fed maintaining interest rate at the same level amid easing episodes outside the period when the Fed was constrained.

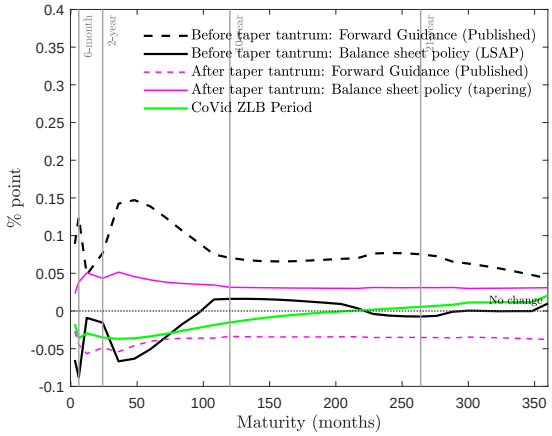
The results in Panel (b) in Figure 21 suggest that if unconstrained, the Fed has likely a better chance to influence the long end of the yield curve when using conventional interest rate targets

along with forward guidance. Panel (b) in Figure 21 shows that an interest rate cut without forward guidance (before the 2008-2015 ZLB period) counterintuitively shifts the shortest end of the yield curve up, leaving the longest end unchanged. Meanwhile, utilizing forward guidance along with the conventional interest rate cuts after the 2008-2015 ZLB period shifts the whole yield curve downward, bringing the yield curve down by 0.05 percentage points, an additional 0.07 percentage points downward movement on average. Similarly, a rate hike before the introduction of forward guidance before the 2008-2015 ZLB period counterintuitively shifts the shortest end of the yield curve down by a lesser magnitude compared to an interest rate cut, and leaves the longest end of the yield curve unchanged. Utilizing forward guidance along with the conventional interest rate hikes after the 2008-2015 ZLB period instead shifts the whole yield curve upward by an additional 0.05 percentage points on average, and even by an additional 0.1 percentage points for yields of bonds with 36-month maturity.

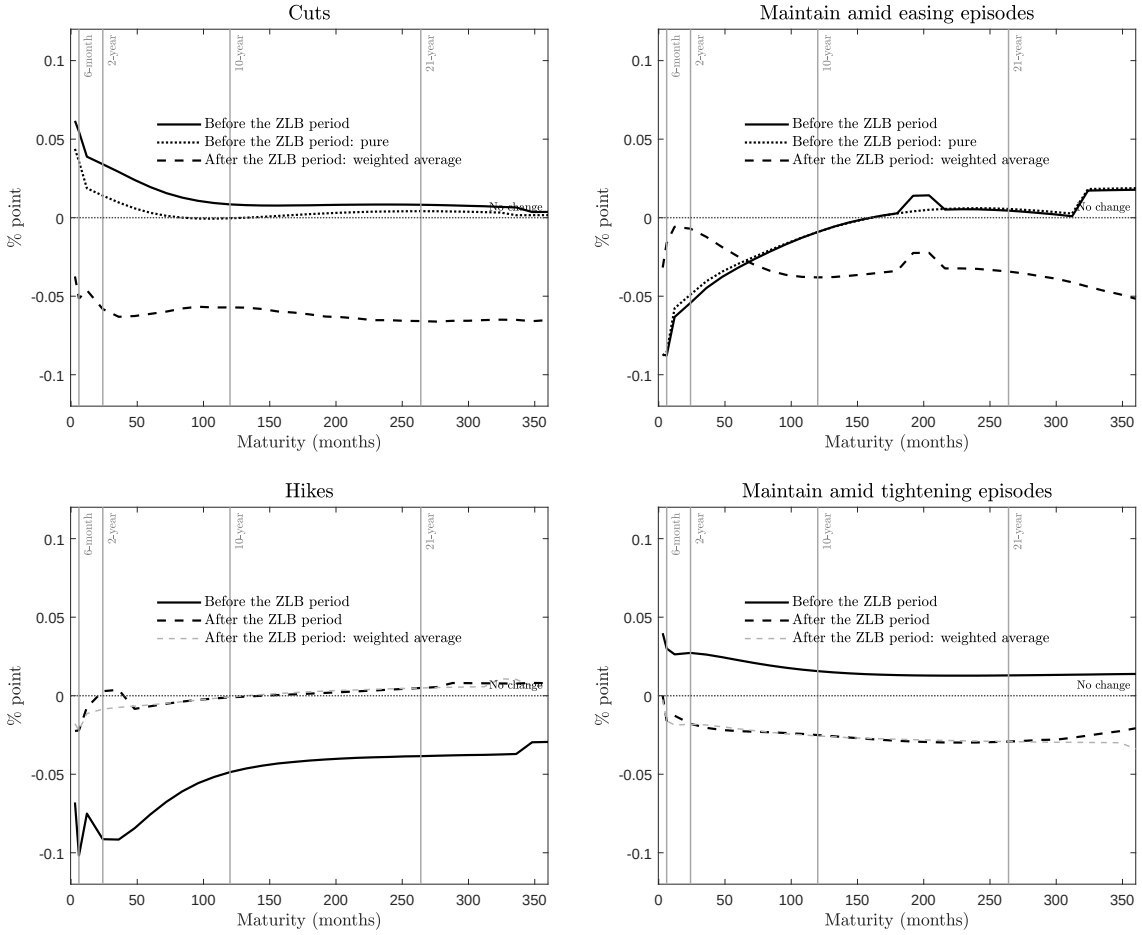
Finally, the results in Panel (b) in Figure 21 also suggest that even when the Fed was unconstrained, maintaining interest rate at the same level and utilizing proper forward guidance during both tightening and easing episodes achieves comparable results to cutting interest rate *with* forward guidance. After the introduction of forward guidance, maintaining interest rates amid easing episodes shifts down the yield curve by 0.05 percentage points, an additional 0.03 percentage points for the yields of bonds with 108-312 maturities compared to the case without forward guidance. Similarly, maintaining interest rate amid tightening episodes after the introduction of forward guidance achieves nearly the same results as cutting interest rate *with* forward guidance: this strategy shifts down the yield curve by 0.025 percentage points on average, an additional 0.05 percentage point for all maturities compared to the case without forward guidance.

Figure 21: The impact of the Federal Reserve's monetary policy tools on $\Delta \boldsymbol{y}_{\bar{t}}$

(a) Constrained



(b) Unconstrained



6. Conclusion

In this paper, I attempt to add to the understanding of market reaction to FOMC statements by observing and quantifying the surprise change in the US Treasury yield curve resulting from different monetary policy tools deployed by the Federal Reserve (the Fed). To do so, I decompose the daily change of the US Treasury yield curve from January 1st, 1995, to March 9th, 2024, into surprise and anticipated components, and I identify the subset of surprise components of the daily change of the US Treasury yield curve following the 257 FOMC announcements from February 1st 1995 to January 31st 2024 as the US monetary policy surprise which I then map into each monetary policy tools by the Federal Reserve (the Fed) that impact different parts of the yield curve. By doing so, I quantify market reaction to FOMC announcements, enabling me to estimate the possible impact of each monetary policy tool on the US Treasury yield curve.

The empirical strategy in Section 3 can be summarized into two consecutive steps: First, I extract the surprise daily change of the US Treasury yield curve for $t = 1, \ldots, 7295$ days from January 1st, 1995 to March 9th, 2024, $\mathbf{\Delta}_t^{\text{Surprise}}$, then I take a subset of these surprises that occur on FOMC announcement days during this period, $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ for $\bar{t} = 1, \ldots, 257$ starting from announcement on February 1st 1995 to January 31st 2024. My decomposition of the US Treasury yield curve enables certain narratives on market reaction surrounding FOMC announcements to be established based on past expectations and new information as illustrated on select dates in Figure 2. This decomposition also clarifies what is often perceived as misleading yield curve movements throughout the years as illustrated on select dates in Figure 4. These narrative-based explanations also motivate how different monetary policy tools map to distinct parts of the yield curve based on the factors they influence in each monetary policy regime of the Fed.

The second and last step in my empirical strategy is to identify the daily surprise $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ on the subset of FOMC announcement days $\bar{t} = 1, \ldots, 257$ as monetary policy surprise. I did this by conducting a nonparametric Wilcoxon signed rank test to establish that these surprises are distinct from daily surprises on "normal" days without FOMC announcement and that FOMC announcement on day $\bar{t}$ is the main event that drives the anticipated change of the US Treasury yield curve. Thus, $\mathbf{\Delta}_{\bar{t}}^{\text{Surprise}}$ results solely from the FOMC announcement and not from any other event and is indeed the market reaction to FOMC announcement.

By deploying this two-step strategy, I established in Section 3 and Section 4 that each surprise to the slope, level and curvature factors, $\eta_{L,\bar{t}}$, $\eta_{S,\bar{t}}$ and $\eta_{C,\bar{t}}$ respectively can be uniquely mapped to each of the Federal Reserve's monetary policy tools that correspond to different parts of the yield curve. Indeed, the influence of unanticipated aspects of FOMC decisions reflected on the identified monetary policy surprise $\mathbf{\Delta}_{\bar{t}}$ have a more significant influence on the daily change of the yield curve compared to days without FOMC announcement. The identified monetary policy surprise on the shortest end of the yield curve captures the switch between economic episodes in the US before the 2008-2015 ZLB period, while surprise to the level factor is associated with the most dominant impact of FOMC announcement on the yield curve before the 2008-2015 ZLB

period. Thus, before the 2008-2015 ZLB period, the conventional monetary policy tools primarily operated via surprise to the slope factor transmitted to the long end of the yield curve.

Most importantly, I established that the identified monetary policy surprise to the curvature factor maps to the most dominant unconventional monetary policy tool during the ZLB period, which was forward guidance. My hypothesis test result in Section 3 indicates that the unanticipated **published** forward guidance from the Fed influences the yield curve through its impact on the surprise change of the curvature factor during the 2008-2015 ZLB period. Moreover, the influence of **unpublished** forward guidance identified by Sablik (2022) and Sutherland (2023) are weaker compared to the results for **published** forward guidance. The stylized impact of FOMC announcements on the US Treasury yield curve described using the state-space model of the yield curve estimated in Section 3 suggests the growing importance of forward guidance identified on the surprise to the medium-term curvature factor, $\eta_{C,\bar{t}}$ in influencing the change in the US Treasury yield curve above other monetary policy tools in different regimes.

More interestingly, my estimation results in Section 5.3 suggest that **published** forward guidance has a more substantial effect when the Fed was unconstrained compared to when the Fed was constrained. When the Fed was *constrained* at the Zero Lower Bound (ZLB), balance sheet policies such as asset purchases and sales have increasingly more considerable influence compared to forward guidance in moving the long-term interest rates[7]. When the Fed was *unconstrained*, utilizing forward guidance along with conventional interest rate target achieves the intended results: when deployed with interest rate cut, it shifts the yield curve down by 0.05 percentage point, and when deployed with rate hikes, it lifts the long end of the yield curve by a much lesser magnitude.

My estimation results in Section 5.3 suggest that in both easing and tightening episodes, the Fed will be better off maintaining interest rates at the same level to stimulate the economy at any point in time when they are unconstrained. I showed that the yield curve shifts down by 0.05 percentage points when the Fed keeps the interest rates at the same level amid easing episodes after the introduction of forward guidance post-2008-2015 ZLB period. Similarly, when the Fed keeps the interest rate at the same level amid tightening episodes after the introduction of forward guidance, the yield curve shifts by 0.025 percentage points on average, nearly the same effects as cutting interest rate *with* forward guidance. By keeping the interest rate at the same level amid tightening episodes, the Fed can thus provide larger room for further cutting to avoid being at the ZLB, where their only viable option will be asset purchase.

[7] Jarociński (2021) and few other studies documented the problem of disentangling the effect of LSAP and forward guidance during the 2008-2015 ZLB period, pointing out that LSAP announcement also serves as a commitment device in the form of Odyssean forward guidance following Campbell, et al. (2012).

References

Adrian, Tobias, Crump, Richard K. and Emanuel Moench (2013), "Pricing the term structure with linear regressions", *Journal of Financial Economics*, Vol. 110(1), pp. 1110-138.

Altavilla, C. Brugnolini, L., Gürkaynak, b, Refet S., Motto, R. and Giuseppe Ragusa (2019), "Measuring Euro Area Monetary Policy", *Journal of Monetary Economics*, Vol. 108, pp. 162-179.

Andrade, Philippe and Filippo Ferroni (2021), "Delphic and odyssean monetary policy shocks: Evidence from the euro area", *Journal of Monetary Economics*, Vol. 117, pp. 816-832.

Andreasen, Martin M. (2012), "An Estimated DSGE Model: Explaining Variation in Nominal Term Premia, Real Term Premia and Inflation Risk Premia", *European Economic Review*, Vol. 56, pp. 1656-1674.

Bernanke, B.S., (2013), "Communication and monetary policy", *Speech At the National Economists Club Annual Dinner, Herbert Stein Memorial Lecture, Washington, D.C.*, November 19,2013.

Bauer, Michael D. and Glenn D. Rudebusch (2014), "The Signaling Channel for Federal Reserve Bond Purchases", *International Journal of Central Banking*, Vol. 10(3), pp. 233-289.

Bauer, Michael D. and Eric T. Swanson (2023), "An Alternative Explanation for the Fed Information Effect", *American Economic Review*, Vol. 113(3), pp. 664–700.

Bundick, B., Smith, A. and Trenton Herriford (2022), "The Term Structure of Monetary Policy Uncertainty", Federal Reserve Bank of Kansas City Working Paper No. 22-02.

Campbell, J.R., Fisher, J.D., Justiniano, A., Melosi, L. (2017), "Forward guidance and macroeconomic outcomes since the financial crisis", *NBER Macroeconomics Annual*, Vol. 31, pp. 283–357.

Campbell, Jeffrey R., Evans, Charles L., Fisher, Jonas D.M. and Alejandro Justiniano (2012), "Macroeconomic Effects of Federal Reserve Forward Guidance", *Brookings Papers on Economic Activity*, Vol. 43(1), Spring 2012, pp. 1-80.

Cieslak, A. and A. Schrimpf (2019), "Non-monetary news in central bank communication", Journal of International Economics, Vol.118, pp. 293–315.

Cochrane, John H. and Monika Piazzesi (2002), "The Fed and Interest Rates - A High-Frequency Identification", *American Economic Review*, Vol. 92(2), pp. 90-95.

D'Amico, Stefania and Thomas B. King (2013), "Flow and Stock Effects of Large-Scale Treasury Purchases: Evidence on the Importance of Local Supply", *Journal of Financial Economics*, Vol. 108(2), pp. 425-448.

D'Amico, Stefania, Kim, Don H. and Min Wei (2010), "Tips from TIPS: the Informational Content of Treasury Inflation-Protected Security Prices", *FEDS Working Papers No. 2014-24*.

Diebold, Francis X. and Canlin Li (2006), "Forecasting the Term Structure of Government Bond Yields", *Journal of Econometrics*, Vol. 130, pp. 337-364.

Diebold, Francis X., Rudebusch Glenn D. and Aruoba, S. Boragăn (2006), "The Macroeconomy and the Yield Curve: a Dynamic Latent Factor Approach", *Journal of Econometrics*, Vol. 131, pp. 309-338.

Ellingsen, T. and Ulf Söderstom (2001), "Monetary policy and interest rates", *American Economic Review*, Vol. 91 (5), pp. 1594–1607.

Gagnon, J., Raskin, M., Remache, J. and Brian Sack (2011), "The Financial Market Effects of the Federal Reserve's Large-Scale Asset Purchases", *International Journal of Central Banking*, Vol. 7(1), pp. 3-43.

Gertler, M. and Peter Karadi (2015), "Monetary Policy Surprises, Credit Costs, and Economic Activity", *American Economic Journal: Macroeconomics*, Vol. 7(1), pp. 44-76.

Gürkaynak, Refet S. and Jonathan H. Wright (2012), "Macroeconomics and the Term Structure", *Journal of Economic Literature*, Vol. 50(2), pp. 331-367.

Gürkaynak, Refet S., Sack, Brian and and Jonathan H. Wright (2007), "The U.S. Treasury yield curve: 1961 to the present", *Journal of Monetary Economics*, Vol. 8(2), pp. 2291-2304.

Gürkaynak, Refet S., Sack, Brian and Eric T. Swanson (2005), "Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements", *International Journal of Central Banking*, Vol. 1(1), pp. 55-93.

Hamilton, James D. and Jing Cynthia Wu (2012), "The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment, *Journal of Money, Credit and Banking*, Vol. 44, pp. 3—46.

Hanson, Samuel G. and Jeremy C. Stein (2015), "Monetary policy and long-term real rates", *Journal of Financial Economics*, Vol. 115(3), pp. 429-448.

Hoesch, L., Rossi, B. and T. Sekhposyan (2020), "Has the information channel of monetary policy disappeared? Revisiting the empirical evidence", *American Economic Journal: Macroeconomics*, Vol. 15(3), pp. 355-387.

Inoue, Atsushi and Barbara Rossi (2021), "A New Approach to Measuring Economic Policy Shocks, With An Application to Conventional and Unconventional Monetary Policy", *Quantitative Economics*, Vol. 12, pp. 1085-1138.

Jarociński, Marek (2021), "Estimating Fed's Unconventional Policy Shocks", *ECB Working Paper No. 2021/2585*.

Jarociński,M. and Peter Karadi (2020), "Deconstructing monetary policy surprises: the role of information shocks", *American Economic Journal: Macroeconomics*, Vol. 12(2), pp. 1-43.

Joyce, M., Lasaosa, A., Stevens, I., and Matthew Tong (2011), "The Financial Market Impact of Quantitative Easing in the United Kingdom", *International Journal of Central Banking*, Vol. 7(3), pp. 113—161.

Kim, Don H. and Jonathan H. Wright (2005), "An Arbitrage-Free Three Factor Term Structure Model and the Recent Behavior of Long-Term Yields and Distant-Horizon Forward Rates", *FEDS Working Papers No. 2005-33*.

Krishnamurthy, A. and Annette Vissing-Jorgensen (2011), "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy", *Brookings Papers on Economic Activity*, Vol. 42(2), pp. 215-287.

Kroszner (2022), "'Faith-Based' Monetary Policy Frameworks", *Cleveland Fed Conversations on Central Banking: Challenges and Opportunities for Central Bank Communications*, May 13, 2024

Kuttner, Kenneth N. (2001), "Monetary policy surprises and interest rates: Evidence from the Fed funds futures market", *Journal of Monetary Economics*, Vol. 47(3), pp. 523-544.

Lane, Philip R. (2019), "The yield curve and monetary policy", *A Speech at the Public Lecture for the Centre for Finance and the Department of Economics at University College London*. 25 November 2019.

Lunsford, K. (2020), "Policy language and information effects in the early days of Federal Reserve forward guidance", *American Economic Review*, Vol. 110(9), pp. 2899-2934.

Melosi, L. (2017), "Signaling effects of monetary policy", *Review of Economic Studies*, Vol. 84(2), pp. 853–884.

Miranda-Agrippino, Silvia and Giovanni Ricco (2021), "The Transmission of Monetary Policy Shocks", *American Economic Journal: Macroeconomics*, Vol. 13(3), pp. 74-107.

Nakamura, Emi and Jón Steinsson (2018), "High-frequency identification of monetary non-neutrality: the information effect", *The Quarterly Journal of Economics*, Vol. 133(3), pp. 1283-1330.

Neely, Christopher J. (2011), "The Large-Scale Asset Purchases Had Large International Effects", *Federal Reserve Bank of St.Louis Working Paper Series, 2010-018D.*

Nelson, Charles R. and Andrew F. Siegel (1987), "Parsimonious Modeling of Yield Curves", *The Journal of Business*, Vol. 60(4), pp. 473-489.

Orphanides, Athanasios (2023), "The Forward Guidance Trap", *Bank of Japan Discussion Paper No. 2023-E-6*.

Romer, David H. and Christina D. Romer (2000), "Federal Reserve Information and the Behavior of Interest Rates," *American Economic Review*, Vol. 90(3), pp. 429-457.

Rudebusch, Glenn D., and Eric T. Swanson (2012), "The Bond Premium in a DSGE Model with Long-Run Real and Nominal Risks", *American Economic Journal: Macroeconomics*, Vol. 4(1), pp. 105-143

Sutherland, Christopher S. (2023), "Forward Guidance and Expectation Formation: A Narrative Approach", *Journal of Applied Econometrics*, Vol. 38(2), pp. 222-241.

Swanson, Eric T. (2021), "Measuring the effects of Federal Reserve forward guidance and asset purchases on financial markets", *Journal of Monetary Economics*, Vol. 118,pp. 32-53.

Markets Group, Federal Reserve Bank of New York (2017), Responses to Survey of Primary Dealers, distributed on 30th November 2017 and received by 4th of December 2017.

Tang, J. (2015), "Uncertainty and the signaling channel of monetary policy", *Federal Reserve Bank of Boston Working Papers*, No. 15–8.

Woodford, M. (2012), "Methods of policy accommodation at the interest-rate lower bound", *Proceedings - Economic Policy Symposium - Jackson Hole, Federal Reserve Bank of Kansas City*, pp. 185-288.

Wu, Jing Cynthia and Fan Dora Xia (2016), "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound", *Journal of Monetary Economics*, Vol. 48(2-3), pp. 253-291.

Wu, Tao (2014), "Unconventional Monetary Policy and Long-Term Interest Rates", *IMF Working Paper No. 2014/189*.

Appendix A. Key FOMC dates

Table 2: Conventional Monetary Policy Period (CMP)

Date	Interest Rate Policy	Episode	Forward Guidance	Balance Sheet Policy
9/29/1998	Cut	Global currency crisis	-	-
2/3/1999	Maintain at the same level - Easing	Global currency crisis	-	-
5/16/2000	Hike	Dot-com boom	Statement read: *" ... the Committee believes the risks are weighted mainly toward conditions that may generate heightened inflation pressures in the foreseeable future."*	-
11/6/2001	Cut	Dot-com bust and 9/11	Statement read: *"For the foreseeable future, then, the Committee continues to believe that, against the background of its long-run goals of price stability and sustainable economic growth and of the information currently available, the risks are weighted mainly toward conditions that may generate economic weakness."*	-
1/28/2004	Maintain at the same level - Easing	Flagging recovery and low inflation following the dot-com bust	Statement read: *"With inflation quite low and resource use slack, the Committee believes that it can be patient in removing its policy accommodation."*	-
1/31/2007	Maintain at the same level - Tightening	Housing market boom	-	-

Source: FOMC Press Release. For example, the press release after the monetary policy announcement on the 29th of September 1998 can be found in: https://www.federalreserve.gov/boarddocs/press/general/1998/19980929/default.htm.

Table 3: Unconventional Monetary Policy Period (UMP)

Date	Interest Rate Policy	Forward Guidance	Balance Sheet Policy
11/25/2008	Maintain at the same level	-	LSAP1 to be completed over several quarters.
12/16/2008	Cut to effective lower bound of 0 - 1/4%	Statement read: *"... weak economic conditions are likely to warrant exceptionDiffy low levels of the federal funds rate for some time."*	-
1/28/2009	Maintain at the same level	Statement remained as: *"... for some time."*	Plan to purchase longer term Treasury bonds was announced.
3/18/2009	Maintain at the same level	Statement changed to: *"... for an extended period."*	The expansion of LSAP1 is to be completed by the end of 2009.
8/10/2010	Maintain at the same level	Statement remained as *"... for an extended period."*	The FOMC will keep constant the Federal Reserve's holdings of securities at their current level *"by reinvesting principal payments from agency debt and agency (MBS) in longer-term Treasury securities"* and by continuing to roll over its holdings of Treasury securities as they mature.
9/21/2010	Maintain at the same level	Statement remained as *"... for an extended period."*	-
11/3/2010	Maintain at the same level	Statement remained as *"... for an extended period."*	LSAP2 to be completed by the second quarter of 2011.
8/9/2011	Maintain at the same level	Statement changed to: *"... at least through mid-2013."*	-
9/21/2011	Maintain at the same level	Statement remained as: *"... at least through mid-2013."*	MEP: transactions are to be completed by the end of June 2012.

Source: FOMC Press Release. For example, the press release on the 25th of November 2008 can be found in:
https://www.federalreserve.gov/newsevents/pressreleases/monetary20081125b.htm.
The timeline of the announcement of balance sheet policies during UMP can be found in:
https://www.federalreserve.gov/monetarypolicy/timeline-balance-sheet-policies.htm.
The timeline of forward guidance about the federal funds rate during UMP can be found in:
https://www.federalreserve.gov/monetarypolicy/timeline-forward-guidance-about-the-federal-funds-rate.htm.