Anchored or De-anchored? Inflation Expectations and Monetary Policy*

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Abstract

If inflation expectations are well-anchored, then the Fed has a higher capacity to support aggregate employment without destabilizing inflation. We construct a proxy of the change in the Fed's aggressiveness to inflation and develop an empirical test for inflation expectations anchoring. The proxy for the Fed's aggressiveness is equal to changes in expectations of future policy rates that are unexplained by the information in the inflation news release. The empirical test examines the sensitivity of inflation expectations to monetary policy shocks conditional on that proxy. We then use a measure of inflation expectations adjusted for inflation and liquidity risk premia to demonstrate that bond yield data in the U.S. is consistent with the anchoring of the long-term inflation expectations.

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1 Introduction

Central banks set a specific inflation target to control long-term inflation expectations. The markets view the central bank's inflation-targeting objective as its commitment to act to keep inflation stable. Inflation-targeting regimes' success is difficult to assess because of a lack of high-frequency survey data on long-term inflation expectations.

In this paper, we show that long-term inflation expectations in the U.S. are anchored using daily bond yield data. If the market expects a strong reaction from the Fed to inflation, then the monetary policy has a weaker effect on inflation expectations. The intuition behind the mechanism is as follows. Inflation news affects market expectations of future inflation and the Fed's response at the next FOMC meeting. The Fed's announcement of a higher rate change than expected from the inflation news release shows that the markets anticipate more aggressive reactions from the Fed in the future. If inflation expectations are anchored, markets will not adjust inflation expectations as much.

To show that the effect of monetary policy on inflation expectations is weaker if the markets expect the Fed's inflation response to be more aggressive, we proceed in two steps. First, we measure market expectations about the Fed's reaction to inflation as a residual from the regression of the expected future policy rate on inflation expectations around the CPI release dates. Second, we estimate inflation expectations' sensitivity to monetary policy conditional on the expected Fed's aggressiveness.

We use a simplified version of the monetary policy reaction function from Bauer and Swanson (2023) to illustrate our approach. Let

$$i_t^{pol} = \phi_t \pi_t + MP_t \tag{1}$$

where i_t^{pol} denotes the policy rate at time t, π_t denotes the inflation rate at time t, ϕ_t describes the Fed's aggressiveness to inflation,[1] and MP_t denotes a monetary policy shock or exogenous random deviation from the Fed's reaction function $\phi_t \pi_t$. Due to the Fed's inflation targeting objective, aggressiveness ϕ_t is positive and time-varying. A positive inflation shock leads to an increase in interest rates by the Fed. In the standard model like the Taylor rule, ϕ_t is constant because the degree of monetary aggressiveness is assumed to not vary over time. However, the degree of the Fed's aggressiveness to

[1] In what follows, we use the terms "the Fed's responsiveness to inflation", "the Fed's aggressiveness", and ϕ_t interchangeably.

inflation varies over time (see Bauer and Swanson (2023) for details). When the Fed is pursuing inflation targeting, an inflation shock of the same magnitude will lead to a more aggressive policy response (larger ϕ_t).

From the reaction function (1) it follows that there are three possible sources of changes in the expected future policy rate over time horizon h: (1) changes in expectations of future inflation; (2) changes in the expectations of the Fed's aggressiveness; (3) changes in the expectations of monetary policy shock:

$$\Delta \mathbb{E}_t i^{pol}_{t,h} = \mathbb{E}_t \phi_{t,h} \times \Delta \mathbb{E}_t \pi_{t,h} + \Delta \mathbb{E}_t \phi_{t,h} \times \mathbb{E}_t \pi_{t,h} + \Delta \mathbb{E}_t MP_{t,h} \tag{2}$$

where $\mathbb{E}_t i^{pol}_{t,h}$ is the time t expected policy rate over horizon h, $\mathbb{E}_t \pi_{t,h}$ is the time t average expected inflation rate over h, $\mathbb{E}_t \phi_{t,h}$ is the time t expected aggressiveness of the Fed over h, and $\mathbb{E}_t MP_{t,h}$ is the expected monetary policy over h.

In the first step of our analysis, we identify changes in market expectations about the Fed's aggressiveness to inflation for each horizon h, $\Delta \mathbb{E}_t \phi_{t,h}$, by estimating residuals from an empirical counterpart of equation (2) at Consumer Price Index (CPI) news release dates τ:

$$\Delta i^{pol,e}_{\tau,h} = \alpha \Delta \pi^e_{\tau,h} + \varepsilon_\tau \tag{3}$$

where $i^{pol,e}_{\tau,h}$ is the time τ measure of the expected future policy rate over horizon h, and $\pi^e_{\tau,h}$ is the time τ measure of the average expected future inflation over h. Since at CPI release dates markets do not expect monetary shocks (unless the CPI release date coincides with the FOMC date), residual from this regression adjusted for expected inflation, $\tilde{\varepsilon}_\tau = \frac{\hat{\varepsilon}_\tau}{\pi^e_{\tau,h}}$, provides an estimate of $\Delta \mathbb{E}_\tau \phi_{\tau,h}$. Positive $\tilde{\varepsilon}$ implies that markets have revised their expectations about the Fed's aggressiveness toward inflation upward.

In the second step, we show that inflation expectations react to monetary policy news less if the markets revised their expectations about the Fed's aggressiveness upward. In other words, we estimate the inflation expectations' sensitivity to monetary policy conditional on the expectations about the Fed's aggressiveness by running the following regression:

$$\Delta \pi^e_{t,h} = \beta MP^s_t + \gamma \tilde{\varepsilon}_\tau + \delta MP^s_t \times \tilde{\varepsilon}_\tau + u_t \tag{4}$$

where MP^s_t is a measure of a monetary policy shock. The coefficient δ represents the differential market response to monetary policy based on expectations about the Fed's aggressiveness. The sum $\beta + \delta$ corresponds to the inflation expectations' sensitivity to monetary policy shocks. If inflation expectations decrease after a monetary tightening ($\beta + \delta < 0$), given that the Fed is expected to have a stronger response to inflation ($\tilde{\varepsilon}_t$ is positive), a positive δ implies that inflation expectations adjust less. This means that the effect of monetary policy on inflation expectations is "undone" and hence inflation expectations are anchored. If the Fed is thought to pursue a stronger response to control inflation, then the markets do not respond as much to the current policy shocks.

The rest of this paper is organized as follows: in section 2 we review the related literature, section 3 describes the data, section 4 describes the construction of all the market-based measures of expectations needed for analysis, section 5 contains the empirical results, and section 6 concludes.

2 Related Literature

This paper contributes to the broad literature that studies the effect of economic news on asset prices by using high-frequency data and market-based measures of expectations.

One strand of this literature focuses on the effect of macroeconomic news on inflation compensation. Gürkaynak, Levin, and Swanson (2010) show that inflation compensation in the U.S., a country without an explicit inflation target, exhibits higher responsiveness to economic news than that in the United Kingdom, a country with an explicit inflation target.[2] Gürkaynak, Levin, and Swanson (2010) find that far-ahead nominal forward rates are quite sensitive to news due to the variation in inflation expectations. In contrast, Beechey and Wright (2009) estimate only a small response of forward inflation compensation to real-side macroeconomic news. Bauer (2014) finds that inflation compensation exhibits strong sensitivity to macroeconomic surprises, both for price-level news and real-side news. The reason for this is that intraday data, although more precise, mask the slightly delayed response to the announcements.

Another strand of this literature focuses on the effect of monetary policy news on asset prices. The findings that were not consistent with the standard economic theory were attributed to the "Fed Information Effect". Romer and Romer (2000) show that the Fed's information about expected inflation that is not available to private forecasters can be

[2]The research on emerging economies usually employs low-frequency panel data and arrive to the opposite conclusion about the effects of inflation targeting. For example, Stojanovikj and Petrevski (2021) show that in emerging economies, inflation targeting is associated with lower average inflation (that has negligible favorable effects, as compared to alternative monetary strategies), but it does not lower inflation volatility.

inferred from their interest rate changes. Campbell, Evans, Fisher, Justiniano, Calomiris, and Woodford (2012) provide evidence for the "Fed Information Effect" by documenting that monetary policy contraction is associated with a significant downward revision in Blue Chip forecasts of unemployment. Nakamura and Steinsson (2018) show that monetary policy contraction is associated with a significant upward revision in Blue Chip GDP forecasts. Lunsford (2020) analyzes the Fed's forward guidance announcements from 2000–2006 and finds evidence of a "Fed Information Effect" in the period from 2000–2005, but not afterward.

The closely related paper to ours is by Bauer and Swanson (2023) who find a similar effect as Lunsford (2020) and present an alternate channel called the "Fed Response to News" channel that can also explain the empirical results from Nakamura and Steinsson (2018). The main idea is that incoming, publicly available economic news causes the Fed to change monetary policy and the private sector to revise its forecasts. Their empirical strategy includes economic news on GDP, unemployment, CPI, etc., and shows that it is not only strongly correlated with Blue Chip forecast revisions, but also with high-frequency monetary policy surprises which arrive after the economic news. This is explained by the fact that markets do not have full information about the Fed's reaction function ex-ante. This leads to the predictability of monetary policy surprises ex-post, even if these surprises were unpredictable ex-ante. Our methodology follows this channel in using CPI release news revealed before the FOMC meeting that is not immediately incorporated into the rates.

Our contribution is two-fold. First, we provide a new way to estimate the expected aggressiveness of the Fed. Second, we document the dampened effect of forward guidance conditional on the expected Fed's aggressiveness.

3 Data

We employ the daily continuously compounded zero-coupon Treasury Inflation-Protected Securities (TIPS)[3] yields as measures of real interest rates and breakeven inflation rates as measures of inflation expectations. For both, we use data constructed by Gürkaynak, Sack, and Wright (2010). This data set is available for download on the Board of Governors'

[3] TIPS are fixed-income securities whose coupons and principal payments are indexed to the non-seasonally adjusted CPI for all urban consumers.

website.[4] The data spans maturities from 2 to 20 years. We start our sample period on January 1, 2005, to avoid relying on data from the period when TIPS liquidity was limited. We end our sample on June 30, 2019.

Table 1 reports summary statistics of nominal Treasury yields, TIPS yields, and TIPS inflation compensation from Gürkaynak, Sack, and Wright (2010) data. Nominal and real yield curves and inflation compensation curves are upward-sloping. The skewness of inflation compensation is negative over all horizons but becomes less negative for longer maturities. The excess kurtosis, however, is positive and decreasing in maturity.

Table 1: Summary Statistics of the Gürkaynak, Sack, and Wright (2010) Data

	Mean	St. Dev.	Min	Max	Skewness	Excess Kurtosis
	Panel A: U.S. Treasury Nominal Interest Rates					
i_2	1.74	1.44	0.16	5.25	0.93	-0.35
i_5	2.46	1.17	0.59	5.13	0.50	-0.76
i_{10}	3.32	1.06	1.40	5.29	0.07	-1.38
i_{20}	3.92	1.03	1.85	5.97	-0.00	-1.41
	Panel B: TIPS Yields					
r_2^{TIPS}	0.12	1.29	-2.20	5.48	0.93	1.91
r_5^{TIPS}	0.59	1.07	-1.71	3.91	0.14	-0.47
r_{10}^{TIPS}	1.15	0.90	-0.85	3.75	-0.07	-0.83
r_{20}^{TIPS}	1.57	0.75	0.05	3.32	-0.06	-1.37
	Panel C: TIPS Inflation Compensation					
IC_2^{TIPS}	1.62	0.96	-4.89	3.22	-2.72	12.52
IC_5^{TIPS}	1.87	0.58	-1.78	2.90	-2.33	9.54
IC_{10}^{TIPS}	2.17	0.41	0.17	3.00	-0.97	1.46
IC_{20}^{TIPS}	2.35	0.45	0.82	3.38	-0.50	-0.27
N				4,121		

The table shows summary statistics from Gürkaynak, Sack, and Wright (2010) data between January 1, 2005, and June 30, 2019.

To construct monetary policy shocks, we use the dates of FOMC meetings for our

[4]Available at https://www.federalreserve.gov/econres/feds/the-tips-yield-curve-and-inflation-compensat htm.

sample period from Nakamura and Steinsson (2018)[5] and daily data on Federal funds futures, three-month Eurodollar futures, Treasury bond yields at maturities of 2-, 5- and 10-years from the Bloomberg terminal.

To construct changes in the expected aggressiveness of the Fed, we use the CPI news release dates from the Bureau of Labor Statistics.[6]

4 Market-Based Measures of Expectations

The ultimate goal of this paper is to measure the sensitivity of inflation expectations to monetary policy conditional on market expectations of the Fed's reaction function. To measure expectations of the Fed's reaction function we additionally need a measure of the expected future policy rate. In this section, we describe the construction of market-based measures of (i) inflation expectations, (ii) monetary policy, (iii) expectations of the future policy rate, and (iv) the expectations of the Fed's aggressiveness.

4.1 Inflation Expectations

Market-based measures of inflation expectations provide a rich source of information to investors, policymakers, and researchers. One of them is inflation compensation defined as the difference between the interest rates on nominal and inflation-indexed bonds:

$$IC_{t,h} = i_{t,h} - r_{t,h} \tag{5}$$

where $i_{t,h}$ is the nominal interest rate for a zero-coupon bond of maturity h, $r_{t,h}$ is the real interest rate for a zero-coupon bond of maturity h, and $IC_{t,h}$ is inflation compensation for the same maturity.

It is important to note that due to the risk of changes in inflation, inflation compensation is a noisy measure of inflation expectations. By standard economic theory

$$i_{t,h} = r_{t,h} + \mathbb{E}_t \pi_{t,h} + IRP_{t,h} \tag{6}$$

where $\mathbb{E}_t \pi_{t,h}$ is expected future inflation over h, and $IRP_{t,h}$ is an inflation risk premium.

[5]We cross reference and verify these dates from the Board of Governors' website at http://www.federalreserve.gov/monetarypolicy/fomccalendars.html.

[6]Available at https://www.bls.gov/schedule/news_release/cpi.htm.

It measures the compensation that investors demand to cover the expected rate of future inflation and the risks associated with the uncertainty of future inflation at a given horizon and depends on the covariance between inflation and economic activity.

The most widely used real-time proxy for inflation expectations in the U.S. is the "break-even inflation rate" (BEI) equal to the spread between yields on nominal Treasury securities and on TIPS of comparable maturities.

However, even though the market for TIPS has grown substantially since its inception in 1997, the TIPS yield exceeds the true real interest rate due to the TIPS liquidity premium:

$$r_{t,h}^{TIPS} = r_{t,h} + LRP_{t,h}^{TIPS} \tag{7}$$

where $r_{t,h}^{TIPS}$ is the yield on TIPS, and $LRP_{t,h}^{TIPS}$ is the TIPS liquidity premium.

Consequently, TIPS inflation compensation or BEI can be written as

$$IC_{t,h}^{TIPS} = \mathbb{E}_t \pi_{t,h} + IRP_{t,h} - LRP_{t,h}^{TIPS} \tag{8}$$

which implies that BEI deviates from inflation expectations either due to inflation risk premium or TIPS liquidity premium.

The ultimate goal of this paper is to measure the sensitivity of inflation expectations to monetary policy conditional on market expectations of the Fed's reaction function. That exercise will ideally require applying risk premia adjustments to BEI rates.

Nevertheless, we employ BEI as a measure of inflation expectations and leave the risk premia adjustments for future research. Besides the fact that all estimates of the inflation risk premium and liquidity premium in the literature are highly model-dependent, there is vast empirical evidence suggesting that risk premia vary at business-cycle frequencies, implying that they will be differenced out in the daily bond yield analysis.[7]

Bauer and Swanson (2023) show that economic news predicts high-frequency monetary policy surprises. As per the Full Information Ration Expectations (FIRE) assumption, markets would already incorporate all the publicly available information up until the time of the trade. So, under FIRE, the only reason why Bauer and Swanson (2023) find the predictability of high-frequency monetary policy surprises is the time-varying risk premia. But, Piazzesi and Swanson (2008), Schmeling, Schrimpf, and Steffensen (2022) and Cieslak and Schrimpf (2019) estimate that risk premia in these short-term interest rate futures and monetary policy surprises are too small to explain the estimated degree

[7] See Cochrane and Piazzesi (2005) and Lustig, Roussanov, and Verdelhan (2014).

of predictability in the data. Hence, Bauer and Swanson (2023) operate under the assumption that markets do not fulfill FIRE. Cieslak and Schrimpf (2019) and Schmeling, Schrimpf, and Steffensen (2022) also show that markets do not have full information about the Fed's reaction function before the trade, leading to the predictability of high-frequency monetary policy surprises ex-post. We, therefore, use inflation compensation as a proxy measure for inflation expectations without explicitly taking into account the role of risk premia.

4.2 Monetary Policy

We identify monetary policy shocks using a high-frequency identification method. High-frequency identification controls for market expectations by considering changes in the target rate within a small window and, thus, overcomes two empirical challenges in identifying the effect of monetary policy. The first is that movements in the target rate exhibit both the independent effects of monetary policy and shifts in demand for risk-free assets because the Fed conducts policy endogenously in response to economic events that affect interest rates in the economy. The second is that markets may expect Fed's future actions because Fed officials could signal upcoming rate changes. Thus, when the Fed officially changes the target Federal funds rate, other rates may have already moved in expectation, which may appear as if Fed policy had no effect.

To obtain a measure of shocks, we closely adhere to the methodology of Swanson (2021) by considering the change in the policy indicator in a 1-day window around scheduled FOMC announcements. The policy indicators we employ are the first three principal components of the unanticipated changes over the 1-day windows from January 1, 1999, to June 30, 2019, in the following five interest rates: Federal funds rates futures for the current month, Federal funds rates futures for the month of the next FOMC meeting, eurodollars futures contracts at horizons of 2, 3, and 4 quarters, and 2-, 5-, and 10-year Treasury yields.

We focus only on scheduled FOMC meetings as unscheduled meetings may occur in response to other contemporaneous shocks. The outliers in a few periods can disproportionately affect the estimation of shocks across all dates in the sample. To avoid this problem, we follow Nakamura and Steinsson (2018) and Swanson (2021) who omit the FOMC announcement on September 17, 2001, which took place before markets opened but after financial markets had been closed for several days following the 9/11 terrorist attacks.

We get the unanticipated changes in eight interest rates around FOMC meetings in two steps. First, we convert prices of all five futures to expected yields, in percentage points, by calculating $y_t = 100 - x_t$, where x_t is the quoted price on the contract and y_t is the implied yield to maturity. Second, we difference all variables across a window around FOMC announcements.

We scale changes in the Fed funds futures to take into account FOMC announcement timing. Before an FOMC meeting, the anticipated yield at settlement for the Fed Funds contracts expiring in the current month ($ff1_{t-\Delta t}$) is a weighted average of the average Fed Funds rate before the announcement (r_0) and the rate that is expected to hold for the remainder of the month (r_1):

$$ff1_{t-\Delta t} = \frac{d1}{D1} r_0 + \frac{D1 - d1}{D1} E_{t-\Delta t}(r_1) + \rho 1_{t-\Delta t}$$

where $d1$ is the day of the FOMC meeting, $D1$ is the number of days in the month and $\rho 1$ denotes risk premium. The surprise component is the change in the Federal funds rate target given by

$$mp1_t = \left(ff1_t - ff1_{t-\Delta t}\right) \frac{D1}{D1 - d1}$$

As the window is small, we assume that the change in risk premium is zero. The same procedure is then applied to changes in the Fed funds target after the second FOMC meeting from now (r_2). $ff2$ is the Fed funds futures rate for the month containing the next FOMC meeting:

$$ff2_{t-\Delta t} = \frac{d2}{D2} E_{t-\Delta t}(r_1) + \frac{D2 - d2}{D2} E_{t-\Delta t}(r_2) + \rho 2_{t-\Delta t}$$

where $d2$ is the day of the next FOMC meeting, $D2$ is the number of days in the month of that meeting and $\rho 2$ denotes risk premium. Change in expectations for the second meeting is then given by

$$mp2_t = \left[\left(ff2_t - ff2_{t-\Delta t}\right) - \frac{d2}{D2} mp1_t\right] \frac{D2}{D2 - d2}$$

We collect these eight asset price responses into $T \times n$ matrix X,[8] with rows corre-

[8] $T = 171$ because there are 171 FOMC meetings from January 1, 1999, to June 30, 2019. $n = 8$ because we use eight asset price changes.

sponding to FOMC announcements and columns to different assets. We normalize each column of X to have zero mean and unit variance. As in Swanson (2021) and Gürkaynak, Sack, and Swanson (2005), we present these data in terms of a factor model,

$$X = F\Lambda + \upsilon \tag{9}$$

where F is a $T \times 3$ matrix containing 3 unobserved factors, Λ is a 3×8 matrix of loadings of asset price responses on 3 factors, and υ is a $T \times 8$ matrix of white noise residuals uncorrelated over time and across assets.

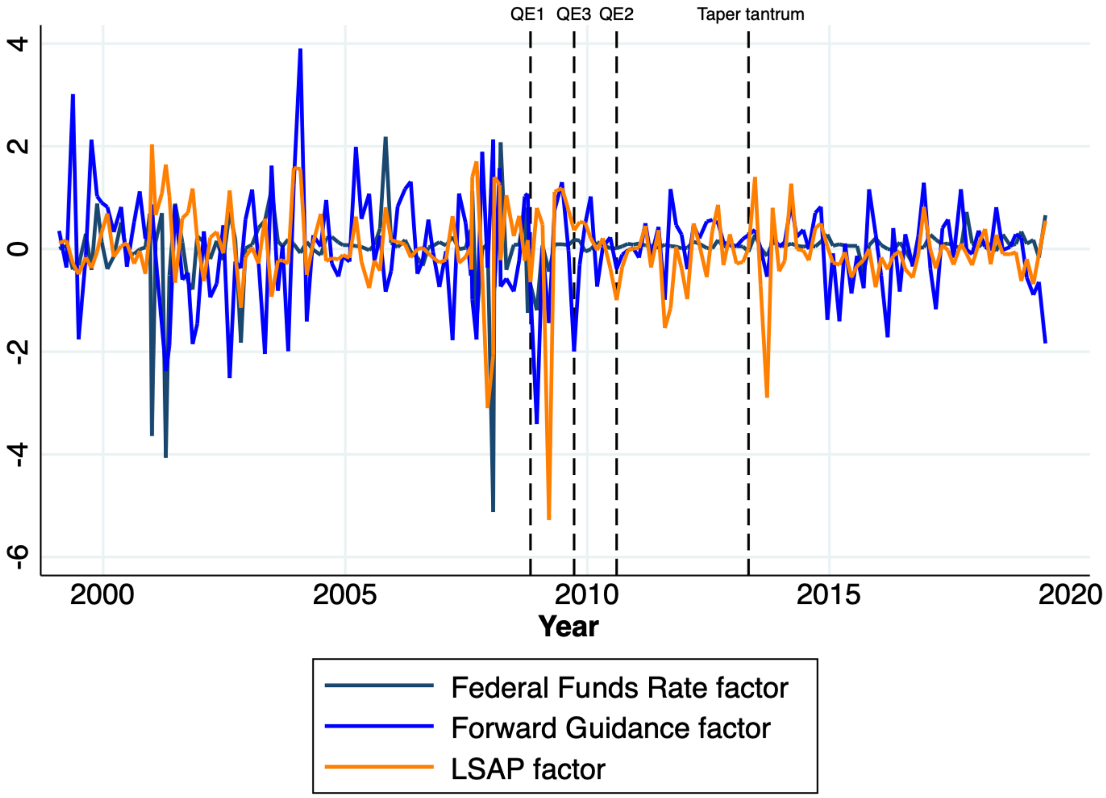
To estimate the unobserved factors F, we extract the first three principal components of X and rotate them to interpret as (i) the surprise component of the change in the Federal funds rate at each FOMC meeting, (ii) the surprise component of the change in forward guidance, and (iii) the surprise component of any LSAP announcements. We impose the following identifying assumptions on the orthonormal rotation matrix. First, changes in forward guidance have no effect on the current Federal funds rate. Second, changes in LSAPs have no effect on the current Federal funds rate. Third, the variance of the LSAP factor is minimized in the pre-ZLB period corresponding to the sample from January 1, 1999, to February 1, 2009.

We perform two normalizations of the rotated factors. First, the sign of the first rotated column is such that it has a positive effect on the current Federal funds rate, the second factor has a positive effect on the four-quarter-ahead Eurodollar future contract ED4, and the third factor has a positive effect on the 10-year Treasury yield. This way an increase in each of the factors corresponds to a monetary tightening. Second, we normalize each rotated factor to have a unit standard deviation, so the coefficients in all the regressions are in units of basis points per standard deviation change in the monetary policy instrument.

We plot the estimated Fed funds rate, forward guidance, and LSAP factors in Figure 1 and show how they line up with FOMC announcements that had significant implications for the LSAP factor. Events are QE1, the announcement of the original LSAP in November 2008; QE2, Bernanke's August 2010 speech suggesting an expansion of LSAPs; QE3, FOMC vote to buy $40b bonds per month in September 2012; Taper tantrum, Bernanke's 2013 FOMC press conference suggesting that FOMC would wind down purchases of mortgage-backed securities.

Table 2 reports the loading matrix implied by the identifying restrictions on the

Figure 1: Estimated Fed Funds Rate, Forward Guidance, and LSAP Factors



The figure displays the estimated Fed funds rate, forward guidance, and LSAP factors from 1999 to 2019. Events are QE1, the announcement of the original LSAP in November 2008; QE2, Bernanke's August 2010 speech suggesting an expansion of LSAPs; QE3, FOMC vote to buy $40b bonds per month in September 2012; Taper tantrum, Bernanke's 2013 FOMC press conference suggesting that FOMC would wind down purchases of mortgage-backed securities.

rotation matrix. Our results are broadly consistent with Swanson (2021) in signs[9] and the magnitude of coefficients although we use daily rate data and employ a shorter sample to identify monetary policy shocks.

Table 2: Estimated Effects of Monetary Policy on Interest Rates, 1999–2019

	*mp*1	*mp*2	*ed*2	*ed*3	*ed*4	2Y Tr.	5Y Tr.	10Y Tr.
Fed Funds	11.38***	7.81***	4.00***	3.58***	2.83***	1.92***	1.19***	0.54***
	(0.19)	(0.17)	(0.13)	(0.06)	(0.12)	(0.14)	(0.08)	(0.10)
Forward	-0.00	1.23***	4.34***	5.57***	6.17***	4.79***	4.77***	3.39***
Guidance	(0.13)	(0.12)	(0.10)	(0.04)	(0.08)	(0.10)	(0.06)	(0.07)
LSAP	0.00	-1.41***	-1.64***	-1.06***	-0.34**	0.91***	2.85***	3.32***
	(0.17)	(0.15)	(0.12)	(0.06)	(0.10)	(0.13)	(0.07)	(0.09)
N	171	171	171	171	171	171	171	171
R^2_{adj}	0.96	0.93	0.95	0.99	0.97	0.93	0.98	0.96

Standard errors in parentheses
$^{*} p < 0.10, ^{**} p < 0.05, ^{***} p < 0.01$

The table provides elements of the structural loading matrix, in basis points per standard deviation change in the monetary policy instrument. *mp*1 and *mp*2 denote the scaled changes in the first and the third Federal funds futures contracts, *ed*2, *ed*3, and *ed*4 denote changes in the second through fourth Eurodollar futures contracts; and 2Y, 5Y, and 10Y Tr. denote changes in 2-, 5-, and 10-year Treasury yields.

A one-standard-deviation increase in the Federal funds rate factor is estimated to raise the current Federal funds rate by 11.4 basis points, the expected Federal funds rate at the next FOMC meeting by about 7.8 basis points, the second, third, and fourth Eurodollar futures rates by 4.0, 3.6, and 2.8 basis points respectively, and the 2-, 5-, and 10-year Treasury yields by about 1.9, 1.2, and 0.5 basis points respectively. The effects of a surprise change in the Federal funds rate are largest at the short end of the yield curve and die off monotonically as the maturity of the interest rate increases, in line with the results from Kuttner (2001) and Gürkaynak, Sack, and Swanson (2005).

The second row suggests that the effect of forward guidance on asset prices is hump-shaped peaking at approximately the one-year horizon and then diminishing at longer horizons, consistent with Gürkaynak, Sack, and Swanson (2005) and Campbell, Evans,

[9] Note that we normalized shocks to correspond to monetary tightening - that is why the signs in the third row are opposite to those in Swanson (2021).

Fisher, Justiniano, Calomiris, and Woodford (2012).[10]

The third row implies that a one standard deviation tightening in LSAP causes the 2-, 5- and 10-year treasury yields to rise on average.[11]

The estimates in this table are not only consistent with the literature but also suggest that the identified factors used in the shock construction correspond to changes in the Federal funds rate, forward guidance, and LSAPs.

4.3 Expectations of Future Policy Rate

Since monetary policy in the U.S. is dominated by three components – Fed funds rate, forward guidance, and LSAP – we proxy expectations of the future policy rate at CPI release dates by three (rotated) principal components from changes in the 8 interest rates around CPI release dates. The rates we employ and identifying assumptions for factors are the same as the ones used for monetary policy shocks. Each of the principal components will correspond to the expectations about the Fed's action in terms of each policy instrument - Fed funds target, forward guidance, and LSAP. Figure 2 depicts the resulting series. Given that these factors identify market expectations about future policy rates, we can conclude that after the financial crisis, markets expected the Fed to operate through forward guidance and LSAP instruments.

4.4 Expectations of the Fed's Aggressiveness

We measure the expected Fed's reaction to inflation by the residuals from the regression given by[12]

$$\tilde{F}^j_\tau = \alpha_0 + \alpha_1 \Delta IC_{\tau,h} + \varepsilon^j_{\tau,h} \tag{10}$$

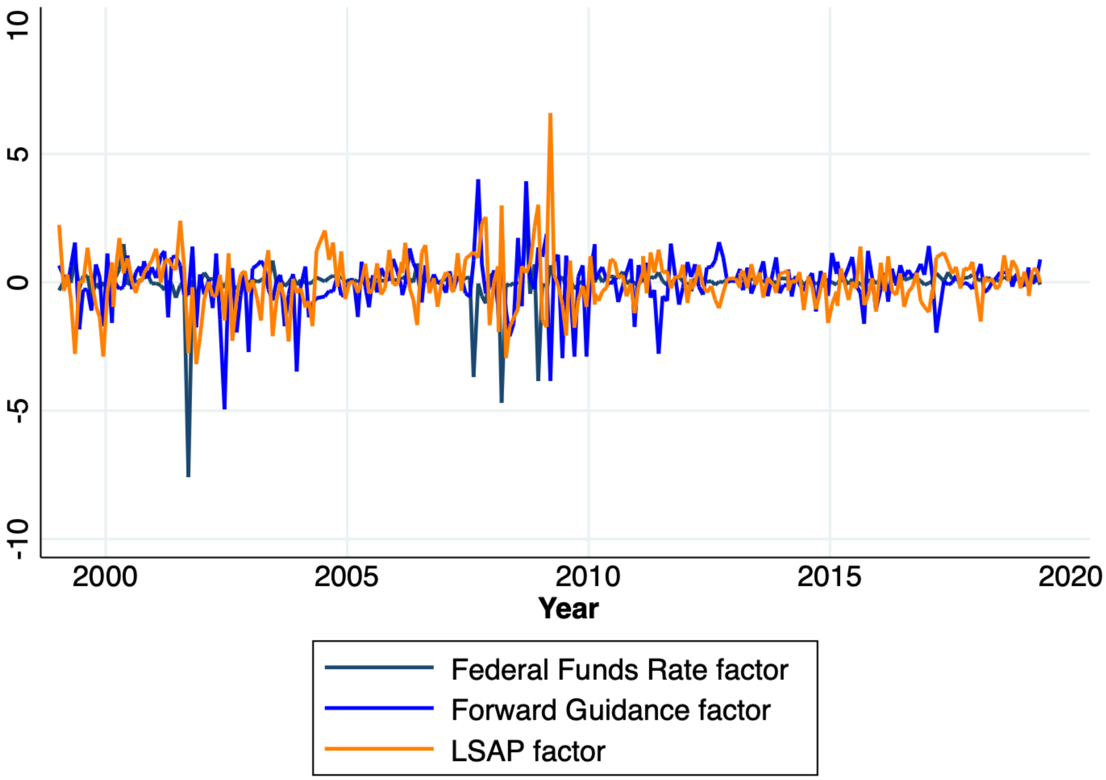
where τ indexes CPI announcement, $\tilde{F}^j$ denotes monetary policy component j (either the Fed funds rate, forward guidance, or LSAP), Δ is the daily change bracketing each CPI announcement, IC_h is the BEI over maturity h, and ε is the regression residual. As a result, we obtain three sets of residuals corresponding to three policy actions, estimated for 19 different maturities from 2 to 20 years. The residual from ε, identifies $\Delta\mathbb{E}_t\phi_{t,h} \times \mathbb{E}_t\pi_{t,h}$, so we define $\tilde{\varepsilon}^j_{\tau,h} = \frac{\hat{\varepsilon}^j_{\tau,h}}{IC_{\tau,h}}$ as a measure of changes in expectation about the Fed's

[10]The effect of forward guidance on the current Federal funds rate is zero by construction.

[11]The effect of LSAP on the current Federal funds rate is zero by construction.

[12]This regression is the counterpart of (3). The only difference is the notation - we substituted it to the estimated proxies for expectations obtained in the previous subsections.

Figure 2: Estimated Fed Funds Rate, Forward Guidance, and LSAP Factors around CPI releases



The figure displays the estimated Fed funds rate, forward guidance, and LSAP factors from 1999 to 2019 around CPI releases. These factors measure expectations about future policy rates. See text for details.

aggressiveness.

By construction, the mean of each residual $\hat{\varepsilon}$ from regression (10) around CPI releases is zero.[13] However, in our analysis we are going to use only residuals that precede FOMC announcements, resulting in 112 observations.[14]

In Figure 3, we display the averages of $\tilde{\varepsilon}$ – the estimated changes in expectation about the Fed's aggressiveness with respect to Fed funds rate, forward guidance, and LSAP factors – for maturities from 2 to 20 years. Two observations stand out. The first is that the average estimates of the change in the Fed's aggressiveness starting from maturity of 10 years onward are very similar to those at longer maturities. This reflects strong co-movement between nominal and real interest rates at longer maturities. The second is that, due to negative inflation compensation observations, on average, for maturities from 10 to 20 years, the markets expect the Fed to lower its aggressiveness through the Fed funds rate and forward guidance and increase it through LSAP.

5 Empirical Results

In this section, we use market-based measures of expectations constructed in the previous section to study the relationship between inflation expectations and monetary policy. Our analysis comprises three steps. First, we document that our identified monetary shocks have a significant effect on nominal interest rates. Second, we provide evidence that real rates respond to forward guidance and LSAP shocks much stronger than nominal rates. Therefore, inflation compensation responds systematically to monetary policy shocks corresponding to forward guidance and LSAPs. Finally, we show that the response of inflation compensation to monetary policy is lower when markets expect the Fed's reaction to inflation to be more aggressive. In other words, the interaction between monetary policy and market expectations about Fed's aggressiveness has an opposite effect on inflation compensation to that of monetary policy.

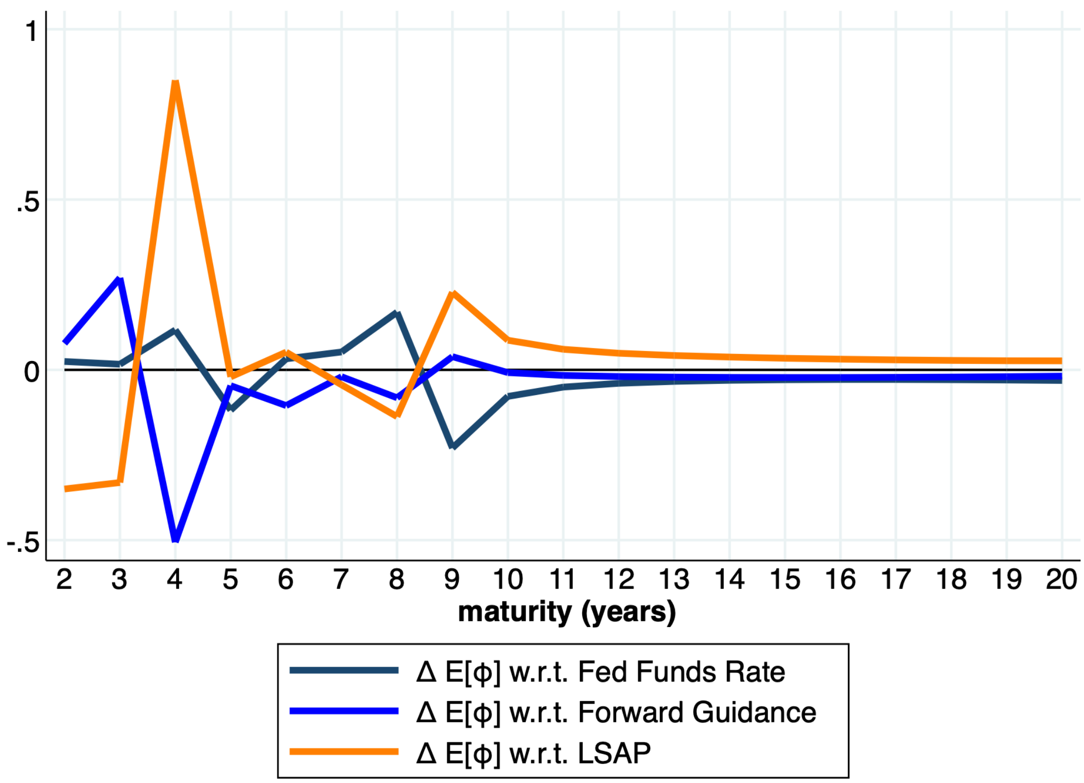
5.1 The Effect of Monetary Policy on Nominal Interest Rates

In this subsection, we estimate the effects of the Fed funds rate, forward guidance, and LSAP on the nominal interest rates derived from U.S. Treasury yields.

[13] There were 187 CPI releases during our sample period from January 1, 2005, to June 30, 2019.

[14] All the empirical results that follow are based on these 112 FOMC announcements.

Figure 3: Estimated Change in the Fed's Aggressiveness



The figure displays the average changes in expectation about the Fed's aggressiveness with respect to Fed funds rate, forward guidance, and LSAP factors for maturities from 2 to 20 years based on data from 2005 to 2019 for CPI releases that precede FOMC announcements. See text for details.

Table 3: Estimated Effects of Monetary Policy on U.S. Treasury Yields

Nominal Yield	2Y	5Y	10Y	20Y
Fed Funds	5.343***	3.258***	0.964	-0.164
	(0.673)	(0.847)	(0.901)	(0.838)
Forward Guidance	3.982***	4.316***	2.965***	1.006
	(0.497)	(0.625)	(0.664)	(0.618)
LSAP	3.305***	6.251***	6.404***	4.265***
	(0.498)	(0.627)	(0.667)	(0.620)
constant	-0.023	0.064	0.191	0.583
	(0.426)	(0.536)	(0.570)	(0.530)
N	112	112	112	112
R^2_{adj}	0.64	0.63	0.54	0.32

Standard errors in parentheses
$^{*}p < 0.10, ^{**}p < 0.05, ^{***}p < 0.01$

Coefficients β from regression (11). Coefficients are in units of basis points per standard deviation change in the monetary policy instruments. The sample period is all regularly scheduled FOMC meetings from January 1, 2005, to June 30, 2019.

Each column of Table 3 provides estimates from an OLS regression of the form

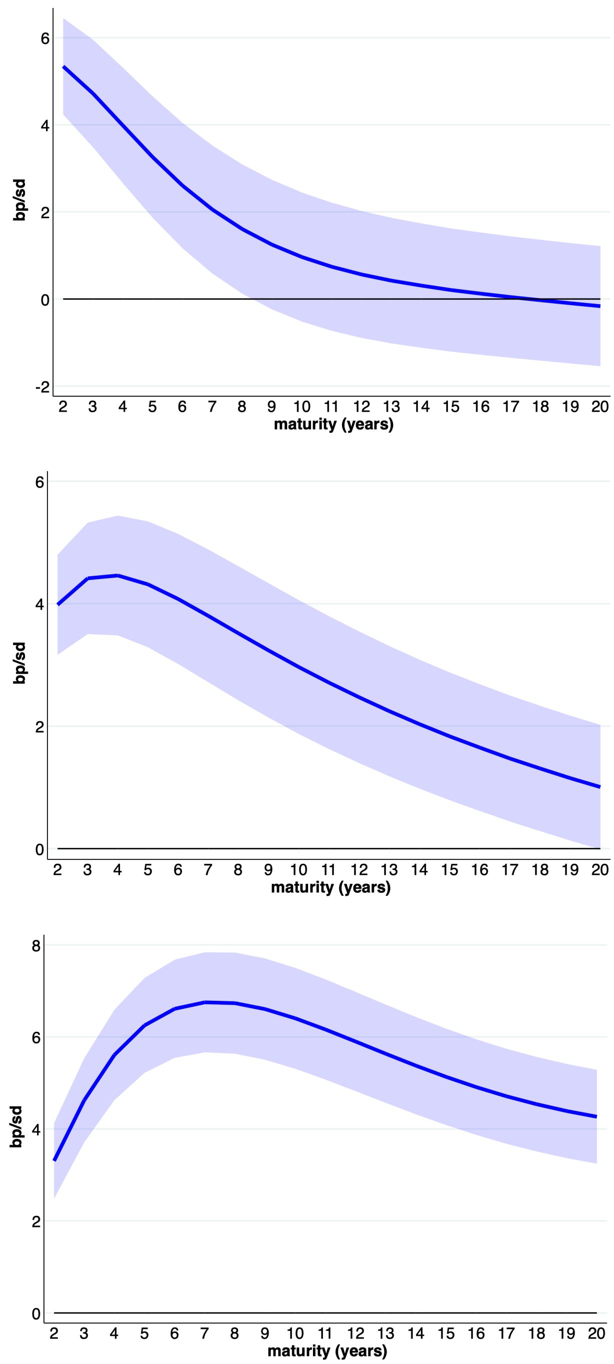
$$\Delta i_{t,h} = \alpha + \tilde{F}_t'\beta + u_t \tag{11}$$

where t indexes FOMC announcements, $i_{t,h}$ denotes nominal yields at a given maturity h, $\tilde{F}$ denotes the monetary policy factors, and Δ is the daily change bracketing each FOMC announcement, and u is a regression residual. The coefficients are in units of basis points per standard deviation surprise in each monetary policy component.

Figure 4 plots the results of these regressions for the effects of the Federal funds rate tightening (top panel), the effects of forward guidance tightening (middle panel), and the effects of LSAP tightening (bottom panel) on nominal interest rates for maturities from 2 to 20 years. The solid blue line in each panel plots the point estimates β as a function of maturity h, and the shaded grey area contains $\pm$1.96-standard-error bands around those estimates.

The first row of Table 3 and the top panel of Figure 4 suggest that a one standard deviation increase in the Federal funds rate causes the 2-year Treasury yields to rise about 5.3 basis points, with effects on longer-term yields that decrease monotonically with

Figure 4: Estimated Effects of Federal Funds (top panel), Forward Guidance (middle panel), and LSAP (bottom panel) Tightening on Nominal Interest Rates



Estimated coefficients $\hat{\beta}$ (solid blue line) and ±1.96-standard-error bands (shaded area) are from regression (11) for maturities from 2 to 20 years. The sample period is all regularly scheduled FOMC meetings from January 1, 2005, to June 30, 2019.

maturity, becoming statistically insignificant at maturity of 8 years.

The second row of Table 3 and the middle panel of Figure 4 show that a one standard deviation increase in forward guidance has a hump-shaped effect on the yields curve, with a peak at the 4-year maturity.

The third row of Table 3 and the bottom panel of Figure 4 imply that a one standard deviation tightening in LSAP is also hump-shaped, peaking at the maturity of 7 years.

5.2 The Effect of Monetary Policy on Real Interest Rates and Inflation Compensation

Having established that our identified shocks have a similar effect on nominal yields as documented in Swanson (2021), in this subsection, we turn to the effect of monetary policy on real interest rates and inflation compensation.

We start by estimating the effect of monetary policy on real interest rates measured by the TIPS yields. Each column of Table 4 provides estimates from an OLS regression of the form

$$\Delta r_{t,h} = \alpha + \tilde{F}_t'\beta + u_t \tag{12}$$

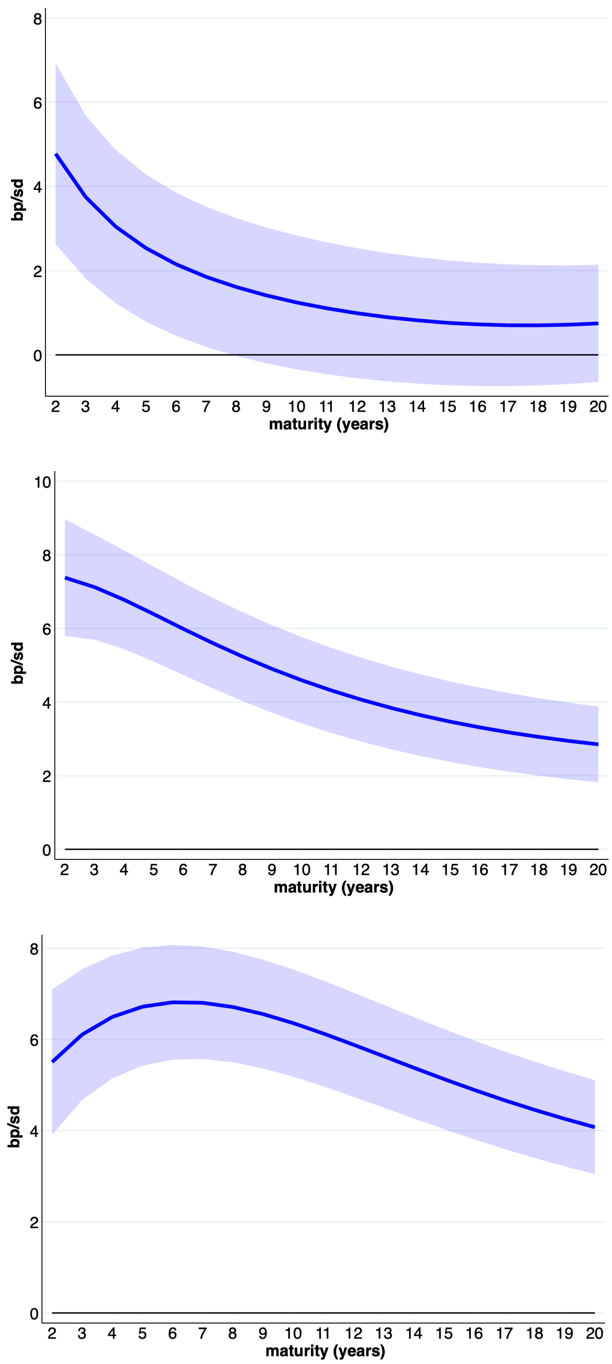
where t indexes FOMC announcements, $r_{t,h}$ denotes TIPS yields at a given maturity h, $\tilde{F}$ denotes the monetary policy factors, Δ is the daily change bracketing each FOMC announcement, and u is a regression residual.

Figure 5 plots the results of these regressions for the effects of the Federal funds rate tightening (top panel), the effects of forward guidance tightening (middle panel), and the effects of LSAP tightening (bottom panel) on real yields for maturities from 2 to 20 years. The solid blue line in each panel plots the point estimates β as a function of maturity h, and the shaded grey area contains ± 1.96-standard-error bands around those estimates.

Table 4 and Figure 5 suggest that real yields respond to an increase in the Federal funds rate slightly less than nominal yields. Meanwhile, the response of real yields to a forward guidance shock is much stronger than that of nominal yields. For the LSAP shock, real yields respond more than nominal yields at shorter maturities but at longer maturities, the effects on real and nominal yields are somewhat similar.

The combined evidence of monetary policy effects on nominal and real yields suggests that inflation will not respond to the shocks in the Fed funds rate, but will respond to shocks in forward guidance at all maturities, and to shocks in LSAP at short maturities. Our conjecture is readily verified by Table 5 and Figure 6 that display estimates from an

Figure 5: Estimated Effects of Federal Funds (top panel), Forward Guidance (middle panel), and LSAP (bottom panel) Tightening on Real Yields



Estimated coefficients $\hat{\beta}$ (solid blue line) and ±1.96-standard-error bands (shaded area) are from regression (12) for maturities from 2 to 20 years. The sample period is all regularly scheduled FOMC meetings from January 1, 2005, to June 30, 2019.

Table 4: Estimated Effects of Monetary Policy on U.S. TIPS Yields

TIPS Yield	2Y	5Y	10Y	20Y
Fed Funds	4.778***	2.536**	1.244	0.747
	(1.308)	(1.063)	(0.966)	(0.846)
Forward Guidance	7.381***	6.389***	4.590***	2.852***
	(0.965)	(0.784)	(0.712)	(0.624)
LSAP	5.504***	6.719***	6.358***	4.075***
	(0.968)	(0.787)	(0.715)	(0.627)
constant	-0.749	-0.516	-0.355	-0.433
	(0.828)	(0.673)	(0.611)	(0.535)
N	112	112	112	112
R^2_{adj}	0.51	0.60	0.56	0.39

Standard errors in parentheses
$^{*} p < 0.10, ^{**} p < 0.05, ^{***} p < 0.01$

Coefficients β from regression (12). Coefficients are in units of basis points per standard deviation change in the monetary policy instruments. The sample period is all regularly scheduled FOMC meetings from January 1, 2005, to June 30, 2019.

OLS regression of the form

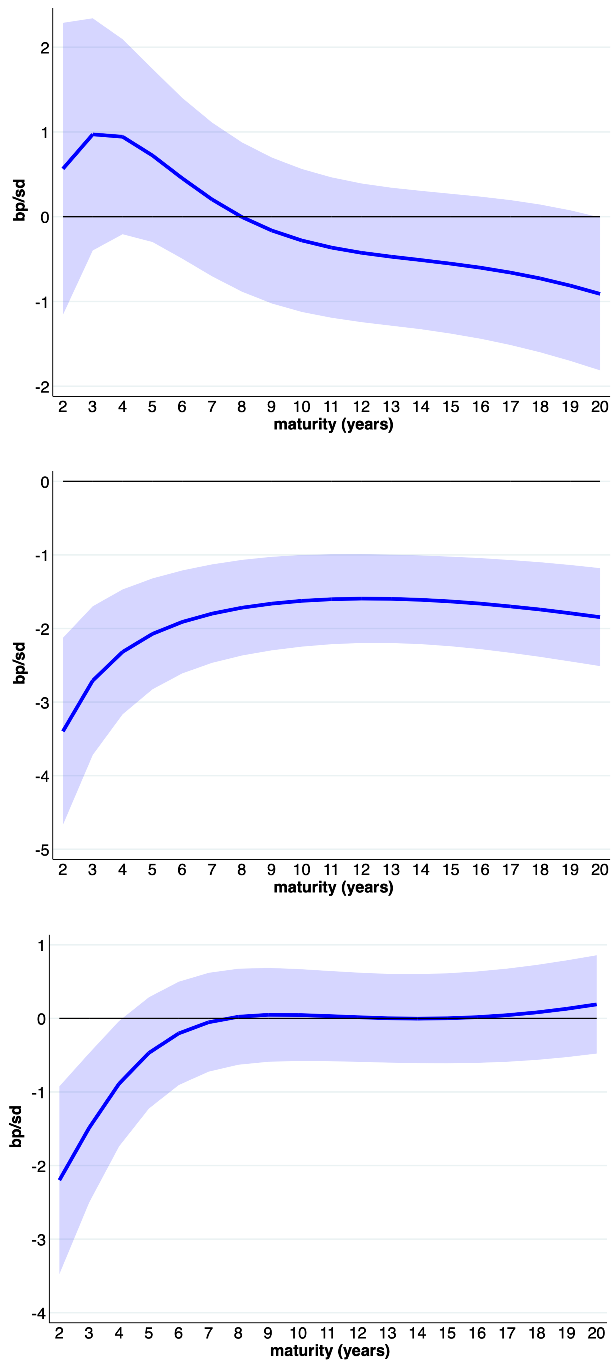
$$\Delta IC_{t,h} = \alpha + \tilde{F}_t' \beta + u_t \tag{13}$$

where t indexes FOMC announcements, $IC_{t,h}$ denotes inflation compensation over a given maturity h, $\tilde{F}$ denotes the monetary policy factors, and Δ is the daily change bracketing each FOMC announcement.

The first row of Table 5 and the top panel of Figure 6 show that a one-standard-deviation increase in the Federal funds has essentially no effect on the inflation compensation.

The second row of Table 5 and the middle panel of Figure 6 show that a one-standard-deviation increase in the forward guidance has a negative but diminishing effect on the inflation compensation. The response of the inflation compensation implied by two-year rates is strongest and statistically significant amounting to -3.4 basis points per standard deviation. It gradually levels off to about -1.9 basis points at the 20-year maturity. All coefficients are highly statistically significant. This evidence suggests that inflation compensation responds systematically to monetary policy shocks corresponding to

Figure 6: Estimated Effects of Federal Funds (top panel), Forward Guidance (middle panel), and LSAP (bottom panel) Tightening on Inflation Compensation



Estimated coefficients $\hat{\beta}$ (solid blue line) and ±1.96-standard-error bands (shaded area) are from regression (13) for maturities from 2 to 20 years. The sample period is all regularly scheduled FOMC meetings from January 1, 2005, to June 30, 2019.

Table 5: Estimated Effects of Monetary Policy on U.S. Inflation Compensation

Inflation Compensation	2Y	5Y	10Y	20Y
Fed Funds	0.565	0.723	-0.280	-0.911*
	(1.047)	(0.621)	(0.513)	(0.548)
Forward Guidance	-3.398***	-2.073***	-1.624***	-1.846***
	(0.772)	(0.458)	(0.378)	(0.404)
LSAP	-2.199***	-0.468	0.046	0.190
	(0.775)	(0.460)	(0.379)	(0.406)
constant	0.726	0.581	0.546*	1.015***
	(0.662)	(0.393)	(0.324)	(0.347)
N	112	112	112	112
R^2_{adj}	0.20	0.16	0.12	0.15

Standard errors in parentheses
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Coefficients β from regression (13). Coefficients are in units of basis points per standard deviation change in the monetary policy instruments. The sample period is all regularly scheduled FOMC meetings from January 1, 2005, to June 30, 2019.

changes in the forward guidance.

The third row of Table 5 and the bottom panel of Figure 6 show that a one-standard-deviation contraction in the LSAPs has a negative effect on the inflation compensation only at short maturities of 2 and 3 years. The response of the inflation compensation implied by two-year rates is -2.2 basis points per standard deviation. The response is not significant for maturities from 4 to 20 years.

The main result of this subsection is that inflation compensation responds systematically to monetary policy shocks corresponding to changes in the forward guidance across all maturities and LSAPs at short maturities. In the next subsection, we will explore if the expectations about the Fed's aggressiveness dampen inflation expectations' response to forward guidance (at all maturities) and LSAP (at short maturities).

5.3 The Effect of Monetary Policy on Inflation Compensation Conditional on the Expected Aggressiveness of the Fed

In this subsection, we examine the effect of monetary policy on inflation compensation conditional on the change in the expected aggressiveness of the Fed. We show that at long maturities, the interaction between the forward guidance instrument and changes in market expectations about the Fed's aggressiveness has an opposite effect to that of monetary policy on inflation compensation. That is, given that markets expect the Fed to be more (less) aggressive, they adjust inflation expectations less (more).

To explore the effects of monetary policy on inflation compensation conditional on the change in the expected aggressiveness of the Fed, we estimate the OLS regressions of the form

$$\Delta IC_t^m = \alpha + \sum_{j=1}^{3} \beta_j \tilde{F}_{j,t} + \sum_{j=1}^{3} \gamma_j \tilde{\varepsilon}_{j,\tau} + \sum_{j=1}^{3} \delta_j \tilde{F}_{j,t} \tilde{\varepsilon}_{j,\tau} + u_t \tag{14}$$

where t indexes FOMC announcements, τ indexes the last CPI announcement preceding FOMC announcement t, IC denotes inflation compensation at a particular maturity m, Δ the daily change bracketing each FOMC announcement, $\tilde{F}$ the monetary policy factors estimated above, $\tilde{\varepsilon}$ market expectations about Fed's aggressiveness given by an estimated residual from regression 10, $\tilde{F}\tilde{\varepsilon}$ an interaction between the monetary policy factors and market expectations about Fed's aggressiveness, and u a regression residual.

Even though by standard economic theory monetary policy tightening should lead to lower inflation (implying $\beta + \delta < 0$), the coefficient δ does not necessarily have to be positive for all maturities to counteract the effects of the monetary tightening. First, in the context of expected inflation anchoring we are primarily interested in the far-ahead expectations, beyond 10 years. This horizon is sufficiently far out so that movements in inflation compensations at these maturities are not attributable to transitory responses of the economy to a shock. Second, because the inflation compensation time series includes some negative observations, revisions in the expected Fed's aggressiveness can be negative. If so, a negative δ will imply anchoring.

From Table 5 and Figure 6 in the previous section, we saw that inflation compensation responds negatively only to forward guidance tightening at all maturities.[15] We also saw in Figure 3 that, on average, the estimated change in the Fed's aggressiveness through forward guidance was negative. Therefore, we expect coefficient δ corresponding to the interactions with forward guidance to be negative at longer maturities to counteract the effects of these shocks.

Table 6 reports the responses of inflation compensation at maturities of 2-, 5-, 10- and 20 years to changes in three monetary policy factors and their interactions with the

[15] We also saw that the inflation compensation responds negatively to LSAP tightening for maturities of 2 and 3 years, but these horizons are too short for standard economic models to return to steady state.

corresponding expectations about the Fed's aggressiveness over the sample from January 1, 2005, to March 20, 2019. As in Table 5, the coefficients in Table 6 are in units of basis points per standard deviation tightening surprise in each monetary policy instrument.

Figure 7 plots the estimated coefficients $\hat{\beta}$ and $\hat{\delta}$ from these regressions for the effects of the Federal funds rate tightening (top panel), the effects of forward guidance tightening (middle panel), and the effects of LSAP tightening (bottom panel) on inflation compensation for maturities from 2 to 20 years. The solid blue line in each panel plots the point estimates β for each maturity, and the shaded blue area contains $\pm$1.96-standard-error bands around those estimates. The solid orange line in each panel plots the point estimates δ for each maturity, and the shaded orange area contains $\pm$1.96-standard-error bands around those estimates.

Our conjecture about negative δ in front of the forward guidance interaction is verified by columns (4) and (5) of Table 6 and the middle panel of Figure 7: for maturities longer than 10 years, the interaction term is significant and negative. For maturities below 10 years, it is not significant.

The evidence in this section suggests that inflation expectations are anchored because their response to monetary policy is smaller than that if expectations are de-anchored. If during the CPI release before the FOMC meeting markets expected Fed to be more aggressive through forward guidance tightening, inflation compensation does not decrease as much. On the contrary, the expectation of the Fed's reaction through the Fed funds rate and LSAP formed during the CPI release does not matter for the markets since it is counteracted by the incoming news about the Fed's future policies.

6 Conclusion

In this paper, we used daily bond yield data to show that the sensitivity of inflation expectations to forward guidance is lower if the Fed is expected to be more aggressive to inflation. Intuitively, the Fed announcement leading to a rate change that is higher than expected from an important news release about inflation indicates that the markets expect the Fed to react more aggressively in the future. If inflation expectations are anchored, markets will not adjust inflation expectations as much.

The main contribution of this paper is to provide a market-based measure of the expected Fed's aggressiveness to inflation. We do this by extracting residuals from a regression of the changes in future policy rates on changes in inflation expectations.

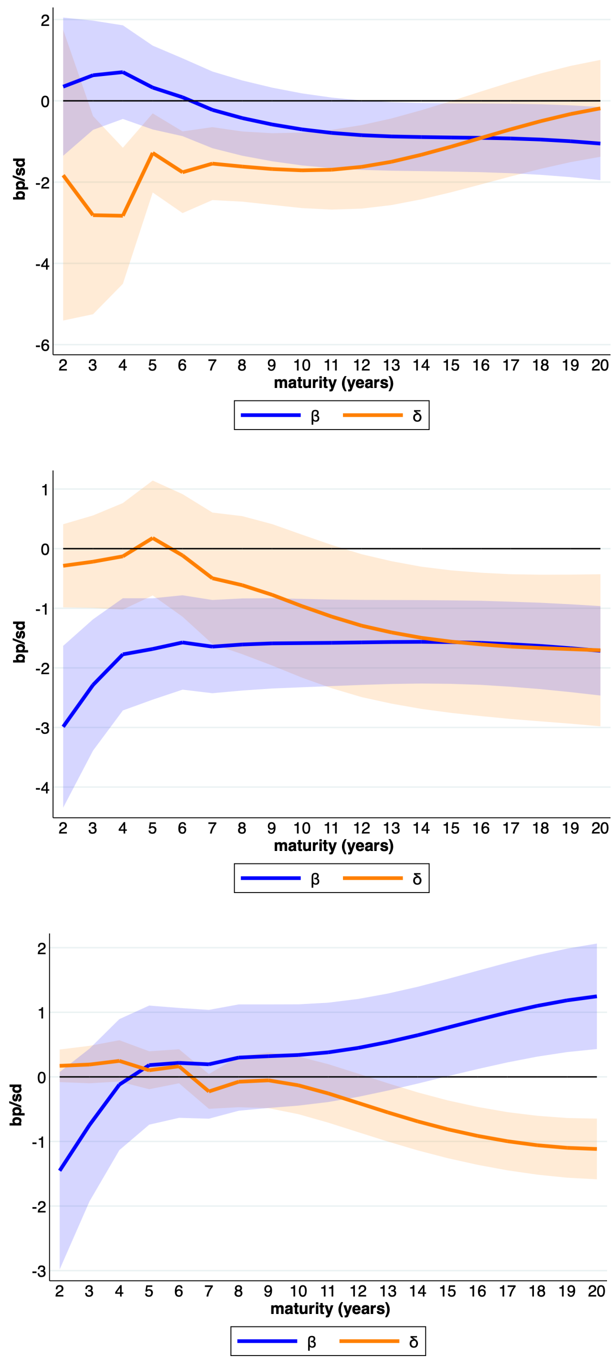
Table 6: Sensitivity of Inflation Compensation to Monetary Policy Conditional on the Expected Aggressiveness of the Fed

Inflation Compensation	2Y	5Y	10Y	15Y	20Y
Fed Funds	0.333	0.268	-0.750	-0.949*	-1.106**
	(1.039)	(0.633)	(0.537)	(0.510)	(0.546)
Forward Guidance	-3.021***	-1.792***	-1.656***	-1.621***	-1.774***
	(0.829)	(0.518)	(0.448)	(0.425)	(0.455)
LSAP	-1.459	0.167	0.380	0.810*	1.308***
	(0.934)	(0.564)	(0.474)	(0.457)	(0.496)
$\tilde{\varepsilon}_1$	-0.717	-1.692***	0.084	0.137	0.700
	(2.378)	(0.579)	(1.156)	(1.294)	(1.330)
$\tilde{\varepsilon}_2$	0.168	-0.156	-0.342	0.212	0.336
	(0.529)	(0.621)	(0.751)	(0.754)	(0.797)
$\tilde{\varepsilon}_3$	0.312	0.635	1.127	0.325	0.414
	(0.551)	(0.648)	(0.945)	(0.883)	(0.871)
$\tilde{F}_1 \times \hat{\varepsilon}_1$	-2.822	-1.214*	-1.812***	-1.213*	-0.260
	(2.176)	(0.621)	(0.564)	(0.681)	(0.723)
$\tilde{F}_2 \times \hat{\varepsilon}_2$	-0.306	-0.016	-1.060	-1.631**	-1.776**
	(0.426)	(0.598)	(0.723)	(0.725)	(0.773)
$\tilde{F}_3 \times \hat{\varepsilon}_3$	0.174	0.030	-0.050	-0.774***	-1.073***
	(0.154)	(0.162)	(0.272)	(0.272)	(0.283)
constant	0.820	0.512	0.604*	0.829***	0.988***
	(0.690)	(0.399)	(0.326)	(0.309)	(0.332)
N	112	112	112	112	112
R^2_{adj}	0.25	0.23	0.18	0.24	0.28

Standard errors in parentheses
$^{*} p < 0.10, ^{**} p < 0.05, ^{***} p < 0.01$

The table provides estimates of regression (14). Coefficients are in units of basis points per standard deviation change in the monetary policy instruments. The sample period is all regularly scheduled FOMC meetings from January 1, 2005, to June 30, 2019.

Figure 7: Effects of Monetary Tightening Conditional on the Expected Fed's Aggressiveness



Estimated coefficients $\hat{\beta}$ (solid blue line) with ±1.96-standard-error bands (shaded blue area) and estimated coefficients $\hat{\delta}$ (solid orange line) with ±1.96-standard-error bands (shaded orange area) are from regression (14). The sample period is all regularly scheduled FOMC meetings from January 1, 2005, to June 30, 2019. See the text for details.

Our main findings can be summarized as follows. First, we provide evidence suggesting that conventional monetary policy does not affect inflation compensation, whereas forward guidance tightening reduces inflation compensation, and LSAP tightening reduces inflation compensation at short horizons. Second, we show that the interaction between forward guidance and the expected Fed's aggressiveness at long maturities increases inflation compensation, partially counteracting the effect of the forward guidance tightening. Our findings are consistent with the anchoring of long-term inflation expectations.

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Appendices