Monetary Policy Financial Transmission and Treasuries Liquidity Premia*

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Abstract

We identify and quantify the macroeconomic dynamic effects of well-identified monetary policy interest rate shocks on the yield curve due to changes in Treasuries liquidity premia. When the Fed raises interest rates, the spread between less-liquid assets and Treasuries of the same maturity and risk increases, as the liquidity value of holding Treasuries increases when the aggregate amount of banks' customer deposits decreases. The longer the maturity, the smaller - but still significant - increase in the spread, as longer-term Treasuries are less liquid and more heavily discounted when interest rates rise. Monetary policy thus affects real interest rates through changes in liquidity premia across the yield curve.

JEL-Classification: E52, E43, E41

Keywords: Treasuries liquidity premia, Monetary policy, Yield curve, Deposits channel

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1 Introduction

The monetarist literature has emphasized the role of deposit fluctuations as proxies for various substitution effects of monetary policy when many asset prices matter for aggregate demand (Nelson, 2003). This paper identifies and quantifies the macroeconomic dynamic effects of substitutions between short- and long-term Treasuries, due to changes in liquidity premia, which occur because of the bank customer deposits' response to monetary policy interest rate movements. We thus identify and quantify monetary policy effects on the yield curve through relative liquidity premia.

Nagel (2016) documents, using static regressions, an observed positive relationship between the short-term Treasury liquidity premium and the Fed funds rate. When the Fed funds rate increases, the spread between non-liquid short-term assets and T-bills increases. Drechsler et al. (2018) present a monetary policy transmission channel through the banking system, or deposits channel, which can explain Nagel's empirical findings. The spread increases as the liquidity value of holding short-term T-bills increases when the aggregate amount of banks' customer deposits decreases.

We use a macro SVAR model to quantify the effects of well-identified monetary policy interest rate shocks on the yield curve due to changes in liquidity premia. Our SVAR includes, as in Gertler and Karadi (2015), the excess bond premium. In addition, we include and assess the evolution of Treasuries liquidity premia for different maturities along the yield curve.

Our methodology is based on Gertler and Karadi (2015) in that we follow the approach from Gürkaynak, Sack, and Swanson (2004) by extracting the two principal components of monetary policy surprises on FOMC announcement days corresponding to exogenous changes in expectations about current (target factor) and future (path factor) monetary policy. After aggregating the resulting target factor, we use it as an external instrument (Stock and Watson, 2012) to identify our monthly SVAR. We finally compute the IRFs of the economy and liquidity premia to a monetary policy shock and infer on their significance using a recursive-design wild bootstrap procedure (Gonçalves and Kilian, 2004; Mertens and Ravn, 2013).

We show that the monetary effects on the yield curve via liquidity premia vary across maturities. When the Fed raises interest rates, the liquidity premium of longer-term Treasuries significantly increases, but by less than that of shorter T-bills, as they are less liquid and more heavily discounted when rates rise. This points to a substitution from long- to short-term Treasuries, leading to a relative steepening of the slope of the yield curve, not related to policy expectations or risk premium, but reflecting liquidity premia reactions to monetary policy.

When measured with Treasury yields, monetary policy interest rate actions thus have a proportionally larger effect on long-term rates than on short-term rates, as the liquidity premium of T-bills increases by more than the liquidity premium of longer-term Treasuries when the policy interest rate increases. Thus a decline in deposits is an indicator of a relatively higher long-term real rate via liquidity premia term structure changes.

Our results can shed light on the expectation hypothesis, as monetary policy affects the term structure through liquidity premia. Moreover, Treasuries liquidity premia fluctuations have recently been used to understand various issues like real equilibrium interest rate movements (Bok, Del Negro, Giannone, Giannoni, and Tambalotti, 2018; Ferreira and Shousha, 2020) or exchange rate forecasting (Engel and Wu, 2018). Our results contribute to quantifying the effect of monetary policy on those fluctuations.

Section 2 discusses the conceptual framework. Empirical results are presented in section 3. Finally, section 4 concludes.

2 The deposit channel and Treasuries liquidity

According to the deposit channel presented by (Drechsler et al., 2018, DSS hereafter), the effect of monetary policy on the Treasury liquidity premium arises from two facts. First, interest rates offered by commercial banks on customers' deposits adjust sluggishly and only partially to changes in monetary policy rates. And second, households and firms adjust their deposit holdings to changes in opportunity cost, reflecting the traditional money demand motives. Changes in the aggregate amount of deposits, and thus of the total liquidity supply, affect the liquidity value of Treasuries.

DSS present a model of banks' pricing behavior, where market power causes deposit interest rate spreads to increase with rises in the Fed funds rate. Deposit rates adjust only partially to Fed funds rate increases, and tend to fully adjust to permanent decreases in the Fed funds rate.

Bank customers respond to this change in opportunity cost, reflecting money demand motives. As the aggregate amount of customer deposits decreases with an increase in the Fed funds rate, the liquidity value of holding T-bills increases. The spread between illiquid bond and T-bill yields thus increases. In DSS, deposits are modeled as providing liquidity service in the utility function. They show that this deposit channel affects lending and thus the monetary policy transmission.

Our empirical results below show that liquidity premia of Treasuries of different maturities react differently to a monetary policy shock. The longer the maturity, the smaller the liquidity premium increases with the Fed funds rate. Longer-term Treasuries are less liquid and are discounted more heavily when rates rise. There is thus a need to model the process of obtaining deposits from liquid assets like Treasuries, which should lead to different liquidity premia for different maturities as we find empirically. One way could be to explicitly model the process by which bonds are discounted to obtain deposits, in line with Reynard and Schabert (2009). Longer-term Treasuries are discounted by more than short-term ones when interest rates increase, reducing their liquidity value.

3 The Identified Effects of Monetary Policy on Liquidity Premia

The method used in this paper proceeds in two steps and is largely based on Gertler and Karadi (2015).

First, we use the high frequency identification (HFI) suggested by Faust, Swanson, and Wright (2004), and follow the approach from Gürkaynak, Sack, and Swanson (2004) by extracting the two principal components of monetary policy surprises on Federal Open Market Committee (FOMC) announcement days corresponding to exogenous changes in expectations about current (target factor) and future (path factor) monetary policy.

Second, we aggregate the resulting target factor and use it as an external instrument (Stock and Watson, 2012) to identify our monthly structural vector autoregressive process (SVAR). We then compute the Impulse Response Functions (IRFs) of the economy and liquidity premia to a monetary policy shock and infer on their significance using a recursive-design wild bootstrap procedure (Gonçalves and Kilian, 2004; Mertens and Ravn, 2013).

3.1 HFI of monetary policy shocks

The main idea of the HFI scheme is to look at changes in an outcome around shocks in a time-window narrow enough to ensure that the changes in that outcome are caused by the shocks and nothing else.

The idea originates from Kuttner (2001), who estimates the effect of changes in Federal Reserve's policy on various interest rates by separating anticipated from unanticipated changes in the target rate using daily data on Fed funds futures. Accordingly, Faust et al. (2004) measure from futures daily data the impact of these unexpected changes in monetary policy on the expected path of interest rates, and identify a VAR imposing that the response of the Fed funds rate to monetary policy shocks matches the one in the data.

Gürkaynak et al. (2004) extend the methodology and argue that there are two factors underlying the response of futures prices to monetary policy. The argument relies on the observation that there has been monetary policy announcements associated with no change in the *target* rate itself, but with changes in the communication over the future *path* of monetary policy causing futures prices to move.[1] Because only considering the target rate would result in missing part of the story, they estimate the two principal components of changes in futures prices on FOMC announcement days and rotate them so as to give them a structural interpretation.

In what follows we expose briefly, based on the above-mentioned literature, how we proceed to measure monetary policy surprises on FOMC announcement days and how we extract the two factors underlying them.

[1]This is especially true after 2007, when the zero lower bound compelled the Federal Reserve to conduct its monetary policy using so-called forward guidance.

Identifying expectations shocks.— We define a set of five monetary policy surprises mp^j for $j = 1, ..., 5$ computed using 1-, 2-, 3- and 4-month Fed funds futures contracts and 6, 9 and 12-month Eurodollar futures contracts.[2] Consistent with the existing literature, we interpet as a change in expectation about current and future monetary policy the daily change in the interest rate implied by the futures contracts on a FOMC announcement day.

The first two surprises, mp^1 and mp^2 are calculated using the Fed funds futures, and respectively reflect the rate expected to prevail until the next FOMC meeting, and that expected to prevail thereafter.[3] Because there are eight scheduled meetings per year, meetings occur on average every six to seven weeks. However, on a day where a meeting takes place, the maturity of the futures due in the month corresponding to the following scheduled meeting ranges from two to three months. We therefore need to compute mp^2 always considering the actual number of months separating one meeting to the next.

The last three surprises mp^j for $j = 3, 4, 5$ are computed as the daily returns on FOMC days of the 6-, 9- and 12-month Eurodollar futures respectively.

Extracting the target and the path factor.— Let X be a $(T \times n)$ matrix whose entries correspond to the above-defined monetary policy surprises mp_t^j for $j = 1, ..., n$ and $t = 1, ..., T$, that is, the surprise component of the daily change in Fed funds futures and Eurodollar futures rates solely associated with FOMC announcements.[4]

We assume X to be generated by a factor model:

$$X = F\Lambda + \nu, \tag{1}$$

where F is a $(T \times \ell)$ matrix of $(\ell < n)$ unobserved factors, Λ a $(\ell \times n)$ matrix of factor loadings, and ν a matrix of orthogonal disturbances. Gürkaynak et al. (2004) show that the response of futures prices is sufficiently characterized by two factors (i.e., $\ell = 2$). We therefore estimate $F = \{F_{1t}, F_{2t}\}_{t=1,...,T}$ through principal-component analysis.

Because the two factors yielded by this method are chosen such as to maximize the share of explained variance, they lack structural interpretation. As in Gürkaynak et al. (2004), we rotate F_1 and F_2 to obtain Z_1 and Z_2. Namely, we define

$$Z = FU, \tag{2}$$

such that U is a (2×2) orthogonal matrix, with Z_2 being associated, on average, with no

[2]The data on futures prices come from `www.quandl.com`. Details are provided in Appendix A.

[3]By construction of the Fed funds futures contracts, which pay off according to the average effective Fed funds rate prevailing over the agreed-upon month, the contract partly reflects the rate realized so far in that month, and the expected rate to prevail until the end thereof. Measuring the suprise in monetary policy associated with an FOMC meeting therefore requires some adjustment. We provide details as to these adjustments in Appendix B.

[4]We normalize the columns of X so that they have zero mean and unit variance.

change in the Fed funds futures rate for the current month. To recover an interpretation as to the magnitude of these factors, we rescale Z_1 (Z_2) to match its units with mp^1 (mp^4).[5]

According to Gürkaynak et al. (2004), this rotation allows us to see Z_1 and Z_2 respectively as the *target* factor and the *path* factor. This is because Z_1 is defined such as to drive surprises in the current target rate on FOMC announcement days, while Z_2 reflects everything (unrelated to the Fed funds target rate) that causes changes to expectations of future monetary policy. Next we describe the way the target factor serves as an external instrument for the estimation of our structural VAR.[6]

3.2 SVAR with external instrument

Let us consider the following p-th order structural Vector Autoregressive (SVAR) model with k endogenous variables:

$$AY_t = \sum_{s=1}^{p} \psi_s Y_{t-s} + \varepsilon_t, \tag{3}$$

where Y_t is a $(k \times 1)$ vector of endogenous variables, A and the ψ_s's are $(k \times k)$ matrices of coefficients, and ε_t is a $(k \times 1)$ vector of structural innovations such that $E[\varepsilon_t \varepsilon_t'] = I_k$ and $E[\varepsilon_t \varepsilon_s'] = 0_k$ for all $t \neq s$.

We estimate the following reduced-form of (3):

$$Y_t = \sum_{s=1}^{p} \phi_s Y_{t-s} + u_t, \tag{4}$$

where $\phi_s = A^{-1}\psi_s$, and u_t is a $(k \times 1)$ vector of reduced-form disturbances such that $E[u_t u_t'] = \Sigma$ and $E[u_t u_s'] = 0_k$ for all $t \neq s$. We have:

$$u_t = B\varepsilon_t. \tag{5}$$

To retrieve the structural impulse response functions (IRFs) implied by (3) from the estimates of (4), we need to identify B. Suppose we are only interested in the response of the system to the structural innovations of one variable y_t^m (the monetary policy rate, in our case). Without loss of generality, assume that this variable is placed first in Y_t such that the vector of structural innovations can be partitioned as:

$$\varepsilon_t = (\varepsilon_t^m \ \varepsilon_t^{\bullet 2} \ \cdots \ \varepsilon_t^{\bullet k})' = (\varepsilon_t^m \ \varepsilon_t^{\bullet})'. \tag{6}$$

Likewise, the relationship between reduced-form residuals and structural innovations can

[5] Appendix B provides details about the rotation and the rescaling.

[6] Before fitting the empirical model, we need to aggregate the monetary policy surprises into a monthly series of shocks. Appendix B provides details about the aggregation.

be partitioned as:

$$B = (s^m \ s^\bullet). \tag{7}$$

To compute the structural IRFs, we thus need to identify only the first column s^m. Suppose further that we have a set of instruments Z_t that fulfills the following two conditions:

$$\begin{aligned} E(Z_t \varepsilon_t^{m\prime}) &= \alpha \quad (8) \\ E(Z_t \varepsilon_t^{\bullet\prime}) &= 0_{k-1}. \quad (9) \end{aligned}$$

These conditions are similar to those of a standard instrumental variable, i.e. the relevance and the exogeneity conditions, respectively. Under these conditions, we can identify s^m in a two-stage procedure summarized as follows.

I. First Stage: Estimate (4) and get the reduced-form residuals:

$$(\hat{u}_t^m \ \hat{u}_t^\bullet) = Y_t - \sum_{s=1}^{p} \hat{\phi}_s Y_{t-s}. \tag{10}$$

Regress the reduced-form residuals that stems from the equation of the variable of interest on the set of instruments:

$$\hat{u}_t^m = \gamma Z_t + \xi_t, \tag{11}$$

and get the fitted values $\tilde{u}_t^m = \hat{\gamma} Z_t$.

II. Second Stage: Regress the reduced-form residuals $\hat{u}_t^\bullet$ stemming from the equations of the $k-1$ other variables $y_t^\bullet$ on the fitted values $\tilde{u}_t^m$ separately:

$$\begin{pmatrix} \hat{u}_t^{\bullet 2} \\ \hat{u}_t^{\bullet 3} \\ \vdots \\ \hat{u}_t^{\bullet k} \end{pmatrix} = \begin{pmatrix} \tilde{u}_t^m & 0 & \cdots & 0 \\ 0 & \tilde{u}_t^m & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \tilde{u}_t^m \end{pmatrix} \begin{pmatrix} \beta^{\bullet 2} \\ \beta^{\bullet 3} \\ \vdots \\ \beta^{\bullet k} \end{pmatrix} + \begin{pmatrix} \eta_t^{\bullet 2} \\ \eta_t^{\bullet 3} \\ \vdots \\ \eta_t^{\bullet k} \end{pmatrix} \tag{12}$$

The column s^m can finally be identify using:

$$\kappa^{-1} s^m = (1 \ \hat{\beta}^{\bullet 2} \ \cdots \ \hat{\beta}^{\bullet k})', \tag{13}$$

where κ is a scaling factor identified up to a sign convention, whose closed solution can be found in Gertler and Karadi (2015, footnote 4).

The system (3) can be finally estimated using the p reduced-form $\hat{\phi}_s$'s, the $((k-1) \times 1)$ vector $\hat{\beta}^\bullet$ and κ, by imposing the corresponding constraints on the first column of B.

Notwithstanding, we are ultimately interested in computing the IRFs resulting from the

VAR(p). Using the lag operator L defined such that $L^p\eta_t = \eta_{t-p}$, Equation (4) is equivalent to

$$(I_k - L\phi_1 - \cdots - L^p\phi_p)Y_t = u_t. \tag{14}$$

Denoting $\Phi(L) = (I_k - L\phi_1 - \cdots - L^p\phi_p)$, and provided the VAR in (4) is stable, we can obtain its infinite-order vector moving average representation

$$Y_t = \Phi(L)^{-1}u_{t-i} = \sum_{i=0}^{\infty}\Gamma_i u_{t-i}, \tag{15}$$

where $\Gamma_0 = I_k$ and $\Gamma_i = \sum_{s=1}^{i}\Gamma_{i-s}\phi_s$ for $i = 1, 2, \ldots$ The notation in (15) is convenient for it enables us to see that the matrices $\Gamma_i = \partial Y_{t+i}/\partial u_t'$ are the IRFs. Indeed, the j, k entry of Γ_i is the response of the j-th element of Y_t after i periods to a one-time unit shock to the k-th element of u_t. Because we identified the first column of B in the previous section, we can get a causal interpretation of the effect of the orthogonalized shock of interest on the whole system through $\partial Y_{t+i}/\partial s^m\varepsilon_t^m$.

Finally, to account for potential conditional heteroskedasticity and avoid any generated regressor problem, we use a recursive-design wild bootstrap procedure to compute confidence intervals (CIs) for the IRFs.

The idea is to draw T independent observations $\{\nu_t\}_{t=1,\ldots,T}$ of a random variable ν_t such that

$$\nu_t = \begin{cases} +1 & \text{with probability } 1/2 \\ -1 & \text{with probability } 1/2 \end{cases} \tag{16}$$

and to recursively generate a pseudo-series Y_t^* according to

$$Y_t^* = \sum_{s=1}^{p}\hat{\phi}_s Y_{t-s}^* + \hat{u}_t\nu_t, \tag{17}$$

where $\hat{\phi}_s$ and $\hat{u}_t$ have been obtained after estimating (4).

Using the pseudo-series of instruments $Z_t^* = Z_t\nu_t$, one can reestimate the SVAR described above N times. The α-level CIs are then simply the $(\alpha/2)$-th and $(1-\alpha/2)$-th percentile of the resulting distribution of bootstrapped IRFs.

3.3 Data

First, we take as the policy rate the 1-year T-Bill rate and instrument it using the target factor previously defined.[7]

Second, to characterize the response of the economy to a monetary policy shock, we include

[7] We thank Jarociński and Karadi (2020) for providing us with the updated series of the target factor. Appendix A describes the data, its sources and availabilty in details.

in our SVAR the log of the consumer price index (logCPI) and the log of the industrial production index (logIP), as in Gertler and Karadi (2015). We add the excess bond premium (EBP) (Gilchrist and Zakrajšek, 2012) to match their specification and to account for the so-called credit channel of monetary policy.

Finally, we include the liquidity premia at maturities ranging from 3 months to 10 years. The liquidity premia are the spreads between Resolution Funding Corporation (Refcorp) bonds yields and Treasury zero-coupon bonds yields. As argued by Longstaff (2002), Refcorp bonds are special because their principal is fully collateralized by Treasury bonds. Thus, Refcorp bonds hold the same credit risk as Treasury bonds. Since Treasury bonds are more liquid, comparing their prices with those of Refcorp bonds provides an ideal way of capturing liquidity premia.

Our dataset comes monthly and goes from June 1991 to May 2019. Note that Gertler and Karadi (2015) use a narrower sample to identify the contemporaneous response of their system to a monetary policy shock than the one on which they impose the resulting constraints. They therefore assume that the instrumental subsample is a representative characterization of the way surprises in monetary policy affect the economy. We do not need to make this assumption because the Refcorp bonds were first issued in 1991.

3.4 Results

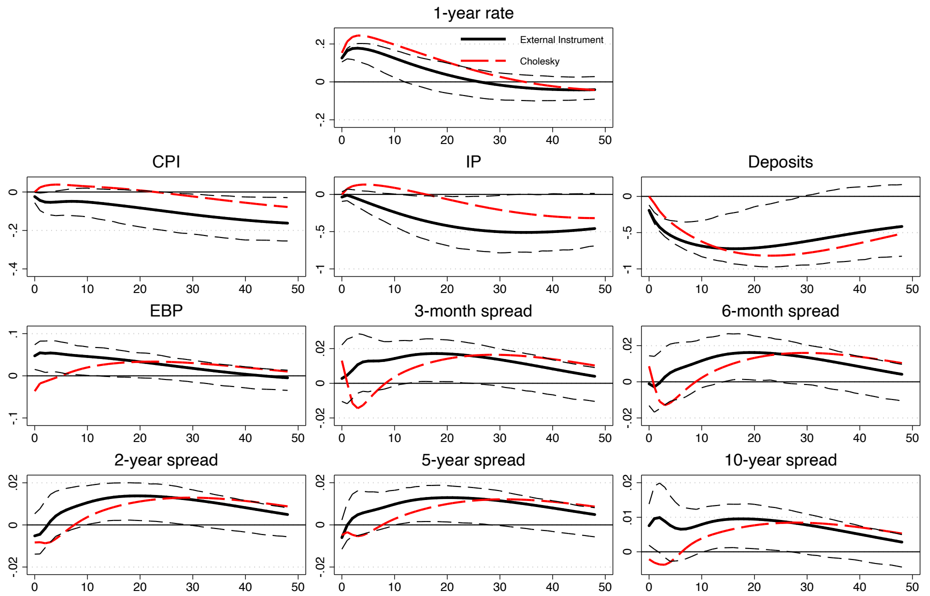
Figure 1 plots the estimated structural IRFs (black solid lines) together with the respective 95 percent boostrapped CIs (black dashed lines). Each subplot therefore shows the response of the above-metionned variable to a one-standard deviation monetary policy shock (i.e., a monetary policy tightening). The red dotted lines show the IRFs stemming from the well known recursive identification, which places the economic variables first (logCPI, logIP), and the financial variables second (1-year rate, liquidity premia). We included the latter to assess the robustness and the advantage of the identification through external instrument.

Focusing on the IRFs obtained through the instrumental approach reveals that a one standard-deviation positive shock to the target factor generates a response of the 1-year rate of about 20 basis points that dies out within two years.[8] This monetary tightening triggers a response of the economy consistent with theory: i) a significant and delayed decline in the CPI level (about 15 bp.), followed by a persistent and significant decline, ii) a significant decrease of output (proxied by industrial production) within a year following the shock, peaking after around two years (about 50 bp.).

Regarding log-deposits, the excess bond premium and liquidity premia, the SVAR estimation corroborates the mechanisms behind both the deposit and the credit channel of monetary policy. First, the significant increase in the EBP (about 50 bp.), echoing Gertler and Karadi (2015), provides evidence that monetary policy tightening deteriorates general credit condi-

[8] Recall that the target factor is rescaled so as to match units with the first monetary policy surprise, mp_t^1.

Figure 1: IRFs to Monetary Policy Shocks



Impulse: 1-year rate. **Instrument:** Target Factor. **First Stage:** F = 17.61, R^2 = 5.04, N = 334.
CIs: Recursive wild bootstrap with 1000 replications, 0.95 level. **Set Up:** 2 lags, 1991.6 - 2019.5.
Cholesky Order: 1y rate, CPI, IP, Deposits, EBP, 3m spread, 6m spread, 2y spread, 5y spread, 10y spread.

Notes: Each subgraph plots the IRF of the variable mentioned above to a one standard deviation surprise monetary policy tightening (solid black line) together with the CIs surrounding it (dashed black lines) and the Cholesky-identified IRF (red dashed line). See below the figure for more details.

tions for up to one year following the shock. Second, the significant long-lasting decrease in log-deposits (about 70 bp. at most) coupled with the significant increase of the liquidity premium at all maturities replicates the mechanism theorized in Drechsler et al. (2018).

When the monetary policy interest rate increases, rates paid on banks' customer deposits do not adjust proportionally. This leads to a decrease in aggregate banks' customer deposits, thus the liquidity value of Treasuries increases. Most importantly, the response of the liquidity premia across maturities are characterized by a decreasing but significant relationship. Indeed, the longer the maturity, the smaller the premium increases, as longer-term Treasuries are less liquid and get discounted more heavily when interest rates rise.

We get a similar general picture if we look at the Cholesky-identified IRFs. It is worth noticing that the shock under study is no more identified using the instrument. It relies on the ad-hoc assumptions that a one-standard deviation positive shock to the Fed funds rate triggers a contemporaneous response of the financial variables included in the SVAR (the EBP and the premia), but that is affects the economy (CPI, industrial production) only with a lag.

One noticeable strength of the instrumental approach is that it eradicates the well-documented price puzzle. Furthermore, it produces a significant response of all the spreads (which would likely be non-significant otherwise). In the Cholesky-identified case, only short-term premia seem to increase on impact following the shock. This corroborates our main result according to which longer-term premia react less to monetary policy.

4 Conclusion

We have estimated the macro dynamic effects of monetary policy on real interest rates through changes in liquidity premia along the yield curve. When the Fed raises interest rates, the spread between less-liquid assets and Treasuries of the same maturity and risk increases, which is significant 1 to 2 years after the policy shock. The longer the maturity, the smaller — but still significant — increase in the spread.

Our empirical results point to the need of explicitly modeling the process of obtaining deposits from liquid assets like Treasuries, to account for the different liquidity premia at different maturities. Moreover, our results should lead to a better understanding of the expectation hypothesis, accounting for the fact that monetary policy affects the term structure through liquidity premia, and of real equilibrium interest rates and exchange rates fluctuations, which are substantially influenced by liquidity premia fluctuations according to recent research.

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A Data

In this appendix we describe the variables used throughout the paper. Table 1 summarizes the source, frequency and timespan of our data.

Liquidity Premia.— Liquidity premia are defined as the difference in yield between two equally risky assets whose liquidity differ. Please note that we take monthly averages of higher frequency data when necessary.

1. Our main measures of liquidity are the spreads between Resolution Funding Corporation (Refcorp) bonds yields and Treasury zero-coupon bonds yields. As argued by Longstaff (2002), Refcorp bonds are special because their principal is fully collateralized by Treasury bonds. Thus, Refcorp bonds hold the same credit risk as Treasury bonds. Since Treasury bonds are more liquid, comparing their prices with those of Refcorp bonds provides an ideal way of capturing liquidity premia.

2. Following Krishnamurthy and Vissing-Jorgensen (2012), we make use of the difference between the Moody's Seasoned Aaa Corporate Bond Yield (mnemonic `AAA`) and the 10-Year Treasury Constant Maturity Rate (`GS10`) both available on the Federal Reserve Bank of St. Louis' FRED database.

3. Alternatively, as suggested by Nagel (2016), we make use of the spread between the 3-Month General Collateral Repurchase Agreement (GC repo) Rate and the 3-Month Treasury Constant Maturity Rate. The former comes from Bloomberg (mnemonic `USRGCGC ICUS Curncy`) and is computed as the middle between the bid and ask rates, and the latter from FRED (`GS3M`).

4. Another measure of the liquidity premium is the spread between on-the-run and off-the-run Treasury securities. The securities we use have a 10-year maturity. See Adrian et al. (2017) for additional details.

Futures Prices.— Daily data on futures prices come from Quandl database. In particular, we take the 30-Day, 2-Month, 3-Month and 4-Month Federal Funds Futures settlement price (mnemonics `CHRIS/CME_FF*`, for `*={1,2,3,4}`). In addition, we use the 6-Month, 9-Month and 12-Month Eurodollar Futures settlement price (`CHRIS/CME_ED*`, for `*={6,9,12}`). These are non-adjusted prices based on spot-month continuous contract calculations, originating from CME. Seldom, missing entries were given their previously known value.

Economic Variables.— Economic variables entering the VAR are monthly and come from the Federal Reserve Bank of St. Louis' FRED database. These are the 1-year Treasury yield (mnemonic `GS1`), the Consumer Price Index (`CPIAUCSL`) and the Industrial Production Index (`INDPRO`).

Table 1: Data Sources, Timespans and Transformations

Variables	Source	Timespan	Frequency
a. Interest Rates			
Effective Federal Funds Rate	`fred.stlouisfed.org`	1954.07–2007.06	Monthly
3-Month General Collateral Repurchase Agreement	`Bloomberg`	1991.06–2019.06	Daily
Moody's Seasoned Aaa Corporate Bond Yield	`fred.stlouisfed.org`	1954.07–2019.06	Monthly
Z-Year Treasury Constant Maturity Rate*	`fred.stlouisfed.org`	1954.07–2019.06	Monthly
Z-year Refcorp bond yield*	`www.quandl.com`	1990.02–2019.06	Daily
b. Futures Prices			
X-Month Federal Funds Futures settlement price†	`www.quandl.com`	1990.02–2019.06	Daily
Y-Month Eurodollar Futures settlement price‡	`www.quandl.com`	1990.02–2019.06	Daily
10-year On-the-run/Off-the-run spread	Adrian et al. (2017)	1991.6–2019.06	Monthly
c. Econ. Variables			
Consumer Price Index	`fred.stlouisfed.org`	1954.07–2019.06	Monthly
Industrial Production Index	`fred.stlouisfed.org`	1954.07–2019.06	Monthly
c. Instrument			
Target Factor (narrower window)	Jarociński and Karadi (2020)	1990.1–2019.06	Monthly

Notes: At maturities: $^*X = \{0.25, 0.5, 1, 2, 5, 10\}$, $^\dagger X = \{1, 2, 3, 4\}$, and $^\ddagger Y = \{6, 9, 12\}$.

B Methodology

In this appendix, we provide additional details regarding the methodology. We expose how we formally extract changes in expectations about future monetary policy using futures daily data, and how we rotate the resulting factors into interpretable dimensions of the Fed's conduct of its monetary policy.

Identifying Expectations Shocks.— Let us denote by $ff^1_{t-\Delta t}$ the settlement rate implied by the Fed funds rate futures contract expiring within the month, Δt days before a scheduled FOMC announcement. By construction of the futures contracts, which pay off according to the average effective Fed funds rate prevailing over the agreed-upon month, $ff^1_{t-\Delta t}$ partly reflects the rate realized so far in that month, r_0, and the expected rate to prevail until the end thereof, r_1. Accordingly, denoting d^1 the day of the month on which an FOMC meeting will take place, and D^1 the number of days in that same month, we have:

$$ff^1_{t-\Delta t} = \frac{d^1}{D^1} r_0 + \frac{D^1 - d^1}{D^1} E_{t-\Delta t}[r_1] + \rho^1_{t-\Delta t}, \tag{18}$$

where ρ^1 accounts for any (risk, term or liquidity) premium present in the contract. Assuming that there is no systematic change in the premium ρ^1 within an FOMC announcement day, the surprise associated with a change in the Fed funds target rate, $E_t[r_1] - E_{t-1}[r_1]$, is

$$mp^1_t = \frac{D^1}{D^1 - d^1}(ff^1_t - ff^1_{t-1}). \tag{19}$$

Similarly, one can measure the change in expectation, mp^2_t, about the rate that will prevail after the next FOMC meeting, r_2, by examining the futures of corresponding maturity. Because there are eight scheduled meetings per year, the next meeting arises within the next two months.[9] Denoting by m the number of months separating the current meeting from the next, it follows that

$$ff^{1+m}_{t-\Delta t} = \frac{d^{1+m}}{D^{1+m}} E_{t-\Delta t}[r_1] + \frac{D^{1+m} - d^{1+m}}{D^{1+m}} E_{t-\Delta t}[r_2] + \rho^{1+m}_{t-\Delta t}, \tag{20}$$

where the superscript i in $ff^i_{t-\Delta t}$ indicates the number of months from $t - \Delta t$ within which the futures is due. The change in expectation is therefore characterized by

$$mp^2_t = \frac{D^{1+m}}{D^{1+m} - d^{1+m}} \left[(ff^{1+m}_t - ff^{1+m}_{t-1}) - \frac{d^{1+m}}{D^{1+m}} mp^1_t \right]. \tag{21}$$

There are two particular cases one needs to account for. First, when a meeting happens late in the month, the weight given to the surprise is relatively big. To prevent from the potential

[9]As in **?**, we assume unscheduled meetings to be expected as happening with zero probability.

noise in the data to affect our measurement, when a meeting occurs within the last seven days of the month, we take the unweighted change in next month's futures price as the monetary policy surprise. Second, for meetings taking place on the first day of a month, we make use of the unweighted price-difference between the Fed funds futures rate due in the month of the meeting and the one which is due in the previous month.

Finally, for the remaining contracts, namely the 6-, 9- and 12-month Eurodollar futures (whose price is denoted by ed_t^i), one can directly take the daily return as the surprise itself due to their spot settlement nature. Thus, for $j = 4, 5, 6$ and $i = 6, 9, 12$ respectively, we have

$$mp^j = ed_t^i - ed_{t-1}^i. \tag{22}$$

Rotation of the Factors.— As in Gürkaynak et al. (2004), we rotate F_1 and F_2 to obtain Z_1 and Z_2. Namely, we define

$$Z = FU, \tag{23}$$

where

$$U = \begin{bmatrix} u_{11} & u_{12} \\ u_{21} & u_{22} \end{bmatrix}', \tag{24}$$

such that U is a (2×2) orthogonal matrix, with Z_2 being associated, on average, with no change in the Fed funds futures rate for the current month. The orthogonality between Z_1 and Z_2 requires

$$E(Z_1 Z_2) = u_{11}u_{12} + u_{21}u_{22} = 0. \tag{25}$$

Then, knowing that

$$F_1 = \frac{u_{22}Z_1 - u_{12}Z_2}{u_{11}u_{22} - u_{12}u_{21}}, \tag{26}$$

$$F_2 = \frac{u_{21}Z_1 - u_{11}Z_2}{u_{12}u_{21} - u_{11}u_{22}}, \tag{27}$$

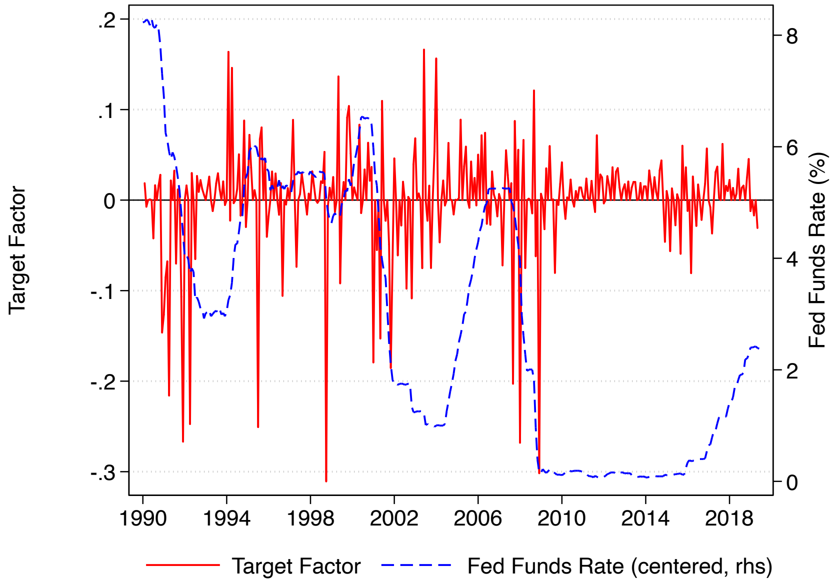
we can assume that Z_2 has no impact on mp^1 by imposing the final restriction

$$\lambda_2 u_{11} - \lambda_1 u_{12} = 0, \tag{28}$$

where λ_1 and λ_2 are the loadings on mp^1 of F_1 and F_2 respectively. To recover an interpretation as to the magnitude of these factors, we rescale Z_1 (Z_2) to match its units with mp^1 (mp^4). The rotation matrix U is obtained by solving the last four equations.

In the words of Gürkaynak et al. (2004), this rotation allows us to see Z_1 and Z_2 respectively as the *target* factor and the *path* factor. This is because Z_1 is defined such as to drive surprises in the current target rate on FOMC announcement days, while Z_2 reflects everything (unrelated to the Fed funds target rate) that causes changes to expectations of future monetary policy.

Figure 2: Cumulated Series of Monetary Policy Shocks and Fed Funds Rate



Notes: The figure plots the Fed Funds rate (dashed line, centered around zero) and the cumulated series of shocks to expectations about monetary policy around FOMC announcement days identified as the Target Factor (solid line). The latter is the instrument we use for the 1-year rate in the monthly SVAR.

Aggregating the Shocks.— The last step before introducing our empirical model requires that we aggregate the monetary policy surprises into a monthly series of shocks that will ultimately serve our specification as an instrument.

Monetary policy announcements do not always occur on the exact same day of the month. As argued in Gertler and Karadi (2015), a shock happening at the beginning (say, on the first day) of a month will have a larger effect on that month than a shock happening relatively later. Accordingly, shocks happening at the end (say, on the last day) of a month will have little impact on that month, but are likely to impact next month as well.

One may want to account for this possibility, and that can be done simply by: i) cumulating the shocks over the entire time window, ii) taking monthly averages of the cumulated series, iii) first-differencing the resulting series to get the monthly average surprises.

Figure 2 plots the series stemming from this aggregation of the Target Factor Z_1 (solid red line) on the left-hand scale, together with the Fed funds rate (red dashed line) on the right-hand scale. The latter has been centered around zero for comparability with the monetary policy shocks series. By construction, the factor series cumulates monetary policy surprises that relate to the target of the central bank. This explains why the effective funds rate appears to be driven by the monetary policy surprises. Recall that these surprises were identified in such way as to ensure they were exogenously driven by changes in the expectations about the future target rate.