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INTEREST RATE SPREADS AND FORWARD GUIDANCE

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Abstract

Announcements of future monetary policy rate changes have been found to be imperfectly passed through to various interest rates. We provide evidence for rates of return on less liquid assets to respond by less than, e.g., treasury rates to forward guidance announcements of the US Federal Reserve, suggesting that single-interest-rate models tend to overestimate their macroeconomics effects. We apply a macroeconomic model with interest rate spreads stemming from differential pledgeability of assets, implying that assets provide liquidity services to different extents. Consistent with empirical evidence, announcements of future reductions in the policy rate lead to an increase in liquidity premia. The output effects of forward guidance do not increase with length of the guidance period and are substantially less pronounced than they are predicted to be by a standard New Keynesian model. We thereby provide a solution to the so-called "forward guidance puzzle".

JEL classification: E32, E42, E52
Key words: Forward guidance; Unconventional monetary policy; Liquidity premium

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1 Introduction

Ever since the financial crisis of 2007-2009 and monetary policy rates close to zero, forward guidance – the communication of central banks about the likely future course of their policy stance – has gained considerable importance for the conduct of monetary policy by major central banks, including the US Federal Reserve and the European Central Bank. This way of expectations management aims at steering longer-term interest rates, e.g., a flattening of the yield curve, by providing guidance about future real short-term interest rates. Based on the New Keynesian paradigm, this should stimulate aggregate demand today and may even break deflationary spirals at zero interest rates (see, e.g., Eggertsson and Woodford (2003)). Recent empirical studies, however, emphasize that New Keynesian models massively overstate the effects of forward guidance announcements,[1] which has led Del Negro et al. (2015) to coin this the "forward guidance puzzle".[2]

In this paper, we show that the puzzle is solved when the effects of forward guidance on interest rates that are actually more relevant for private sector consumption and investment decisions than the monetary policy rate are taken into account. Our analysis is motivated by the empirical observation that interest rates on various assets respond to forward guidance announcements in a substantially different way. For example, Del Negro et al. (2015) examine asset price effects around forward guidance announcements by the Federal Open Market Committee (FOMC) at three dates in 2011 and 2012 with an explicit calendar-based forward guidance. At these dates, the press releases state that the federal funds rate stays at low levels at least through a period of 2 or 3 years ahead (see Appendix A.1 for details). Extending the list of asset prices examined by Del Negro et al. (2015), Table 1 present changes in asset prices in a one-day window around the three FOMC dates (as in Krishnamurthy and Vissing-Jorgensen (2011)). While the magnitude of the announcement effects varies between dates due to expectations and economic conditions, the columns 2-4 shows that treasury yields fall at all dates. As also found by Del Negro et al. (2015), corporate bond yields (see columns 5-8) tend to fall by less compared to yields of treasuries with the same maturity (and might even rise), implying that the corporate-treasury spreads unambiguously increase.[3] Since the underlying assets mainly differ by liquidity, but are similar in terms of safety, as argued by Krishnamurthy and Vissing-Jorgensen (2012), forward guidance seems to alter liquidity premia.[4] Given that borrowing and saving decisions are typically related to interest rates on less liquid assets, the observation that these interest rates respond to a smaller extent than treasury rates is indica-

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[1]See, for example, Del Negro et al. (2015), Carlstrom et al. (2015), or Kiley (2016).

[2]Several contributions, for instance McKay et al. (2016) or Del Negro et al. (2015), have already addressed this puzzle.

[3]The forward guidance announcement on 2012-09-13 seems to have been anticipated by market participants. In our econometric analysis in Section 2 that focusses on the identification of unanticipated effects of forward guidance, we do not observe a clear reduction in futures rates, which we do for the first two dates. Accordingly, interest-rate changes were less pronounced on this date compared to the other two dates.

[4]Similar findings are reported by Campbell et al. (2012) on the effect of forward guidance in the period from 2007 to 2011.

Table 1: One-Day Changes of Asset Returns and Spreads

Dates	Treasuries			Corporate Bonds			
	3Y	5Y	10Y	3Y	5Y	10Y(A)	10Y(B)
2011-08-09	-12	-20	-20	-2	-11	-9	-7
2012-01-25	-5	-11	-7	-3	-5	1	-1
2012-09-13	-1	-5	-2	-2	-1	3	11

Notes: Table shows absolute changes of asset returns in a one-day window around selected FOMC announcement (end-of-day minus day before). All numbers are given in basis points rounded to integers. Maturity is measured either years (Y). Corporate Bond 10Y(A) and (B) refer to long-term bonds with AAA and BAA rating, respectively.

tive for forward guidance to be less effective than suggested by New Keynesian models without a liquidity premium.

In the first part of the paper, we present an econometric analysis revealing that liquidity premia rise systematically in response to stimulative forward guidance announcements. We apply the method of Gürkaynak et al. (2005) to extract a surprise component in the announcements of FOMC meetings between 1990 and 2016,[5] and examine how measures of liquidity premia, which have been suggested in the literature, respond to the changes in the anticipated future paths of the monetary policy instrument. Decomposing policy announcements into a target factor and a path factor, we find that changes in these two factors affect interest rates in different ways and, in particular, that a stimulative forward guidance shock increases interest rate spreads that are suggested as measures for liquidity premia by Krishnamurthy and Vissing-Jorgensen (2012) and Nagel (2016). Furthermore, we construct a common liquidity factor, as Del Negro et al. (2017), and find that it increases as well.

Based on this empirical evidence, the second part of the paper presents a macroeconomic model that rationalizes the increase of liquidity premia after stimulative central bank announcements. We show that this separation of the policy rate from interest rates on stores of wealth substantially weakens the GDP response to these announcements, providing a straightforward solution to the forward guidance puzzle. To this end, we introduce an endogenous liquidity premium to a New Keynesian model by accounting for differential pledgeability of assets, as in Schabert (2015) and Williamson (2016). To understand why forward guidance is so powerful in New Keynesian models without liquidity premia, recall that current consumption depends on all expected future real monetary policy rates in these models. For given inflation expectations, an anticipated reduction of the short-term nominal policy rate for one single period in, say, k periods ahead will, therefore, increase consumption in all k periods before the interest rate change actually takes place, while the impact effect is – counterfactually – predicted

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[5]This method has widely been used to analyse the effects of monetary policy and forward guidance on financial markets and has for instance, also been applied by Campbell et al. (2012), Swanson (2017), and Gertler and Karadi (2015). Our results are qualitatively unchanged when we consider a sample ending in 2008, i.e., a sample exluding the recent zero lower bound episode.

to grow with the horizon (larger k). A central assumption for this effectiveness of monetary policy announcements is that interest rates that are relevant for private agents' intertemporal choices move – up to first order – by one-for-one with the monetary policy rate. This however neglects the empirical observation that other interest rates, which are more relevant for private-sector transactions than the federal funds rate are separated by spreads that might change endogenously with the state of the economy and with monetary policy (see Krishnamurthy and Vissing-Jorgensen (2012) and Nagel (2016)).

By contrast, our model with a liquidity premium allows the policy rate set by the central bank to differ from other interest rates. We incorporate a stylized banking sector in a New Keynesian model with an explicit specification of central bank operations. Banks are required to hold reserves from the central bank to meet the liquidity demands of their depositors. Reserves can only be obtained in open market operations against assets that are eligible to serve as collateral (i.e., Treasury bills), where the central bank controls the price of money by setting the policy rate.[6] Thus, returns on eligible assets closely follow the policy rate, whereas interest rates on non-eligible assets (such as corporate debt) tend to be higher due to an (il-)liquidity premium. Due to the rate-of-return dominance, the latter assets serve as agents' preferred store of wealth, such that interest rates on less liquid (non-eligible) assets rather than the monetary policy rate affect agents' saving and consumption choices. Due to this separation of interest rates, the changes in aggregate demand effects that a reduction in the monetary policy rate induces via intertemporal substitution tend to be less pronounced compared to the case where endogenous changes in the liquidity premium are neglected and intertemporal substitution is governed by the monetary policy rate (as in standard New Keynesian models).[7]

We show analytically that a typical forward guidance scenario, i.e., a reduction of the current policy rate accompanied with an announcement to keep future policy rates low, leads to a rise in the liquidity premium and moderate increases in output and inflation. We decompose these effects into the ones of the reduction in the current policy rate and of the announcement of low future interest rates, where in both cases the reaction of liquidity premia is key for understanding the effects and is consistent with our empirical evidence. First, the reduction in the current policy rate in isolation has conventional expansionary effects, as it leads to a surge in aggregate demand and, thus, in inflation. While the real (and also the nominal) interest rate on less liquid assets tend to decrease to clear the market for commodities when contemporaneous consumption increases, this effect is – for plausible values of the elasticity of intertemporal substitution – less pronounced than the reduction in the policy rate, such that the liquidity premium increases. Second, the announcement to reduce the future policy rate

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[6]While we abstract from an interbank market for federal funds, the model features a federal reserve treasury repo rate. We consider the latter as the policy rate, which is supported by the observation that it hardly differs from the federal funds rate, see, e.g., Bech and Stebunovs (2012).

[7]This mechanism has also been applied by Bredemeier et al. (2017) to explain the seemingly puzzling observation of moderate fiscal multiplier even when government expenditures are accompanied by an accommodative monetary policy.

implies that the central bank will increase the amount of money supplied per eligible asset in the future, implying that future output is stimulated and that the liquidity value of these assets rises already today. In contrast, the valuation of non-eligible assets is not directly affected by the policy announcement, such that agents' demand for these assets fall, which tends to reduce their prices. As a consequence, their interest rates increase (while the current policy rate is unchanged), such that the interest rate spread between non-eligible and eligible assets widens and the immediate response of aggregate demand to forward guidance is dampened.

In a quantitative analysis, we calibrate our model for US data, in particular, to quantitatively match the response of the liquidity premium to an isolated forward guidance announcement as found in our econometric analysis. We then study further macroeconomic effects of announcements by the central bank to keep the monetary policy rate 25 basis points below steady state for one or two years, respectively. We find that such an announcement triggers output to increase by about 0.1 percent relative to its steady state value from the time of the announcement until the policy rate is raised again. Compared to the prediction of our model with a liquidity premium, we find the immediate output effects of the four-quarter forward guidance in a model version without the liquidity premium, which corresponds to a standard New Keynesian model, to be ten times larger. Moreover, the length of the guidance period hardly affects the impact output response, which again clearly differs from the prediction of a model version without liquidity premia. Notably, effects of conventional (unanticipated) monetary policy shocks do not substantially differ between the model versions with and without the liquidity premium. Overall, our analysis shows that a New Keynesian model without a liquidity premium vastly overestimates the output effects of forward guidance. By contrast, in our model with an endogenous liquidity premium, the quantitative predictions align well with empirical evidence. Specifically, Gertler and Karadi (2015) find that forward guidance has moderate and only delayed expansionary output effects, while the length of the guidance period hardly has any effect.

Our paper relates to several empirical studies. The econometric analysis applied in this paper is based on the approach of Gürkaynak et al. (2005), who analyze the effects of US monetary policy on asset prices using high-frequency data and show that forward guidance is capable of affecting bond yields and stock prices. Campbell et al. (2012) and Campbell et al. (2016) extend this analysis to further assets and also to private sector forecasts of inflation and unemployment. While Campbell et al. (2012) find counterintuitive reactions of private sector expectations (for instance, unemployment expectations rise after an announced interest rate reduction), the findings of Campbell et al. (2016) are qualitatively consistent with predictions of the basic New Keynesian model. Quantitatively, though, the effects are considerably weaker than predicted by the New Keynesian model. Del Negro et al. (2015) also analyze the effects of forward guidance on forecasts and find that an announced 15 basis point decrease in short-term rates in 4 quarters leads to increases in GDP growth forecasts by about 0.3 percentage points.

Gertler and Karadi (2015) analyze the effects of monetary policy shocks using a high-frequency identification procedure in a VAR that includes quarterly US data on real activity and various financial variables. Some of their results are suggestive for effects of forward guidance, which seem, however, to be quantitatively limited. Bundick and Smith (2016) examine zero lower bound episodes and apply a high-frequency identification of forward guidance changes in futures contracts, which they use as shocks in a VAR with monthly data. D'Amico and King (2015) identify forward guidance shocks in their VAR based on sign restrictions. All of these papers find that forward guidance about future interest rate reductions tend to lead to moderate and gradual, rather than strong and sudden, increases in output and inflation that peak after a few quarters. These effects are consistent with the results of our quantitative analysis, but not with a standard New Keynesian model that predicts the effect to be much stronger and to peak immediately at the announcement.

Our paper further relates to theoretical studies that address the effects of forward guidance on macroeconomic outcomes. Del Negro et al. (2015) address the excess response to policy announcements in the New Keynesian model by introducing a perpetual youth structure, which leads to a higher discounting of future events and thereby reduces current responses. McKay et al. (2016, 2017) show that the effects of forward guidance are much more limited in a model with heterogeneous agents that face the risk of hitting a borrowing constraint. A further set of papers by Carlstrom et al. (2015), Kiley (2016), and Chung et al. (2015) demonstrate that the effects are dampened when firms are subject to sticky information instead of a direct sticky price friction, as this confines the forward-lookingness of the Phillips curve. Relatedly, Wiederholt (2015) shows that forward guidance has limited effects in a model where households have dispersed inflation expectations. Campbell et al. (2016) differentiate between Delphic and Odyssean forward guidance and find that the predictions of their medium scale model, in which government bond holdings provide direct utility, do not reflect the forward guidance puzzle. Caballero and Farhi (2017) construct a model where the economy is pushed to the zero lower bound because of a shortage of safe assets. In their model, forward guidance does not foster recovery, but only leads to increases in risk premia in their setting, which relates to the rise in liquidity premia implied by our model. A liquidity premium stemming from eligibility of certain assets in open market operations (which we apply for the analysis of forward guidance effects) has been shown by Linnemann and Schabert (2015) and Bredemeier et al. (2017) to explain the observed delayed overshooting of exchange rates and to reconcile theory and evidence on the role of monetary policy for the fiscal multiplier, respectively.

The remainder of the paper is structured as follows. Section 2 provides empirical evidence on the response of liquidity premia on monetary policy announcements. Section 3 presents the model. We derive analytical results on forward guidance effects for a simplified version and present impulse responses for a calibrated version of the model in Section 4. A conclusion is given in Section 5.

2 Empirical Effects of Forward Guidance on Liquidity Premia

In this section, we document empirically that liquidity premia on near-money assets tend to rise in response to forward guidance announcements that financial markets consider to be accommodative. We explain how we measure the value of liquidity services of near-money assets in the data in Section 2.1. In Section 2.2, we provide an analysis of asset returns and interest rate spreads at all FOMC meeting dates between 1990 and 2016 using the approach of Gürkaynak et al. (2005). This method allows to separate the effects of unanticipated forward guidance announcements from those of simultaneously announced changes in other monetary policy instruments, such as the current federal funds rate or asset purchase programmes. We apply this approach to identify the response of liquidity premia to forward guidance.

2.1 Measurement of Liquidity Premia

We use various market-based measures of the value of liquidity services of near-money assets by calculating interest rate spreads between assets that differ in the degree of liquidity in financial markets, but feature similar characteristics in terms of safety and maturity. In this way, we rule out that movements in the spreads are mainly determined by differences in credit risk or term premia. As the measure for highly liquid near-money assets, we use US Treasuries at various maturities. Those can be seen as close substitutes for money as, typically, Treasuries are allowed to serve as collateral for obtaining liquidity from the Federal Reserve system. The less liquid assets that we consider were suggested and applied for this purpose in the related literature.

Specifically, we use the following spreads as measures of liquidity premia. Krishnamurthy and Vissing-Jorgensen (2012) state that the spread between high rated corporate bonds and Treasuries is primarily driven by liquidity. We therefore use the spreads between high rated commercial papers and corporate bonds with maturities of 3 months and 3, 5, and 10 years on the one hand and Treasuries of the same maturities on the other hand. As some credit risk may remain even in very high rated corporate bonds, we also follow Krishnamurthy and Vissing-Jorgensen (2012) in using spreads between relatively illiquid certificates of deposit (CD), which are very safe due to coverage by the Federal Deposit Insurance Corporation (FDIC), and Treasury bills at maturities of 3 and 6 months. Finally, we use the spread between the rate on 3-month general collateral repurchase agreements (GC repos, hereafter) and the 3-month T-bill rate. Nagel (2016) considers this spread to be a particularly clean measure of the value of liquidity, as the repos are secured by collateralization. We end up with 8 different spreads, for which we collect daily data with observations ranging from January 1990 to September 2016. A detailed description of the data set and the construction of the spreads is given Section A.2 of the appendix.

We acknowledge that these spreads also contain a small noise component, for instance due to small remaining differences in credit risk or additional safety attributes of Treasuries as

discussed by Krishnamurthy and Vissing-Jorgensen (2012). We therefore follow Del Negro et al. (2017) and construct a factor model with all spreads to extract their common component over time, which can be interpreted as a purified liquidity premium. This further yields the advantage of having one single summary measure for the value of liquidity. We calculate the liquidity factor for a sample from 1990-01-02 to 2016-09-16 using principle component analysis. To account for missing values in our data, we employ a method by Stock and Watson (2002) that relies on an expectation maximization algorithm.[8] To give the resulting factor f_t a quantitative interpretation as a measure of the liquidity premium in basis points, we assume that f_t is related to the liquidity premium LP_t by

$$LP_t = a + bf_t, \tag{1}$$

where a and b are unknown parameters. We apply the same assumptions as Del Negro et al. (2017) to obtain values for a and b. First, we assume that the average value of the liquidity premium before the outbreak of the financial crisis in July, 2007 equals 46 basis points. This number is a long-run estimate for the liquidity value of Treasuries by Krishnamurthy and Vissing-Jorgensen (2012) for a sample from 1926 to 2008. Second, Del Negro et al. (2017) argue that the asset in their sample with the highest spread to Treasuries at the peak of the crisis (a BBB rated bond, whose credit risk is hedged by a credit default swap) was essentially illiquid. The average size of this spread of 342 basis points in the last quarter of 2008 therefore gives a value for the liquidity premium at this time. Using these two assumptions, we can construct a daily time series for the liquidity premium in equation (1) that we plot in Figure 5 in the Appendix. The mean value of the liquidity premium in the figure reads 54 basis points with a standard deviation of 49 basis points (see also Table 4 in the Appendix). For a very short period at the height of the financial crisis, the premium rises up to values of about 450 basis points.[9] There are only a few days with a negative value for the liquidity premium in the whole sample of over 16 years, all of which occur in the first years of the 1990s. Figure 6 in the Appendix provides time series plots of all individual liquidity spreads along with a linear projection of the common factor and a constant on each spread. They show that the common liquidity factor captures a large part of the variation for the majority of the series.

2.2 Regression Analysis

We now analyze the effect of forward guidance on the valuation of liquidity in financial markets using the approach of Gürkaynak et al. (2005). This approach takes into account the following points. First, forward guidance announcements are usually given simultaneously with announcements about the federal funds rate or – at least in the years following the financial

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[8]As a robustness check for our treatment of missing values, we also calculated the common factor for the maximum balanced sample of our data, which ranges from 1997-01-02 to 2013-06-28. We find that the common factor is very similar to the one estimated on the whole data set.

[9]The focus of the analysis by Del Negro et al. (2017) lies on this episode in the end of 2008 as well as its aftermath.

crisis – asset purchases, which requires to separate the individual effects. Second, since financial markets are forward looking, only unanticipated components of the policy changes should matter for market interest rates and spreads and hence those components need to be identified. Anticipated policy actions should already be priced into the markets ex ante, therefore leading to only limited reactions after publication. Ignoring this may mislead to concluding that a policy had no effect. Related to this issue, a by words accommodative policy announcement can actually have negative effects on markets when the press release was interpreted as bad news for the economy. Finally, the Federal Reserve can affect markets by refraining from taking action in a situation, where a policy adjustment was expected –, i.e., also reactions on the non-appearance of a forward guidance announcement can be informative for the effects of forward guidance if such announcement had been expected by market participants. The method by Gürkaynak et al. (2005) addresses all of these identification issues and it allows to quantify the content of forward guidance announcements. We extend their analysis to the time period from January 1990 to September 2016 and to different types of assets and liquidity spreads.

The method extracts the surprise component of forward guidance announcements by looking at the changes in futures rates around FOMC meetings. Gürkaynak et al. (2005) show, based on work by Kuttner (2001), how federal funds and Eurodollar futures data can be used for this purpose. After constructing such monetary surprise measures for futures with maturities between 1 and 12 months, we extract their first two principle components. A transformation of these two factors allows us to give them a structural interpretation. Following the terminology of Gürkaynak et al. (2005), we denote the first one as the "target factor", which measures the unanticipated change in the current federal funds rate, and the second one as the "path factor", which measures the unanticipated change of expectations about the path of the federal funds rate.[10] The path factor can be interpreted as a quantitative measure of forward guidance. In a last step, we regress the change of asset returns and our liquidity measures on the target and the path factor to study the effects of forward guidance.

In detail, we collect daily data on federal funds futures that expire in the current and the next 3 months as well as Eurodollar futures with maturities of 6, 9 and 12 months around all FOMC meetings between January 1990 and September 2016.[11] Federal Funds futures settle at a rate that is calculated as the average daily effective federal funds rate for the delivery month. Changes of the current month futures rate will then reflect adjustments in the expectations of market participants about the federal funds rate in the rest of the month, while changes in futures rates with longer maturities reflect expectation adjustments about the federal funds

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[10]Swanson (2017) also uses the approach by Gürkaynak et al. (2005), but estimates three factors, giving the third one the interpretation to capture changes in asset purchase programmes. We also address the separate effect of quantatitive easing policies in our analysis, though in a different way.

[11]Gürkaynak et al. (2005) use intraday data with windows of 30 minutes around the FOMC meetings, which is not available to us. Using data at this high frequencies reduces the risk of endogeneity problems that can occur when other news of importance to financial markets are released at the day of the meeting. They show, however, that all of their results are highly robust to the usage of daily data.

rate in the month when the contract expires. In Appendix A.3, we provide details on the futures data and we show how rate changes at FOMC dates need to be scaled with respect to the day of the month at which the meeting takes place, in order to extract the surprise component of the FOMC press release for current and future monetary policy. We follow the related literature to use Eurodollar instead of federal funds futures for maturities of more than 6 months, as Gürkaynak et al. (2007) show that Eurodollar futures provide a better measure of market expectations about future federal funds rates at those longer horizons.

We compile the surprise changes of the various futures in a matrix X of size $[T \times v]$, where T denotes the number of FOMC dates and v the number of different futures. Our sample covers $T = 237$ FOMC dates in total and we use $v = 5$ futures with maturities of 1, 3, 6, 9, and 12 months. Each row of X measures the expectation changes about monetary policy between the end-of-day value at the FOMC meeting date and the end-of-day value at the day before for the v futures. We then assume that X can be described by a factor model of the form

$$X = F\Lambda + \epsilon, \tag{2}$$

where F is a $[T \times f]$ matrix of $f < v$ unobserved factors, Λ is a $[f \times v]$ matrix of factor loadings, and ϵ a $[T \times v]$ matrix of white noise. Using the same selection of futures, Gürkaynak et al. (2005) show that X is appropriately described by 2 factors. We therefore set $f = 2$ and, after demeaning and standardizing X, estimate two factors in F, named F_1 and F_2, by principle component analysis. Without further transformation, the factors F are a statistical decomposition that explains a maximal fraction of the variance of X, but they lack an economic interpretation. In order to give F a meaningful interpretation, we follow Gürkaynak et al. (2005) and rotate it according to

$$\widetilde{F} = FU, \tag{3}$$

where U is a $[2 \times 2]$ matrix, to obtain two new factors $\widetilde{F}_1$ and $\widetilde{F}_2$. In line with Gürkaynak et al. (2005), the elements of U are chosen such that the columns of $\widetilde{F}$ remain orthogonal to each other and that the second factor, $\widetilde{F}_2$, has no effect on the current federal funds rate.[12] This rotation implies that the unexpected change of the current target of the federal funds rate is tightly linked to $\widetilde{F}_1$, while $\widetilde{F}_2$ covers all other aspects of FOMC announcements that change the expectations about the path of the federal funds rate in the next 12 months. Following Gürkaynak et al. (2005), we name $\widetilde{F}_1$ the target factor and $\widetilde{F}_2$ the path factor, where the latter constitutes our quantitative measure of forward guidance shocks after FOMC meetings. We find the correlation between $\widetilde{F}_1$ and the first column of X, which measures the surprises in the current federal funds rate target, to be 0.93.[13] To allow for an interpretation in basis points, we normalize the elements of $\widetilde{F}$ as in Campbell et al. (2012), such that an increase of 0.01 in

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[12]Details on this transformation are given in Appendix A.3.

[13]Notably, Gürkaynak et al. (2005), who apply a different sample period. report the almost identical value of 0.95.

$\widetilde{F}_1$ corresponds to a surprise change of 1 basis point in the federal funds target and that an increase of 0.01 in $\widetilde{F}_2$ corresponds to a surprise change of 1 basis point in the 12-months-ahead Eurodollar futures rate.[14]

We now estimate the effect of the target and the path factor on the change of the asset returns and liquidity spreads with the regression model

$$\Delta y_t = \beta_0 + \beta_1 \widetilde{F}_{1,t} + \beta_2 \widetilde{F}_{2,t} + \beta_3 qe_t + e_t, \tag{4}$$

where Δy_t is the one-day change of an asset return or spread around the FOMC meeting at time $t \in T$, β_0 is a constant, β_1 and β_2 are the coefficients on target and path factor, respectively, and e_t is an error term. β_3 is the coefficient on the dummy variable qe_t, which takes a value of 1 at FOMC meetings with important decisions regarding quantitative easing.[15] This variable ensures that our results are not driven by these events, which were shown, e.g., by Krishnamurthy and Vissing-Jorgensen (2011), to have affected financial markets considerably.

Results for asset returns are given in Table 2. The first row shows the effect of a change in the current federal funds rate, as measured by the target factor, while the second row shows the effect of a change in forward guidance, as measured by the path factor. The coefficients can be interpreted in the following way. As an example, the return on the 1 year Treasury increases by 0.62% to a 1% increase of the target factor (which measures a 1% surprise increase of the current federal funds rate) and by 0.28% to a 1% increase of the path factor (which implies a 1% surprise interest rate increase in one year). For the Treasuries and the corporate bonds, the effect of changes in the current federal funds rate is very strong and highly significant for short maturities, but becomes smaller as the term to maturity increases. The opposite holds true for the effect of changes in forward guidance. Coefficients are relatively small for maturities below one year and then evolve in a hump-shaped way over longer horizons with a peak at 5 years of remaining maturity. These results are in line with previous findings by Gürkaynak et al. (2005), Campbell et al. (2012), and Swanson (2017).[16] The explanatory power of the regressions, as measured by the R^2 statistic, also evolves in a hump-shaped way with especially high values of about 0.80 in case of the Treasuries with longer maturities. The certificates of deposit and the GC repo react to the target factor in a similar fashion as the short-run commercial paper rate, while the response to the path factor is relatively small and mostly

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[14] Given our estimate of the path factor, we can now rationalize our findings for the three dates discussed in the introduction. On 2011-08-09, the path factor assumes a value equivalent to a -2.3 standard deviation innovation, while the values on 2012-01-25 and 2012-09-13 read -1 and -0.4 standard deviations. This indicates that the forward guidance given on the first date was the least expected announcement of the three and thereby explains the relatively large response of asset returns and spreads on that date.

[15] The variable qe_t takes a value of 1 at the following 6 dates. 2009-03-18: Announcement of QE1. 2010-11-03: Announcement of QE2. 2011-09-21: Announcement of "Operation Twist" 2012-09-13: Announcement of QE3. 2012-12-12: Announcement of additional long-term Treasury purchases. 2013-12-18: Begin to taper asset purchases.

[16] The absolute size of the coefficients can, however, not be compared one-to-one with all papers of the related literature due to differing unit normalizations of $\widetilde{F}_1$ and $\widetilde{F}_2$.

Table 2: Response of Asset Returns to Changes in Monetary Policy

	Treasuries					GC
	3M	1Y	3Y	5Y	10Y	3M
Change in Federal Funds Rate $\widetilde{F}_1$	0.65***	0.62***	0.33***	0.19***	0.028	0.31***
	(0.079)	(0.065)	(0.043)	(0.037)	(0.037)	(0.077)
Change in Forward Guidance $\widetilde{F}_2$	0.16***	0.38***	0.69***	0.79***	0.70***	0.0087
	(0.041)	(0.041)	(0.058)	(0.058)	(0.054)	(0.038)
R^2	0.54	0.76	0.81	0.84	0.77	0.23
Number of Observations T	237	237	237	237	237	213
	Commercial Paper / Corporate Bonds					CD
	3M	3Y	5Y	10Y(A)	10Y(B)	3M
Change in Federal Funds Rate $\widetilde{F}_1$	0.27**	0.38***	0.15**	-0.025	-0.0037	0.38***
	(0.11)	(0.11)	(0.060)	(0.040)	(0.031)	(0.14)
Change in Forward Guidance $\widetilde{F}_2$	0.034	0.52***	0.58***	0.39***	0.39***	0.15*
	(0.069)	(0.083)	(0.070)	(0.038)	(0.037)	(0.077)
R^2	0.10	0.43	0.65	0.50	0.50	0.22
Number of Observations T	122	165	165	237	237	212

Notes: Table shows responses of asset returns to changes in the federal funds rate, measured by the target factor, and to changes in forward guidance, measured by the path factor, at FOMC meetings between January 1990 and September 2016. Constant and QE-Dummy included in all regressions. Heteroskedasticity-robust (White) standard errors in parentheses. Asterisks mark significance at 10% (*), 5% (**), 1% (***). Maturity is measured either in months (M) or in years (Y). Corporate Bond 10Y(A) and (B) refer to long-term bonds with AAA and BAA rating, respectively. CD: Certificate of Deposit; GC: General Collateral Repo.

Table 3: Response of Liquidity Spreads to Changes in Monetary Policy

	Liquidity	Commercial Paper / Corporate Bond spread				
	Premium LP	3M	3Y	5Y	10Y(A)	10Y(B)
Change in Federal Funds Rate $\widetilde{F}_1$	-0.41***	-0.30***	0.15*	0.043	-0.053	-0.032
	(0.13)	(0.11)	(0.088)	(0.055)	(0.056)	(0.042)
Change in Forward Guidance $\widetilde{F}_2$	-0.28***	-0.11*	-0.13***	-0.17***	-0.30***	-0.31***
	(0.059)	(0.068)	(0.048)	(0.035)	(0.037)	(0.035)
R^2	0.29	0.10	0.09	0.19	0.46	0.51
Number of Observations T	237	122	165	165	237	237

		GC spread		CD spread		
		3M		3M	6M	
Change in Federal Funds Rate $\widetilde{F}_1$		-0.37**		-0.26*	-0.35*	
		(0.15)		(0.15)	(0.18)	
Change in Forward Guidance $\widetilde{F}_2$		-0.16***		-0.011	-0.11	
		(0.060)		(0.084)	(0.12)	
R^2		0.55		0.21	0.41	
Number of Observations T		213		212	212	

Notes: Table shows responses of liquidity spreads to changes in the federal funds rate, measured by the target factor, and to changes in forward guidance, measured by the path factor, at FOMC meetings between January 1990 and September 2016. Constant and QE-Dummy included in all regressions. Heteroskedasticity-robust (White) standard errors in parentheses. Asterisks mark significance at 10% (*), 5% (**), 1% (***). Maturity is measured either in months (M) or in years (Y). Corporate Bond 10Y(A) and (B) refer to long-term bonds with AAA and BAA rating, respectively. CD: Certificate of Deposit; GC: General Collateral Repo. All spreads are calculated relative to Treasuries of the same maturity.

insignificant due to the relatively short maturities of these assets. The LIBOR does not react significantly on changes either in the current federal funds rate or in forward guidance. The limited relevance of monetary policy changes on bank rates is also reflected in relatively small values of R^2. Taken together, rates on Treasuries tend to react stronger to both $\widetilde{F}_1$ and $\widetilde{F}_2$ than the rates on the various less liquid assets at the same maturity.

This finding is confirmed in Table 3 which shows the response of our liquidity measures to the surprise changes in monetary policy. First and foremost, we present results on the liquidity premium from our factor model (1). We find that the premium reacts strongly on both, changes in the current and the expected path of the federal funds rate. A 1% reduction of the current federal funds rate target increases the valuation of liquidity by 0.41%, while the liquidity premium rises by 0.28% today to a 1% reduction of the expected federal funds rate over the next year. Accordingly, markets value the liquidity property of near-money assets higher in response to all types of expansionary monetary policy. This finding constitutes the main result of our empirical analysis. Regressions of the individual spreads provide additional supportive evidence. In line with the relatively stronger response of Treasuries, observed in Table 2, coefficients on the target and path factor have a negative sign in the majority of cases. Also following the pattern of the asset returns, the coefficients as well as the significance of forward guidance changes become stronger for longer maturities, whereas the effect of the current federal funds rate on liquidity spreads is particularly strong for shorter maturities.

Note that Tables 5 and 6 in the Appendix repeat the above analysis for a sample excluding the recent zero lower bound episode (sample end in December 2008). Overall, the results are similar.

3   The Model

In this section, we present a macroeconomic New Keynesian model with an endogenous liquidity premium for the analysis of forward guidance, which is based on Bredemeier et al. (2017), from which we adopt most of the notation. To endogenize the liquidity premium, we consider commercial banks that demand high powered money, i.e., reserves, that are supplied by the central bank via open market operations against eligible securities to serve withdrawals of demand deposits, which relate to households' goods market transactions. Our model distinguishes between several assets in order to account for rates of return, which respond differently to forward guidance shocks in the data. Decisively, assets differ with respect to liquidity, i.e., to their ability to serve as substitutes for central bank money. The price of reserves equals the monetary policy rate and is set by the central bank. The interest rate on eligible assets (i.e., Treasury bills) is closely related to the policy rate, as they are close substitutes to central bank money, whereas interest rates on non-eligible assets differ by a liquidity premium. Given that the latter assets (rather than money or Treasury bills) actually serve as agents' store of value, their real interest rates reflect private agents' intertemporal consumption and investment

choices. To isolate the main mechanism, we neither model frictions that justify the existence of banks nor other financial market frictions. In fact, the model is constructed to feature only a single non-standard element in form of the liquidity premium.

In each period, the timing of events in the economy, which consists of households, banks, intermediate goods producing firms, retailers, and the public sector unfolds as follows: At the beginning of each period, aggregate shocks materialize. Then, banks can acquire reserves from the central bank via open market operations. Subsequently, the labor market opens, goods are produced, and the goods market opens, where money is used as a means of payment. At the end of each period, the asset market opens. Throughout the paper, upper case letters denote nominal variables and lower case letters real variables.

3.1 Households

There is a continuum of infinitely lived and identical households of mass one. It maximizes the expected sum of a discounted stream of instantaneous utilities $u_t = u(c_t, n_t)$,

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, n_t), \tag{5}$$

where $u(c_t, n_t) = [c_t^{1-\sigma}/(1-\sigma)] - \theta n_t^{1+\sigma_n}/(1+\sigma_n)$ with $\sigma \geq 1$, σ_n, $\theta \geq 0$. c_t denotes consumption, n_t working time, E_0 the expectation operator conditional on the time 0 information set, and $\beta \in (0,1)$ is the subjective discount factor. Households can store their wealth in shares of firms $z_t \in [0,1]$ valued at the price V_t with the initial stock of shares $z_{-1} > 0$. The budget constraint of the household reads

$$\left(D_t/R_t^D\right) + V_t z_t + P_t c_t + P_t \tau_t \leq D_{t-1} + (V_t + P_t \varrho_t) z_{t-1} + P_t w_t n_t + P_t \varphi_t, \tag{6}$$

where P_t denotes the price level, w_t the real wage rate, τ_t a lump-sum tax, ϱ_t dividends from intermediate goods producing firms, φ_t profits from banks and retailers, and D_t demand deposits that are offered by a banking sector at the price $1/R_t^D$. We assume that households rely on money for purchases of consumption goods, while we abstract from purchases of goods via credit for simplicity. To purchase goods, households could in principle hold cash, which is dominated by the rate of return of other assets. Instead, we consider the demand deposits to serve the same purpose. Households typically hold more deposits than necessary for consumption expenditures such that the goods market constraint, which resembles a standard cash in advance constraint, can be summarized as

$$P_t c_t \leq \mu D_{t-1}, \tag{7}$$

where $D_{t-1} \geq 0$ denotes holdings of bank deposits at the beginning of period t and $\mu \in [0,1]$ denotes an exogenously determined fraction of deposits withdrawn by the representative household. Given that households can withdraw deposits at any point in time, they have no

incentive to hold non-interest-bearing money. Maximizing the objective (5) subject to the budget constraint (6), the goods market constraint (7), and $z_t \geq 0$ for given initial values leads to the following first-order conditions for working time, consumption, shares, and deposits:

$$-u_{n,t} = w_t \lambda_t, \tag{8}$$

$$u_{c,t} = \lambda_t + \psi_t, \tag{9}$$

$$\beta E_t \left[\lambda_{t+1} R_{t+1}^q \pi_{t+1}^{-1} \right] = \lambda_t, \tag{10}$$

$$\beta E_t \left[\left(\lambda_{t+1} + \mu \psi_{t+1} \right) \pi_{t+1}^{-1} \right] = \lambda_t / R_t^D, \tag{11}$$

where $u_{n,t} = \partial u_t / \partial n_t$ and $u_{c,t} = \partial u_t / \partial c_t$ denote marginal (dis-)utility from labor and consumption, $R_t^q = (V_t + P_t \varrho_t) / V_{t-1}$ is the nominal rate of return on equity, and λ_t and ψ_t denote the multipliers on the budget constraint (6) and the goods market constraint (7). Finally, the complementary slackness conditions that hold in the household's optimum are $0 \leq \mu d_{t-1} \pi_t^{-1} - c_t$, $\psi_t \geq 0$, $\psi_t \left(\mu d_{t-1} \pi_t^{-1} - c_t \right) = 0$, where $d_t = D_t / P_t$, as well as (6) with equality and associated transversality conditions. Under a binding goods market constraint (7) that implies $\psi_t > 0$, the deposit rate tends to be lower than the expected return on equity (see 10 and 11), as demand deposits provide transaction services.

3.2 Commercial Banks

There is a continuum of perfectly competitive banks $i \in [0, 1]$. A bank i receives demand deposits $D_{i,t}$ from households and supplies risk-free loans to firms $L_{i,t}$ at the price $1/R_t^L$. Bank i further holds short-term government debt (i.e., treasury bills) $B_{i,t-1}$ and reserves $M_{i,t-1}$ for withdrawals of deposits by households. The central bank supplies reserves via open market operations either outright or temporarily under repurchase agreements. The latter correspond to a collateralized loan offered by the central bank. In both cases, treasury bills serve as collateral for central bank money, while the price of reserves in open market operations in terms of treasuries (the repo rate) equals R_t^m. Specifically, reserves are supplied by the central bank only in exchange for treasuries $\Delta B_{i,t}^C$, while the price of money is the repo rate R_t^m:[17]

$$I_{i,t} = \Delta B_{i,t}^C / R_t^m \quad \text{and} \quad \Delta B_{i,t}^C \leq B_{i,t-1}, \tag{12}$$

where $I_{i,t}$ denotes additional money received from the central bank. Hence, (12) describes a central bank money supply constraint, which shows that a bank i can acquire reserves $I_{i,t}$ in exchange for the discounted value of Treasury bills carried over from the previous period $B_{i,t-1}/R_t^m$. We abstract from modelling an interbank market for overnight loans in terms of reserves and the associated (federal funds) rate and assume – consistent with US data (see Bredemeier et al., 2017) – that the Treasury repo rate and the federal funds rate are identical,

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[17]This relates to Benigno and Nisticó (2017) who assume that bond holdings directly alleviate liquid constraints in the goods market.

implying that the central bank sets the repo rate R_t^m. Reserves are demanded by bank i to meet liquidity demands from withdrawals of deposits

$$\mu D_{i,t-1} \leq I_{i,t} + M_{i,t-1}. \tag{13}$$

By imposing the constraint (13), we implicitly assume that a reserve requirement is either identical to the expected withdrawals or slack. Banks supply one-period risk-free loans $L_{i,t}$ to firms at a period t price $1/R_t^L$ and a payoff $L_{i,t}$ in period $t+1$. Thus, R_t^L denotes the rate at which firms can borrow. Banks can further invest in short-term government bonds that are issued at the price $1/R_t$, which are eligible for open market operations. Given that bank i transferred T-bills to the central bank under outright sales and that it repurchases a fraction of T-bills, $B_{i,t}^R = R_t^m M_{i,t}^R$, from the central bank, its holdings of T-bills before it enters the asset market equal $B_{i,t-1} + B_{i,t}^R - \Delta B_{i,t}^C$ and its money holdings equal $M_{i,t-1} - R_t^m M_{i,t}^R + I_{i,t}$. Hence, bank i's profits $P_t \varphi_{i,t}^B$ are given by

$$P_t \varphi_{i,t}^B = \left(D_{i,t}/R_t^D \right) - D_{i,t-1} - M_{i,t} + M_{i,t-1} - I_{i,t} \left(R_t^m - 1 \right) \tag{14}$$
$$- \left(B_{i,t}/R_t \right) + B_{i,t-1} - \left(L_{i,t}/R_t^L \right) + L_{i,t-1}.$$

Notably, the aggregate stock of reserves only changes with the central bank money supply, $\int_0^1 M_{i,t} di = \int_0^1 (M_{i,t-1} + I_{i,t} - M_{i,t}^R) di$, and is fully backed by Treasury bills, whereas demand deposits can be created by the banking sector subject to (13). Banks maximize the sum of discounted profits, $E_t \sum_{k=0}^\infty p_{t,t+k} \varphi_{i,t+k}^B$, where $p_{t,t+k}$ denotes the stochastic discount factor $p_{t,t+k} = \beta^k \lambda_{t+k}/\lambda_t$, subject to the money supply constraint (12), the liquidity constraint (13), the budget constraint (14), and the borrowing constraints $\lim_{s \to \infty} E_t[p_{t,t+k} D_{i,t+s}/P_{t+s}] \geq 0$, $B_{i,t} \geq 0$, and $M_{i,t} \geq 0$. The first-order conditions with respect to deposits, T-bills, corporate and interbank loans, money holdings, and reserves can be written as

$$\frac{1}{R_t^D} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{1 + \mu \varkappa_{i,t+1}}{\pi_{t+1}}, \tag{15}$$

$$\frac{1}{R_t} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{1 + \eta_{i,t+1}}{\pi_{t+1}}, \tag{16}$$

$$\frac{1}{R_t^L} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \pi_{t+1}^{-1}, \tag{17}$$

$$1 = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{1 + \varkappa_{i,t+1}}{\pi_{t+1}}, \tag{18}$$

$$\varkappa_{i,t} + 1 = R_t^m \left(\eta_{i,t} + 1 \right), \tag{19}$$

where $\eta_{i,t}$ and $\varkappa_{i,t}$ denote the multipliers on the money supply constraint (12) and the liquidity constraint (13), respectively. Further, the following complementary slackness conditions hold: i) $0 \leq b_{i,t-1} \pi_t^{-1} - R_t^m i_{i,t}$, $\eta_{i,t} \geq 0$, $\eta_{i,t} \left(b_{i,t-1} \pi_t^{-1} - R_t^m i_{i,t} \right) = 0$, and ii.) $0 \leq i_{i,t} + m_{i,t-1} \pi_t^{-1} - \mu d_{i,t-1} \pi_t^{-1}$, $\varkappa_{i,t} \geq 0$, $\varkappa_{i,t} \left(i_{i,t} + m_{i,t-1} \pi_t^{-1} - \mu d_{i,t-1} \pi_t^{-1} \right) = 0$, where $d_{i,t} = d_{i,t}/P_t$, $m_{i,t} = M_{i,t}/P_t$, $b_{i,t} = B_{i,t}/P_t$, and $i_{i,t} = I_{i,t}/P_t$, and the associated transversality conditions.

3.3 Production Sector

The production sector of the economy consists of intermediate goods producing firms, which sell their goods to monopolistically competitive retailers that are subject to a Calvo-type sticky price friction. The retailers sell a differentiated good to bundlers, who assemble final goods using a Dixit-Stiglitz technology.

The intermediate goods producing firms are identical, perfectly competitive, owned by the households, and produce an intermediate good y_t^m with labor n_t according to the production function

$$y_t^m = n_t^\alpha,$$

with the labor elasticity of production α. They sell the intermediate good to retailers at the price P_t^m. We neglect retained earnings and assume that firms rely on bank loans to finance wage outlays before goods are sold. The firms' loan demand satisfies

$$L_t / R_t^L \geq P_t w_t n_t. \tag{20}$$

Firms are committed to fully repay their liabilities, such that bank loans are default-risk free. The problem of a representative firm can then be summarized as $\max E_t \sum_{k=0}^\infty p_{t,t+k} \varrho_{t+k}$, where ϱ_t denotes real dividends $\varrho_t = (P_t^m/P_t) n_t^\alpha - w_t n_t - l_{t-1} \pi_t^{-1} + l_t / R_t^L$, subject to (20). The first-order conditions for loan and labor demand are then given by

$$1 + \gamma_t = R_t^L E_t [p_{t,t+1} \pi_{t+1}^{-1}], \tag{21}$$

$$P_t^m / P_t \alpha n_t^{\alpha-1} = (1 + \gamma_t) w_t, \tag{22}$$

where γ_t denotes the multiplier on the loan demand constraint (20). Given that we abstract from financial market frictions, the Modigliani-Miller theorem applies here, such that the multiplier γ_t equals zero. This can immediately be seen from combining the banks' loan supply condition (17) with the firm's loan demand condition (21), which implies $\gamma_t = 0$. Hence, the loan demand constraint (20) is slack, such that the firm's labor demand (22) will be undistorted and read $P_t^m / P_t = w_t / (\alpha n_t^{\alpha-1})$.

Monopolistically competitive retailers, indexed with $k \in [0,1]$ buy intermediate goods y_t^m at the price P_t^m to relabel them to a good $y_{k,t}$. The latter are sold at a price $P_{k,t}$ to perfectly competitive bundlers. Only a random fraction $1 - \phi$ of the retailers is able to reset their price $P_{k,t}$ in an optimizing way each period., while the remaining retailers of mass ϕ have to keep the price of the previous period, $P_{k,t} = P_{k,t-1}$. The problem of a price adjusting retailer reads $\max_{\widetilde{P}_{k,t}} E_t \sum_{s=0}^\infty \phi^s \beta^s \phi_{t,t+s} \left(\left(\Pi_{k=1}^s \widetilde{P}_{k,t} / P_{t+s} \right) - mc_{t+s} \right) y_{k,t+s}$, where marginal costs are $mc_t = P_t^m / P_t$. The first-order condition can be written as $\tilde{Z}_t = \frac{\varepsilon}{\varepsilon-1} Z_t^1 / Z_t^2$, where $\tilde{Z}_t = \widetilde{P}_t / P_t$, $Z_t^1 = \xi_t c_t^{-\sigma} y_t mc_t + \phi\beta E_t \pi_{t+1}^\varepsilon Z_{t+1}^1$ and $Z_t^2 = \xi_t c_t^{-\sigma} y_t + \phi\beta E_t \pi_{t+1}^{\varepsilon-1} Z_{t+1}^2$.

The perfectly competitive bundlers combine the various $y_{k,t}$ to the final consumption good y_t using the technology $y_t^{\frac{\varepsilon-1}{\varepsilon}} = \int_0^1 y_{k,t}^{\frac{\varepsilon-1}{\varepsilon}} dk$, where $\varepsilon > 1$ is the elasticity of substitution between the

different varieties. The cost minimizing demand for each good is given by $y_{k,t} = (P_{k,t}/P_t)^{-\varepsilon} y_t$. The bundlers sell the final good y_t to the households at the price P_t, which can be written as the consumer price index (CPI) $P_t^{1-\varepsilon} = \int_0^1 P_{k,t}^{1-\varepsilon} dk$.

The evolution of this price index equals $1 = (1-\phi)\tilde{Z}_t^{1-\varepsilon} + \phi\pi_t^{\varepsilon-1}$. In a symmetric equilibrium, $y_t^m = \int_0^1 y_{k,t} dk$ and $y_t = a_t n_t^\alpha / s_t$ will hold, where $s_t = \int_0^1 (P_{k,t}/P_t)^{-\varepsilon} dk$ is an index of price dispersion that evolves according to $s_t = (1-\phi)\tilde{Z}_t^{-\varepsilon} + \phi s_{t-1}(\pi_t)^\varepsilon$ for a given s_{-1}.

3.4 Public Sector

The public sector consists of a government and a central bank. The government issues one-period bonds B_t^T and obtains potential profits of the central bank $P_t\tau_t^m$. Revenues beyond those used to repay debt from last period are transferred to the households in a lump-sum fashion, $P_t\tau_t$, to balance the budget. The government budget constraint is then given by

$$\left(B_t^T/R_t\right) + P_t\tau_t^m = B_{t-1}^T + P_t\tau_t.$$

Given that one period equals one quarter in our setting, this debt corresponds to 3-month Treasury bills. Government debt is held by banks in the amount of B_t and by the central bank in the amount of B_t^C, such that $B_t^T = B_t + B_t^C$. We assume that the supply of Treasury bills is exogenously determined by a constant growth rate Γ

$$B_t^T = \Gamma B_{t-1}^T, \tag{23}$$

where $\Gamma > \beta$. (23) describes the supply of money market instruments that the central bank declares eligible. There is only short-term government debt in the model for simplicity. To appropriately account for the role of long-term Treasury debt, which in particular have been purchases by the US Federal reserve in their large scale asset purchase programmes, we would specify them as partially eligible for central bank operations. It can be shown in a straightforward way that the associated yields would then behave like a combination of the T-bill rate and corporate debt rate.

The central bank supplies money in exchange for Treasury bills either outright, M_t, or under repos M_t^R. At the beginning of each period, the central bank's stock of Treasuries equals B_{t-1}^C and the stock of outstanding money equals M_{t-1}. It then receives an amount ΔB_t^C of Treasuries in exchange for newly supplied money $I_t = M_t - M_{t-1} + M_t^R$. After repurchase agreements are settled, its holdings of Treasuries and the amount of outstanding money are reduced by B_t^R and by M_t^R, respectively. Before the asset market opens, where the central bank can reinvest its payoffs from maturing securities in T-bills B_t^C, it holds an amount equal to $B_{t-1}^C + \Delta B_t^C - B_t^R$. Its budget constraint is thus given by $\left(B_t^C/R_t\right) + P_t\tau_t^m = \Delta B_t^C + B_{t-1}^C - B_t^R + M_t - M_{t-1} - \left(I_t - M_t^R\right)$, which after substituting out I_t, B_t^R, and ΔB_t^C using $\Delta B_t^C = R_t^m I_t$, can be simplified to $\left(B_t^C/R_t\right) - B_{t-1}^C = R_t^m(M_t - M_{t-1}) + (R_t^m - 1)M_t^R - P_t\tau_t^m$. Following central bank practice, we assume that interest earnings are transferred to the government,

$P_t \tau_t^m = B_t^C (1 - 1/R_t) + (R_t^m - 1) \left(M_t - M_{t-1} + M_t^R \right)$, such that holdings of Treasuries evolve according to $B_t^C - B_{t-1}^C = M_t - M_{t-1}$. Restricting the initial values to $B_{-1}^C = M_{-1}$ leads to the central bank balance sheet

$$B_t^C = M_t. \tag{24}$$

Regarding the implementation of monetary policy, we assume that the central bank sets the policy rate R_t^m following a Taylor-type feedback rule, while respecting the zero lower bound:

$$R_t^m = \max \left\{ 1; \left(R_{t-1}^m \right)^{\rho_R} \left[R_m \left(\pi_t / \pi \right)^{\rho_\pi} \left(y_t / \widetilde{y}_t \right)^{\rho_y} \right]^{1-\rho_R} \exp \left(\varepsilon_t^m \cdot \prod_{k=1}^{K} \varepsilon_{t,t-k}^m \right) \right\}, \tag{25}$$

where $\widetilde{y}_t$ is the efficient level of output, $\rho_\pi \geq 0, \rho_y \geq 0, 0 \leq \rho_R < 1, R^m \geq 1$, and ε_t^m denotes a contemporaneous monetary policy shock. Following Laséen and Svensson (2011), $\prod \varepsilon_{t,t-k}^m$ describes a series of anticipated policy shocks, which materialize in period t, but were announced in period $t - k$, that are used to model forward guidance.

The target inflation rate π is controlled by the central bank and will be assumed to equal the growth rate of Treasuries Γ, which is in line with US data (see 4.2.1). Finally, the central bank fixes the fraction of money supplied under repurchase agreements relative to money supplied outright at $\Omega \geq 0 : M_t^R = \Omega M_t$. For the subsequent analysis, Ω will be set at a sufficiently large value to ensure that central bank money injections I_t are non-negative.

3.5 Equilibrium Properties

Given that households, firms, retailers, and banks behave in an identical way, we can omit indices. A definition of the rational expectations equilibrium can be found in Appendix B. It should be noted that the Modigliani-Miller theorem applies here as financial markets are frictionless. The main difference to a standard New Keynesian model is the money supply constraint (12), which ensures that reserves are fully backed by Treasuries. The model in fact reduces to a New Keynesian model with a conventional cash-in-advance constraint if the money supply constraint (12) is slack, which is summarized in Definition 2 in Appendix B.[18]

In our model, rates of return on non-eligible assets (i.e., corporate debt and equity) exceed the policy rate and the Treasury rate by a liquidity premium if (12) is binding. This is the case when the central bank supplies money at a lower price than households are willing to pay, $R_t^m < R_t^{IS}$, where R_t^{IS} denotes the nominal marginal rate of intertemporal substitution of consumption

$$R_t^{IS} = u_{c,t} / \beta E_t \left(u_{c,t+1} / \pi_{t+1} \right), \tag{26}$$

which measures the marginal valuation of money by the private sector.[19] For $R_t^m < R_t^{IS}$,

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[18]It should be noted that a binding money supply constraint does not imply that monetary policy is inferior compared to a regime, where money is supplied in an unbounded way, as shown by Schabert (2015).

[19]Agents are willing to spend $R_t^{IS} - 1$ to transform one unit of an illiquid asset, i.e. an asset that is not accepted as a means of payment today and delivers one unit of money tomorrow, into one unit of money today.

households thus earn a positive rent and are willing to increase their money holdings. Given that access to money is restricted by holdings of Treasury bills, the money supply constraint (12) is then binding. To see this, compare (15) with (11) to get $E_t[\frac{\lambda_{t+1}+\mu\psi_{t+1}}{\lambda_t}\pi_{t+1}^{-1}] = E_t[\frac{\lambda_{t+1}}{\lambda_t}(1+\varkappa_{t+1}\mu)\pi_{t+1}^{-1}]$, which is satisfied if $\varkappa_t = \psi_t/\lambda_t$. Hence, the equilibrium versions of the conditions (18) and (19) imply $(\psi_t + \lambda_t)/\lambda_t = R_t^m(\eta_t + 1)$ and $\beta\pi_{t+1}^{-1}(\lambda_{t+1} + \psi_{t+1}) = \lambda_t$, which can – by using the equilibrium version of condition (9) – be combined to

$$\eta_t = (R_t^{IS}/R_t^m) - 1. \tag{27}$$

Condition (27) implies that the money supply constraint (12) is binding, i.e., $\eta_t > 0$, if the central bank sets the policy rate R_t^m below R_t^{IS}. Given that short-term Treasuries and money are close substitutes, the T-bill rate R_t relates to the expected future policy rate, which can be seen from combining (16) with (18) and (19), $R_t \cdot E_t\varsigma_{1,t+1} = E_t[R_{t+1}^m \cdot \varsigma_{1,t+1}]$, where $\varsigma_{1,t+1} = \lambda_{t+1}(1 + \eta_{t+1})/\pi_{t+1}$. Thus, the Treasury bill rate equals the expected policy rate up to first order,

$$R_t = E_t R_{t+1}^m + \text{h.o.t.}, \tag{28}$$

where h.o.t. represents higher order terms. Notably, the relation (28) accords to the empirical evidence provided by Simon (1990). The bank's first-order conditions (15), (17), and (18) further imply that the deposit rate R_t^D exceeds one and is smaller than the interest rates on loans to firms R_t^L when liquidity is positively valued, i.e., if $\psi_t > 0$. Combining (17), with $\beta E_t \pi_{t+1}^{-1}(\lambda_{t+1} + \psi_{t+1}) = \lambda_t$ (see 17) shows that the loan rate R_t^L relates to the expected marginal rate of intertemporal substitution $(1/R_t^L) \cdot E_t\varsigma_{2,t+1} = E_t[(1/R_{t+1}^{IS}) \cdot \varsigma_{2,t+1}]$, where $\varsigma_{2,t+1} = (\lambda_{t+1} + \psi_{t+1})/\pi_{t+1}$. Likewise, (11) implies that the expected rates of return on equity is related to the expected marginal rate of intertemporal substitution: $E_t\varsigma_{2,t+1} = E_t[(R_{t+1}^q/R_{t+1}^{IS}) \cdot \varsigma_{2,t+1}]$. Hence, the loan rate equals to the expected marginal rate of intertemporal substitution up to first order,

$$R_t^L = E_t R_{t+1}^{IS} + \text{h.o.t.}, \tag{29}$$

as well as to the expected rate of return on equity, $E_t R_{t+1}^q = E_t R_{t+1}^{IS} + \text{h.o.t.}$ Accordingly, the spread between the marginal rate of intertemporal substitution and the monetary policy rate, $R_t^{IS} - R_t^m$, captures how rates of return of non-eligible assets deviate from the monetary policy rate and summarizes how interest rates in the current model differ from those of a standard model. Accordingly, $R_t^{IS} - R_t^m$ constitutes an endogenous liquidity premium. When we derive analytical results in the subsequent section, we therefore focus on the difference between R_t^{IS} and R_t^m to unveil the main mechanism at work.

It should further be noted that as long as the nominal marginal rate of intertemporal substitution R_t^{IS} (rather than the policy rate R_t^m) does not hit the zero lower bound, i.e., $R_t^{IS} > 1$, the demand for money is well defined, as the liquidity constraints of households (7)

and banks (13) are binding. This can be seen by substituting out $\varkappa_t$ in the equilibrium version of (18) with $\varkappa_t = \psi_t/\lambda_t$ and combining with the equilibrium version of (9), which leads to

$$\psi_t = u_{c,t}\left(1 - 1/R_t^{IS}\right). \tag{30}$$

Thus, (30) implies that the household's liquidity constraint (7) as well as the bank's liquidity constraint (13) are binding if R_t^{IS} is strictly larger than one. Notably, liquidity might still be positively valued by households and banks, i.e., $R_t^{IS} > 1$, even when the policy rate is at the zero lower bound, $R_t^m = 1$.

4 The Effect of Forward Guidance in the Model

In this section, we examine the models' predictions regarding the macroeconomic effects of forward guidance. We begin with deriving some analytical results in Section 4.1. Subsequently, we calibrate the model and study its quantitative predictions in Section 4.2. Throughout these sections, we separately analyze two versions of the model, which differ with regard to the relation between the monetary policy rate and the marginal rate of intertemporal substitution.

It should further be noted that we focus, for analytical clarity, on the spread between the nominal marginal rate of intertemporal substitution of consumption R_t^{IS} and the policy rate R_t^m, which exactly measures the liquidity value originating from assets' eligibility (see 27). The spread between the loan rate R_t^L and the treasury R_t, which corresponds to the spreads examined in Section 2, is in fact closely related to the latter (see 28 and 29) and will be applied for the calibration of the model.

4.1 Analytical Results

We separately analyze the cases where the money supply constraint (12) is either binding, which leads to an endogenous liquidity premium, or where money supply is de facto unconstrained, implying that the policy rate R_t^m equals the marginal rate of intertemporal substitution R_t^{IS}. Technically, this means that we assume that the central bank sets the policy rate in the long run either below or equal to $R^{IS} = \pi/\beta$ (where time indices are omitted to indicate steady state values) and examine the local dynamics in the neighborhood of the particular steady state.[20] In a neighborhood of a steady state, the equilibrium sequences are approximated by the solutions to the linearized equilibrium conditions, where $\widehat{a}_t$ denotes relative deviations of a generic variable a_t from its steady state value $a : \widehat{a}_t = \log(a_t/a)$. To facilitate the derivation of analytical results, we assume that outright money supply is negligible, $\Omega \to \infty$, which reduces the set of endogenous state variables. We further assume for convenience that the central bank targets long-run price stability $\pi = 1$, which is further supported by the supply of eligible government debt $\Gamma = 1$[21].

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[20]We further assume that shocks are sufficiently small such that the ZLB is never binding.

[21]Notably, the latter assumption is not necessary for the implementation of long-run price stability, since the central bank can in principle adjust the share of short-term treasuries that are eligible for money supply operations to

Definition 1 *A rational expectations equilibrium for $\Omega \to \infty$, $\Gamma = \pi = \alpha = 1$, and $\rho_{R,y} = 0$ is a set of convergent sequences $\{\widehat{c}_t, \pi_t, \widehat{b}_t, \widehat{R}_t^{IS}, \widehat{R}_t^m\}_{t=0}^{\infty}$ satisfying*

$$\widehat{c}_t = \widehat{b}_{t-1} - \widehat{\pi}_t - \widehat{R}_t^m \text{ if } R_t^m < R_t^{IS}, \tag{31}$$

$$\text{or } \widehat{c}_t \le \widehat{b}_{t-1} - \widehat{\pi}_t - \widehat{R}_t^m \text{ if } R_t^m = R_t^{IS},$$

$$\sigma \widehat{c}_t = \sigma E_t \widehat{c}_{t+1} - \widehat{R}_t^{IS} + E_t \widehat{\pi}_{t+1}, \tag{32}$$

$$\widehat{\pi}_t = \beta E_t \widehat{\pi}_{t+1} + \chi \left[(\sigma_n + \sigma) \widehat{c}_t + \widehat{R}_t^{IS} \right], \tag{33}$$

$$\widehat{b}_t = \widehat{b}_{t-1} - \widehat{\pi}_t, \tag{34}$$

where $\chi = (1 - \phi)(1 - \beta\phi)/\phi$ for a monetary policy rate satisfying

$$\widehat{R}_t^m = \rho_\pi \widehat{\pi}_t + \widehat{\varepsilon}_t^m + \sum_{k=1}^{K} \widehat{\varepsilon}_{t,t-k}^m, \tag{35}$$

where $\rho_\pi > 0$, for a given $b_{-1} > 0$.

Consider first the case, where the money supply constraint (12) is not binding, such that the policy rate equals the marginal rate of intertemporal substitution, $R_t^m = R_t^{IS}$, and there is no liquidity premium. This will be the case if eligible assets are supplied abundantly or if there are no collateral requirements in open market operations. Given that condition (31) is then slack, the model reduces to a standard New Keynesian model with a cash-in-advance constraint. This constraint implies that the policy rate affects the marginal rate of substitution between consumption and working time and therefore enters the aggregate supply constraint (33). In this setting, forward guidance exerts the stark effects that were criticized in the literature (see Del Negro et al., 2015), such as large initial output and inflation effects as well as cumulative output responses that are growing in the horizon of forward guidance.

In case the policy rate is set below the marginal rate of intertemporal substitution, i.e., $R_t^m < R_t^{IS}$, the money supply constraint and, hence, (31) is binding, which implies a positive liquidity premium. As shown by Bredemeier et al. (2017), there exist unique locally convergent equilibrium sequences, if but not only if

$$\rho_\pi < [(1 + \beta)\chi^{-1} + 1 - \sigma]/\sigma \tag{36}$$

is satisfied. Condition (36) implies that an active monetary policy ($\rho_\pi > 1$) is not relevant for equilibrium determinacy and that the central bank can even peg the policy rate ($\rho_\pi = 0$) without inducing indeterminacy. It should further be noted that the sufficient condition (36) is far from being restrictive for a broad range of reasonable parameter values.

Forward guidance announcements of the FOMC in the last years stated to keep policy rates at low levels for a specific period of time. To assess the effect of this kind of forward guidance in our model, we consider the following simple experiment: The central bank announces in period

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implement the desired inflation target, as shown by Schabert (2015).

t to reduce the policy rate for the periods t and $t + 1$. Formally, this forward guidance consists of to components: a shock to the policy rate in t, i.e., $\widehat{\varepsilon}_t^m < 0$, and a shock in $t + 1$ that is announced in t, i.e., $\widehat{\varepsilon}_{t+1,t}^m < 0$ and $K = 1$ in (35). For the linearized model given in Definition 1, we are able to present some analytical results for this experiment that we summarize in the following proposition.[22]

Proposition 1 *Suppose that $R_t^m < R_t^{IS}$, $\sigma = \sigma_n = 1$, and $\rho_\pi < \beta\chi^{-1}$ which guarantees that (36) is satisfied. The effect of a forward guidance announcement in period t that reduces the monetary policy rate in t and $t + 1$ can be separated into the partial effects of a conventional monetary policy shock in t, $\widehat{\varepsilon}_t^m < 0$, and an in period t announced shock for $t + 1$, $\widehat{\varepsilon}_{t+1,t}^m < 0$.*

1. *The reduction of the policy rate $\widehat{R}_t^m$ leads in period t to rise of consumption $\widehat{c}_t$, inflation $\widehat{\pi}_t$, and in the liquidity premium $\widehat{R}_t^{IS} - \widehat{R}_t^m$.*

2. *The reduction of the policy rate $\widehat{R}_{t+1}^m$ in $t + 1$, announced in period t, leads*

   (a) *in period t to a fall of consumption $\widehat{c}_t$, a rise of inflation $\widehat{\pi}_t$, and a rise of the liquidity premium $\widehat{R}_t^{IS} - \widehat{R}_t^m$, and*

   (b) *in period $t + 1$ to a rise of consumption $\widehat{c}_{t+1}$, inflation $\widehat{\pi}_{t+1}$ and in the liquidity premium $\widehat{R}_{t+1}^{IS} - \widehat{R}_{t+1}^m$.*

3. *In total, forward guidance leads to an increase of consumption $\widehat{c}_t$, inflation $\widehat{\pi}_t$ and the liquidity premium $\widehat{R}_t^{IS} - \widehat{R}_t^m$ in both periods, t and $t + 1$.*

Proof. See Appendix C.1. ∎

In line with the evidence presented in Section 2, both reductions in the current monetary policy rate as well as announced reductions in future policy rates lead to rising liquidity premia in our model. The intuition for the spread responses in a period $t + k$ to a reduction in the monetary policy rate R_{t+k}^m (see case 1. and 2.b. in Proposition 1) is as follows. A temporary reduction in the policy rate increases the amount of money available per unit of eligible asset held by private agents, such that contemporaneous consumption increases (compared to previous and future consumption). To clear the market for commodities, the real interest rate on (non-eligible) assets that serve as a store of wealth declines. For an elasticity of intertemporal substitution $1/\sigma$ that is not too low (which is the case for $\sigma = 1$), the decline in the marginal rate of intertemporal substitution is less pronounced than the fall in the policy rate, such that the liquidity premium increases. For an announced reduction in the future policy rate the response of the current liquidity premium (see case 2.a. in Proposition 1) can also easily be understood. As eligible assets can be exchanged against a larger amount of reserves in the subsequent period, the liquidity value of newly issued treasuries rises. Given that the valuation of non-eligible assets is, in contrast, not directly affected by the policy measure, agents' demand for these assets fall, which tends to reduce their price. Hence, their current interest

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[22] Note that the parameter restriction $\rho_\pi < \beta\chi^{-1}$ is hardly restrictive, given that in our calibration used in Section, $\beta\chi^{-1} = 19.72$ which is by far larger than values typically applied for ρ_π of about 1.5.

rates increase (while the current policy rate is unchanged), such that the liquidity premium rises.

This interest-rate increasing property of forward guidance has important implications for its aggregate effects. The additional announcement of a reduction in tomorrow's monetary policy rate does not per se reinforce the expansionary effects of a reduction in today's policy rate. In fact, the rise in liquidity premia exerts a dampening effect on today's consumption, since upward pressure on the returns on non-eligible assets induces households to postpone consumption. This prediction is in stark contrast to that of a standard New Keynesian model where increased inflation today due to the announcement of low future interest rates unambiguously reduces the relevant real interest rate since the nominal rate is directly controlled by the central bank. This additional reduction in the real interest rate reinforces increases in consumption and can make output responses to forward guidance very strong (see Carlstrom et al. (2015) and our quantitative evaluations below). While the standard New Keynesian model has been is criticized for predicting effects of forward guidance which are too strong compared to empirical evidence (e.g., Gertler and Karadi, 2015), the dampening effect stemming from the responses of liquidity premia helps matching empirical findings. We will evaluate this point more deeply in the context of our quantitative results in Section 4.2.

4.2   Numerical Results

In this section, we describe the calibration of the model and present quantitative effects of forward guidance. The model is calibrated to match the empirical response of the liquidity premium to an announcement shock as analyzed in Section 2. Motivated by forward guidance announcements of the FOMC in the last years that stated to keep policy rates at low levels over a period of a 1 to 3 years, we study the effects of policy rate reductions that last several quarters. We show that our model with the liquidity premium generates moderate output and inflation effects that are substantially smaller than in a model version without the liquidity premium, which corresponds to a conventional New Keynesian model.

4.2.1   Calibration

We calibrate the model to selected characteristics of the US economy and a period is assumed to be one quarter. For a first set of parameters, we apply values that are standard in the literature on business cycle analysis. The elasticity of substitution between individual varieties of the intermediate goods producing firms ϵ is set to 6, which implies a steady state mark-up of 20%, the inverse Frisch elasticity σ_n is set to 2, and the labor income share α is set to 2/3. Consistent with broad empirical evidence, the probability that firms are not able to reset prices in the Calvo model is set to $\phi = 0.8$, and the reaction coefficients of the interest rate rule (25) are set to $\rho_\pi = 1.5$, $\rho_y = 0.05$, and $\rho_R = 0.8$.

A second set of parameters is set to match mean observations in our data set from Section 2 (January 1990 to September 2016). The rate of inflation and the policy rate in steady state are set to the average values of the CPI inflation and the federal funds rate.[23] The corresponding values are $\pi = 1.02426^{1/4}$ and $R^m = 1.0304^{1/4}$. We calibrate the long-run liquidity premium between Treasuries that are eligible for open market operations and the less liquid assets that are non-eligible, $\eta = R^L/R - 1$, to 53 basis points, which is the mean value of the common liquidity factor from Section 2.1 between January 1990 and September 2016. This implies $\eta = 0.001322$, which requires a steady-state value of $R^{IS} = 1.03586^{1/4}$. Since $R^{IS} = \pi/\beta$ in steady state, we set $\beta = 0.9972$ to achieve this target. The growth rate Γ of the T-bills in (23) is set to the long-run inflation rate, which roughly accords to the average T-bill growth rate in the pre crisis sample. As in Bredemeier et al. (2017), we assume the ratio of money supplied under repos Ω to equal 1.5 which is based on data about the mean fraction of repos to total reserves of depository institutions in the US between 2003 and 2007. This value further ensures that money injections by the central bank I_t are, in line with the data, always positive.

Finally, the elasticity of intertemporal substitution $1/\sigma$ is set to match the response of the empirical liquidity premium factor, LP_t, to an innovation in the path factor $\widetilde{F}_2$ as presented in Section 2 with the response of a model-implied long-term liquidity premium, $\widehat{\eta}_t^{LT} = \prod_s^q (\widehat{R}_{t+s}^L - \widehat{R}_{t+s})^{1/q}$. For $\sigma = 1.5$ and $q = 4$, the model generates an increase of $\widehat{\eta}_t^{LT}$ by 25 basis points to an (isolated) announced reduction of the policy rate R_t^m by 100 basis points in four quarters. This is close to the corresponding empirical response of the common liquidity factor LP_t by 28 basis points to a 1% reduction of $\widetilde{F}_2$, where the latter is normalized to the effect of a 100 basis point reduction of the expected policy rate in one year.

For the policy experiments, we consider paths of the monetary policy rate announced in advance. For this, it is convenient to assume that the contemporaneous shock, ε_t^m, and all anticipated monetary policy shocks, $\prod \varepsilon_{t,t-k}^m$, in (25) are completely transitory white-noise innovations that are identically and independently distributed as $N(0, \sigma_{m,k}^2)$. The assumption that all anticipated shocks are uncorrelated is innocuous in our analysis and could be relaxed without consequences for the results. We model forward guidance as a path for the monetary policy rate $\{R_{T+h}^m\}_{h=1}^H$ in the upcoming H periods that the central bank announces at the beginning of period $T + 1$, before which the economy is assumed to rest in steady state. We then back out a sequence of present and anticipated future monetary policy innovations $\varepsilon_{T+1}^m = \{\varepsilon_{T+1}^m, \varepsilon_{T+1+k,T+1}^m\}_{k=1}^K$ that yields this desired interest rate path. The calculation of the shocks is based on a procedure by Laséen and Svensson (2011) and Del Negro et al. (2015) that we adjust to our application. We provide details in Section C.2 of the appendix.

**Figure 1:** Effects of Forward Guidance
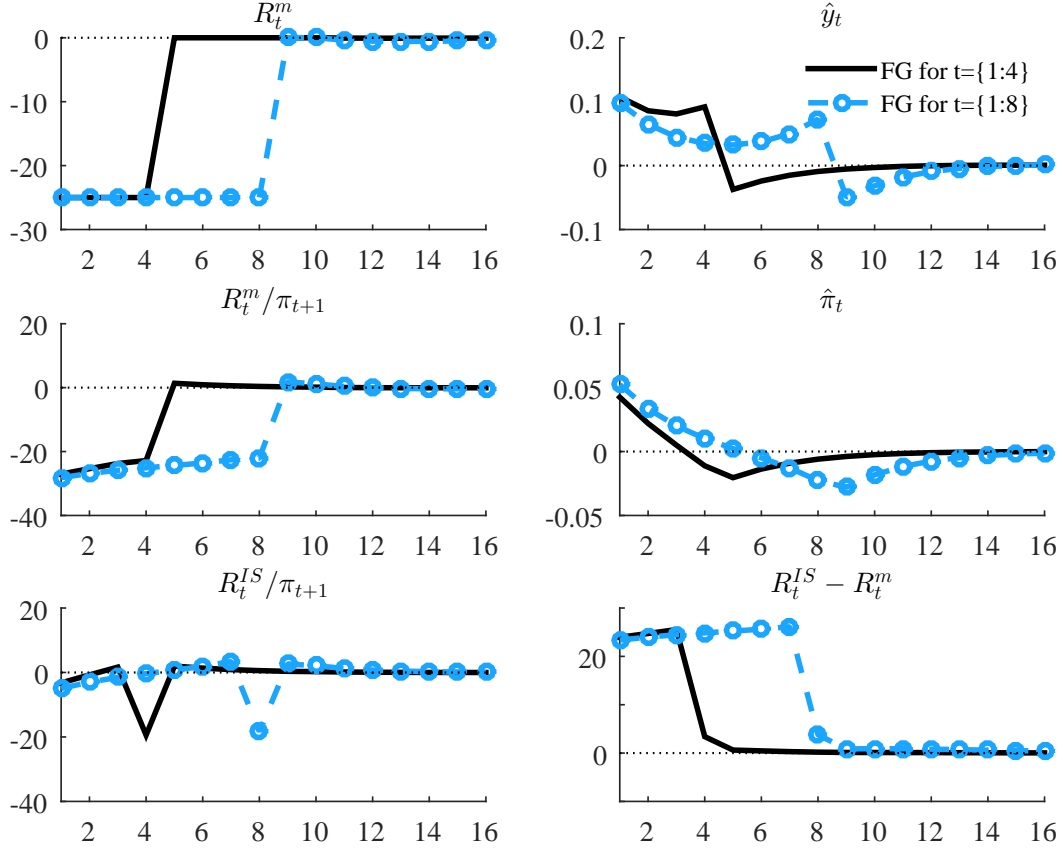
Notes: Impulse responses to forward guidance about policy rate R_t^m announced before quarter 1 in model with endogenous liquidity premium: production y_t, inflation π_t, real policy rate R_t^m/π_{t+1}, private-sector real rate R_t^{IS}/π_{t+1}, liquidity premium $R_t^{IS} - R_t^m$. Y-axis: Deviations from steady state in percent ($\hat{y}_t$, $\hat{\pi}_t$) or in basis points (else). X-axis: quarters. Black line: Announced policy rate reduction of 25 basis points in quarters 1 to 4. Blue circled line: Announced policy rate reduction of 25 basis points in quarters 1 to 8.

4.2.2 Impulse Responses to Forward Guidance

Figure 1 shows impulse responses to different forward guidance scenarios in our model with the endogenous liquidity premium. The two scenarios shown in the figure are credible announcements of the central bank to reduce the policy rate R_t^m by 25 annualized basis points for the next 4 and 8 quarters, respectively. This resembles recent forward guidance experiences, where central banks stated to keep policy rates at low levels over a horizon of about two years, and also relates to the VAR analyses of forward guidance by Gertler and Karadi (2015). The central bank resets the policy rate to its steady state value after the guidance period until quarter 10. After that, monetary policy is governed by the Taylor rule (25), which then implies values in close proximity of the steady state. The assumed path of the nominal interest rate can be seen

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[23]We use monthly data from FRED between January 1990 and December 2016 that we aggregate to quarterly values as the basis for the long-run means. For the CPI we take the series [CPIAUCSL] and for the federal funds rate we take the series [FEDFUNDS].

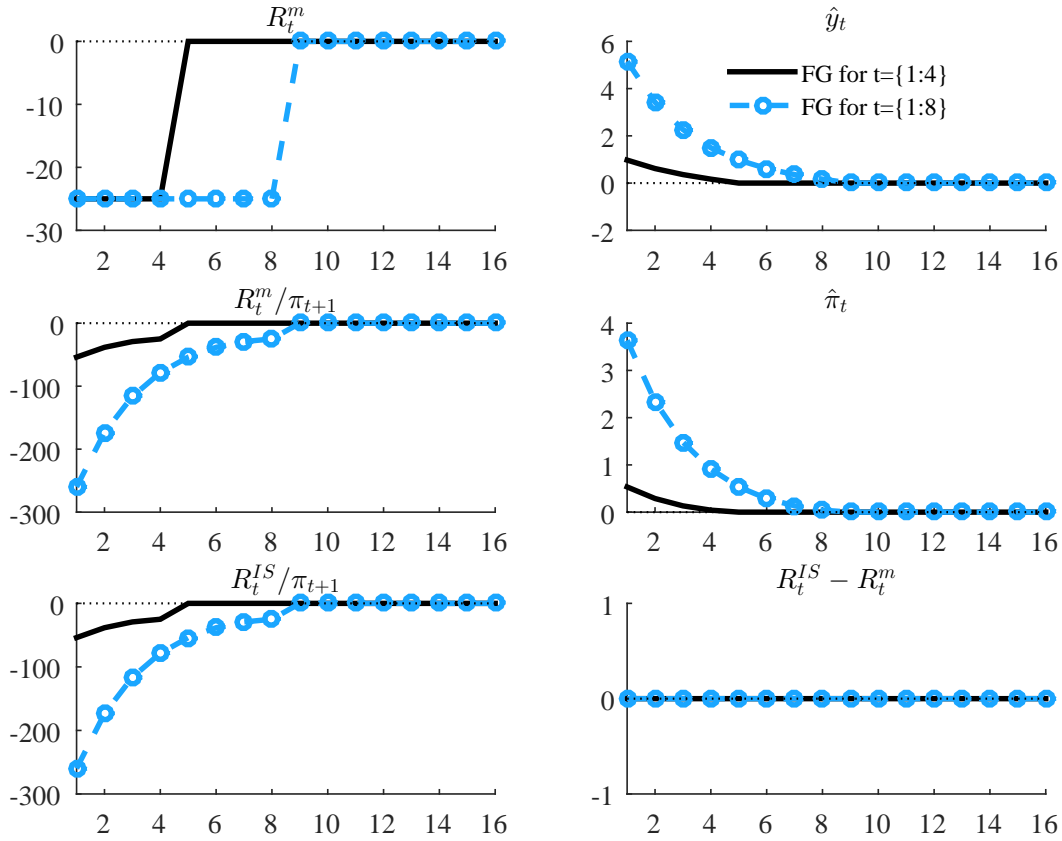**Figure 2:** Comparison with a model version without liquidity premium
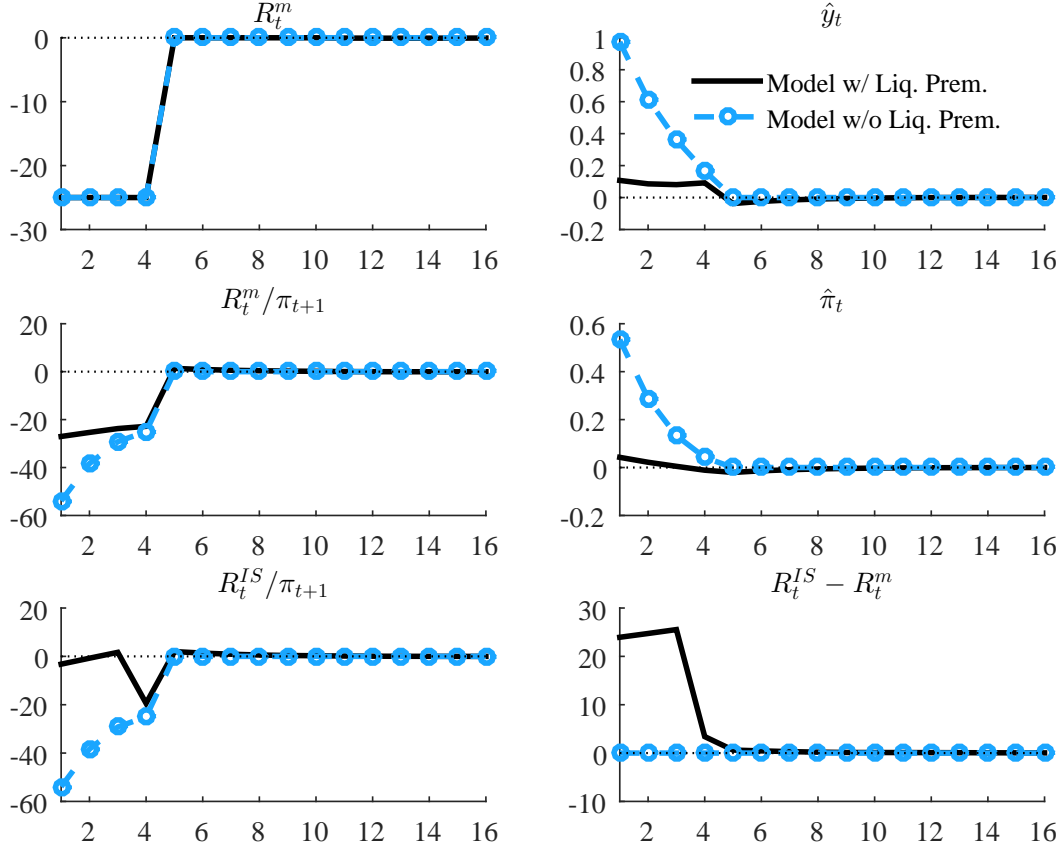
Notes: Impulse responses to policy rate (R_t^m) reduction of 25 basis points in quarters 1 to 4, announced before quarter 1: production y_t, inflation π_t, real policy rate R_t^m/π_{t+1}, private-sector real rate R_t^{IS}/π_{t+1}, liquidity premium $R_t^{IS} - R_t^m$. Y-axis: Deviations from steady state in percent ($\hat{y}_t$, $\hat{\pi}_t$) or in basis points (else). X-axis: quarters. Black line: Baseline model with endogenous liquidity premium. Blue circled line: model version without liquidity premium.

in the upper left panel of Figure 1. The interest rate reduction leads to a moderate increase of output by about 0.1%, see upper right panel of the figure. Output remains close to this level until the end of the guidance period. Once the policy rate increases, output experiences a brief dip before returning to its steady state value.

The real policy rate (middle left panel) behaves similar to the nominal rate where differences reflect the endogenous response of inflation. Inflation (middle right panel) rises on impact by about 0.05 percentage points but it starts decreasing already before the end of the guidance period. Households' real marginal rate of intertemporal substitution, R_t^{IS}/π_{t+1} (lower left panel), which is related to private-sector interest rates via (29), barely moves on impact and only experiences a negative spike at the end of the guidance period, reflecting the change in consumption. The liquidity premium $R_t^{IS} - R_t^m$ (lower right panel) instead increases sharply on impact and remains on that level until output drops. Comparing the scenario of forward guidance about 4 quarters with that about 8 quarters reveals that differences in terms of

Figure 3: Forward guidance in a model version without liquidity premium
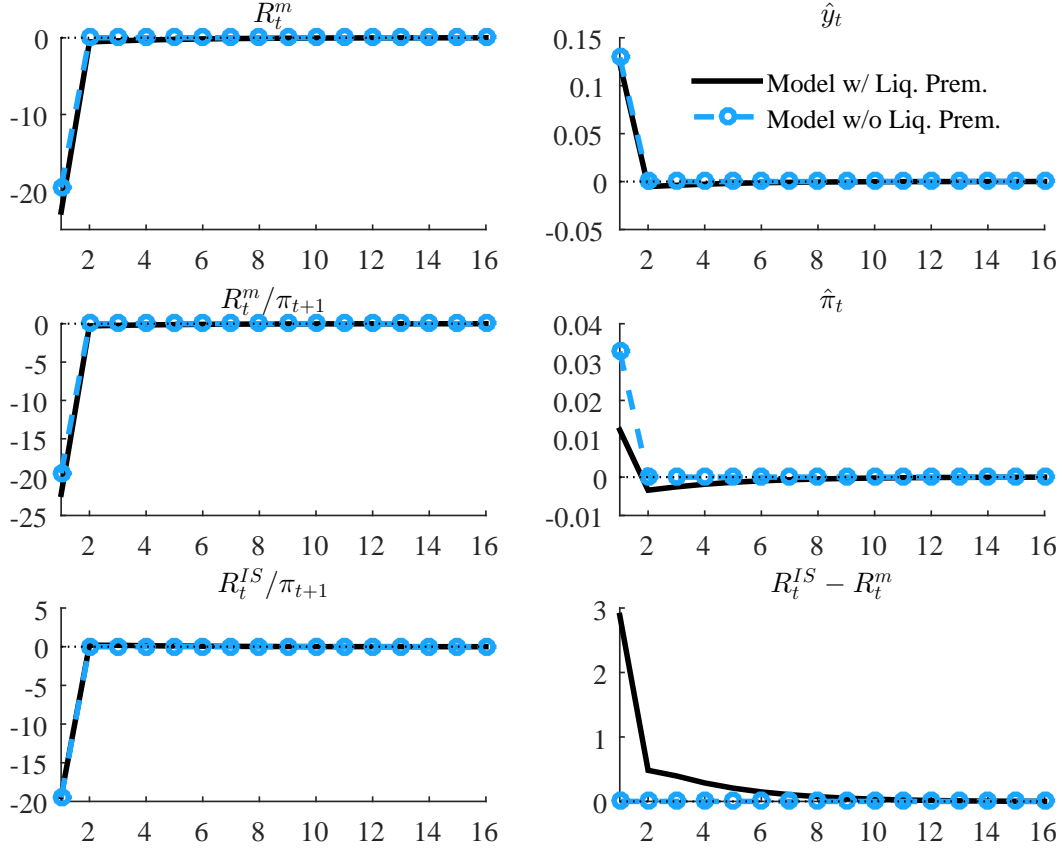

Notes: Impulse responses to forward guidance about policy rate R_t^m announced before quarter 1 in model version without liquidity premium: production y_t, inflation π_t, real policy rate R_t^m/π_{t+1}, private-sector real rate R_t^{IS}/π_{t+1}, liquidity premium $R_t^{IS} - R_t^m$. Y-axis: Deviations from steady state in percent ($\hat{y}_t$, $\hat{\pi}_t$) or in basis points (else). X-axis: quarters. Black line: Announced policy rate reduction of 25 basis points in quarters 1 to 4. Blue circled line: Announced policy rate reduction of 25 basis points in quarters 1 to 8.

the impact responses of output and the liquidity premium are small while inflation is slightly higher on impact in case of the longer horizon. Notably, this observation differs from the criticized prediction of the conventional New Keynesian model (without an endogenous liquidity premium) that the impact responses of output and inflation increase with the horizon of the forward guidance (see McKay et al., 2016) and is in line with the VAR results of Gertler and Karadi (2015) who compare monetary policy shocks with different forward guidance horizons and document that, while forward guidance increases the output effects of monetary policy in the medium run, the forward guidance horizon is not of primary importance empirically. Intuitively, cumulative output effects are more pronounced for the longer forward guidance experiment.

Figure 2 compares the effects of forward guidance in the model featuring the endogenous liquidity premium with a version of the model without the liquidity premium ($\eta_t = 0$, see 27), which corresponds to a conventional New Keynesian model. In both cases, the central bank

Figure 4: Effects of a non-announced reduction in the policy rate for one period

Notes: Impulse responses to conventional monetary policy of 25 basis points on monetary policy rate (R_t^m) in quarter 1 only: production y_t, inflation π_t, real policy rate R_t^m/π_{t+1}, private-sector real rate R_t^{IS}/π_{t+1}, liquidity premium $R_t^{IS} - R_t^m$. Y-axis: Deviations from steady state in percent ($\hat{y}_t$, $\hat{\pi}_t$) or in basis points (else). X-axis: quarters. Black line: Baseline model with endogenous liquidity premium. Blue circled line: model version without liquidity premium.

announces to reduce the policy rate by 25 basis points for the next 4 quarters and to return to steady state afterwards. The results for the model with the liquidity premium are identical to those from the first scenario of Figure 1. Output and inflation in the model version without the liquidity premium increase sharply on impact, in line with the findings by Carlstrom et al. (2015) and others but are too large compared to the empirical effects of forward guidance (see for example Gertler and Karadi, 2015). Compared to the model version with the liquidity premium, the responses on impact are about 10 times higher. In the model version without the liquidity premium, the central bank can steer the growth rate of consumption directly by adjusting the policy rate. The real interest rate falls by more on impact than the nominal rate due to the increase in inflation and, hence, add to the increase of consumption and output.

Figure 7 in the Appendix presents responses to a similar policy where the central bank provides forward guidance for four quarters about the real instead of the nominal policy rate which we perform for comparability to McKay et al. (2016). The results for both model

versions are similar to the ones presented in Figure 1. For this reason, we continue to consider policies where guidance is provided in terms of nominal policy rates.

Figure 3 shows the two forward guidance experiments in the model version without the liquidity premium. We see that the length of the guidance period has a huge impact on the output effect of monetary policy. Specifically, announcing low interest rates also for quarters 5 through 8 increases the impact response of output by factor 5, while there is almost no change in the impact response in the model version with the liquidity premium (see Figure 1).

Finally, Figure 4 shows the responses to a non-announced reduction in the policy rate for one period, in the model versions with and without the liquidity premium. The responses of the two models are very similar, except for the model with the liquidity premium generating a rise in the premium in line with the evidence presented in Section 2. Comparing this standard shock without forward guidance, we see that in the model without the liquidity premium, the impact output responses to both shocks are similar while the forward guidance policy intuitively triggers a longer expansion in output. In the standard model without the liquidity premium, the shock without forward guidance triggers an output expansion which is almost ten times smaller than the one induced by the one-year forward guidance policy.

To sum up, in our model with the liquidity premium, forward guidance increases the liquidity premium consistent with the data and prolongs the output effects of monetary policy, but does not substantially foster the immediate output effects. By contrast, in a standard New Keynesian model (without a liquidity premium), forward guidance affects the immediate output responses of monetary policy in an extreme way. Overall, the predictions of the model with the liquidity premium are in line with the VAR evidence of Gertler and Karadi (2015) who document that output responses to monetary policy shocks are affected by forward guidance, but only in the medium run and even slightly weakened on impact.

5 Conclusion

We show empirically that liquidity premia tend to rise after forward guidance announcements. We augment the conventional New Keynesian model by an endogenous liquidity premium that separates the monetary policy rate from other interest rates that are more relevant for private-sector transactions. We show both analytically and numerically that forward guidance is a much less powerful policy tool in this setting. The forward guidance puzzle can be solved in our framework and we provide a theoretical rationale for the increases in liquidity premia that are present in the data.

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Appendix

A   Appendix to the Empirical Analysis

A.1   The Case Study

The most relevant contents of the FOMC press releases on the three events of the case study in the introduction are the following:

2011-08-09: Economic growth has been "considerably lower" than expected. The federal funds rate target is unchanged at 0-0.25 percent. "[...] economic conditions [...] are likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013."

2012-01-25: The economy has been "expanding moderately". The federal funds rate target is unchanged at 0-0.25 percent. "[...] economic conditions [...] are likely to warrant exceptionally low levels for the federal funds rate at least through late 2014."

2012-09-13: Economic activity has "continued to expand at a moderate pace". The federal funds rate target is unchanged at 0-0.25 percent. "[...] exceptionally low levels for the federal funds rate are likely to be warranted at least through mid-2015." Additional purchases of mortgage-backed securities at a pace of $40 billion per month ("QE3") are announced.

For the full text of the press releases, see `www.federalreserve.gov`. See also Table 1 in Del Negro et al. (2015) for further details.

A.2   Measurement of Liquidity Premia

In this appendix, we describe the data sources and the construction of all interest rate spreads. We also provide summary statistics and figures of all our liquidity measures.

We collect daily return data on various assets to construct the spreads that aim at measuring liquidity premia. All spreads are calculated as the difference in annualized daily returns between Treasuries as the liquid near-money asset and an illiquid asset of similar safety and maturity. We use data from FRED (`https://fred.stlouisfed.org`) and from Bloomberg. Original mnemonics in the data source are given in square brackets.

- The data for the Treasury rates stem from FRED. We use the 'Treasury Constant Maturity Rates' with the mnemonic [DGS'xx'], where 'xx'= $\{3MO, 6MO, 1, 3, 5, 10\}$ refers to the maturity in months (MO) or years (else). We collect daily data from 1990-01-02 to 2016-09-16.

- Following Krishnamurthy and Vissing-Jorgensen (2012) as well as Del Negro et al. (2017), we construct several spreads between the rates on investment grade rated commercial papers or corporate bonds and Treasuries for different maturities. All series are taken from FRED.
  As a short-run measure, we use the '3-Month AA/P1 Nonfinancial Commercial Paper Rate' with mnemonic [DCPN3M] and we calculate the spread relative to the series

[DGS3MO].

For longer maturities, we employ the following four corporate bond indexes: (1) The 'Bank of America (BofA) Merrill Lynch US Corporate 1-3 Year Effective Yield', mnemonic [BAMLC1A0C13YEY], which is a subset of the 'BofA Merrill Lynch US Corporate Master Index' that includes investment grade rated corporate bonds that were publicly issued in the United States. The series that we use includes all securities with a remaining term to maturity between 1 and 3 years. We calculate the spread as [BAMLC1A0C13YEY] – [DGS3]. (2) The 'BofA Merrill Lynch US Corporate AAA Effective Yield', mnemonic [BAMLC0A1CAAAEY], which is a subset of the 'BofA Merrill Lynch US Corporate Master Index' that covers securities with an AAA rating. We calculate the spread as [BAMLC0A1CAAAEY] – [DGS5]. (3) 'Moody's Seasoned Aaa Corporate Bond Yield', mnemonic [DAAA], which consists of bonds with an AAA rating and long remaining terms to maturity. We construct the spread relative to the series [DGS10]. (4) 'Moody's Seasoned Baa Corporate Bond Yield', mnemonic [DBAA], which consists of US bonds with an BAA rating and long remaining terms to maturity. We construct the spread relative to the series [DGS10].

The series on commercial papers and the indexes from BofA Merrill Lynch are available to us from 1997-01-02 onwards. We collect data on the indexes by Moody's beginning on 1990-01-02.

- Krishnamurthy and Vissing-Jorgensen (2012) explain that the spread between the rates on certificates of deposit (CD) and Treasury bills can only reflect a liquidity attribute, since the certificates are basically risk free due to its coverage by the FDIC. CDs are relatively illiquid, as withdrawals before maturity usually imply large contractual penalties. We collect the series 'Certificate of Deposit: Secondary Market Rate' with maturities of 3 and 6 months from FRED with the mnemonics [DCD90] and [DCD6M]. We calculate the spreads relative to the Treasury series [DGS3MO] and [DGS6MO], respectively. Daily data is available to us from 1990-01-02 to 2013-06-28.

- Nagel (2016) suggests the spread between the rates on general collateral repurchase agreements (GC repos, hereafter) and the 3-month T-bill as a measure of the "premium for the liquidity services by near-money assets". He notes that these repos are very illiquid, as the term loan is locked in until maturity, which is also reflected by relatively wide bid-ask spreads. Since GC repos are collateralized with a portfolio of Treasuries, they are essentially risk free. We collect data from Bloomberg with the mnemonic [USRGCGC ICUS Curncy] from 1991-05-21 to 2016-09-16. We follow Nagel (2016) in calculating averages between bid and ask prices. We construct the spread relative to the series [DGS3MO].

Figure 5 shows the times series of the liquidity premium LP in equation (1). Figure 6 provides time series plots of all spreads along with a linear projection on the common factor

Figure 5: Time Series of the Liquidity Premium *LP*
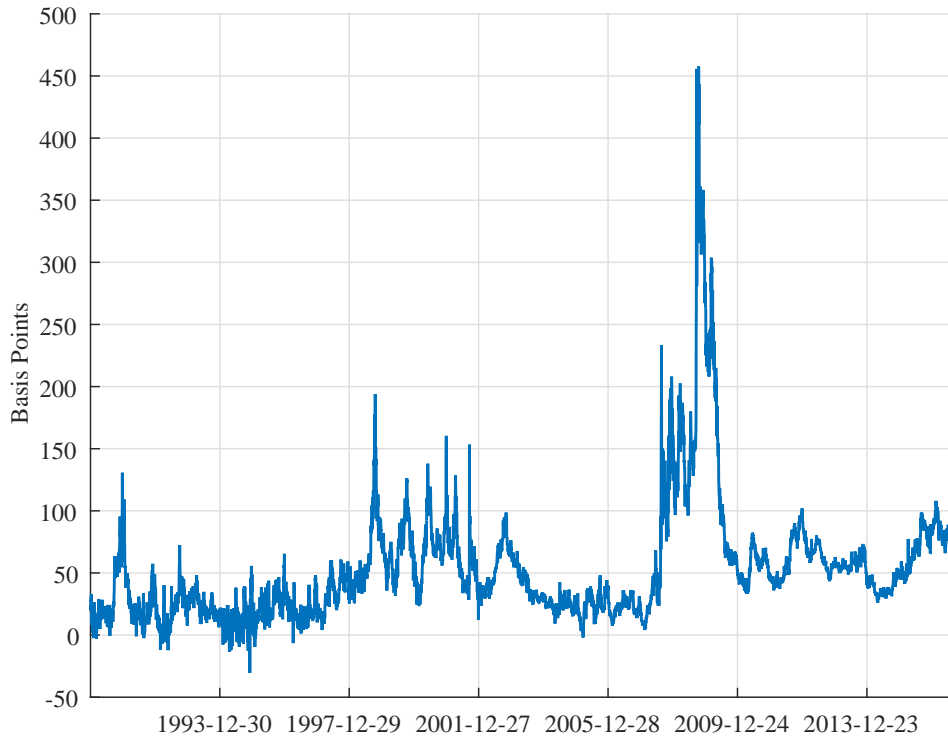
Notes: Plot of a time series of the liquidity premium in equation (1) in basis points using daily data from 1990-01-2 to 2016-09-16, constructed from a panel of 8 liquidity spreads using principal component analysis.

and a constant. Summary statistics on all spreads and the liquidity premium derived from the factor model are given in Table 4.

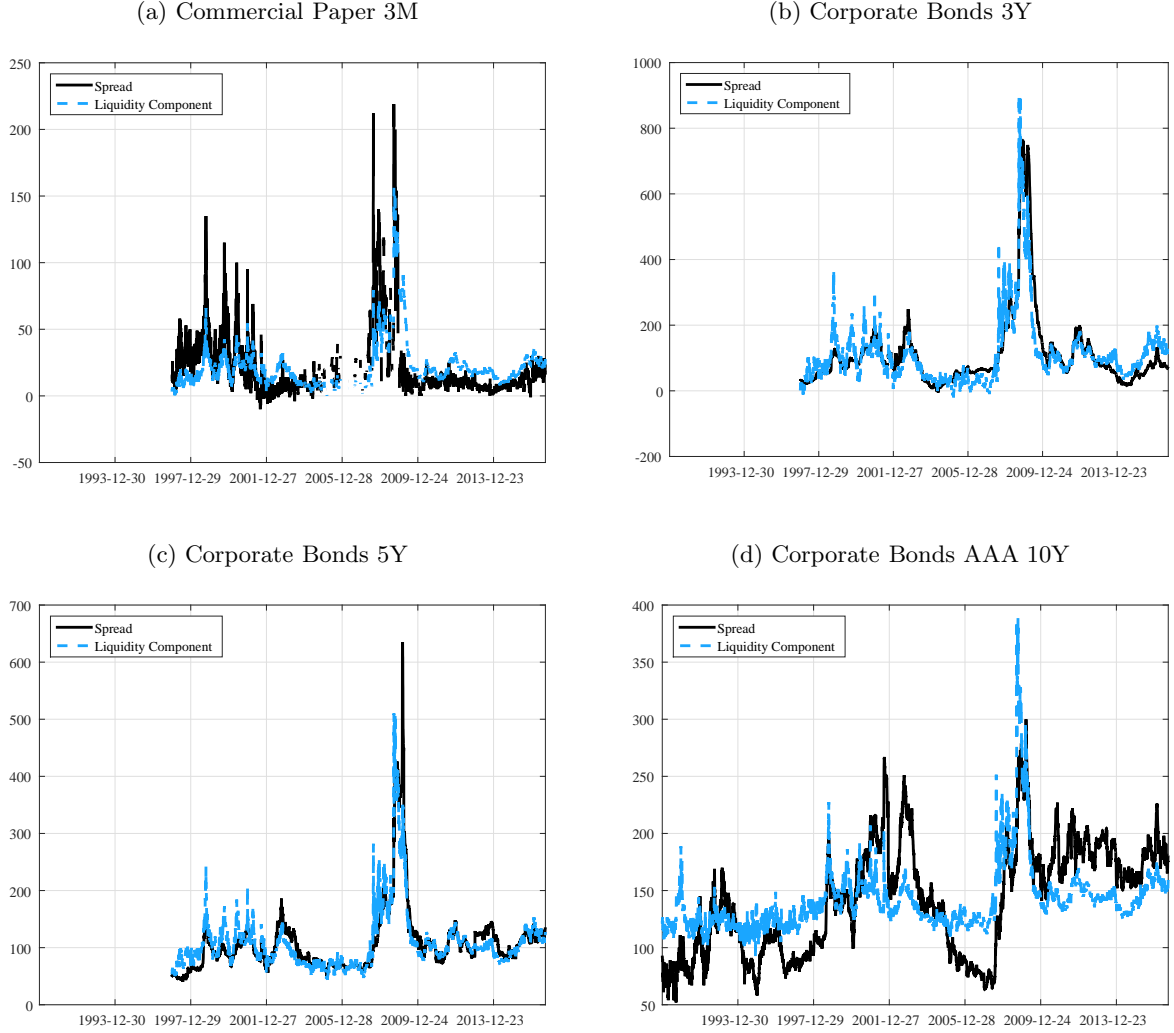## A.3 Estimation of the Target and the Path Factor

In this appendix, we describe the data sources of the federal funds and Eurodollar futures that we use. We explain how futures can be used to extract the surprise component of monetary policy at FOMC meeting dates and how we derive the target and the path factor.

Data Sources

All futures data are taken from Quandl (`https://www.quandl.com`).

- For the federal funds rate, we use the '30 Day Federal Funds Futures, Continuous Contract' series for the front month and the next 3 months thereafter. The mnemonics read [CHRIS/CME_FF'X'], where 'X'= $\{1, 2, 3, 4\}$ is the number of months until delivery of the contract. The raw data for the continuous contract calculation is from the Chicago Mercantile Exchange, where the futures are traded. We extract the daily settlement price (series 'settle'), which is given as 100 minus the average daily federal funds overnight rate for the delivery month, between 1990-01-02 to 2016-09-16.

Figure 6: Time Series of Liquidity Spreads and Common Factor

(a) Commercial Paper 3M

(b) Corporate Bonds 3Y

(c) Corporate Bonds 5Y

(d) Corporate Bonds AAA 10Y

Notes: Figure shows daily time series of liquidity spreads (black lines) along with their linear projections on the common factor and a constant (blue lines).

- For the Eurodollars, we use the 'Eurodollar Futures, Continuous Contract' series with the mnemonic [CHRIS/CME_ED'X'], where 'X'= $\{6, 9, 12\}$ gives the number of months until delivery of the contract. The raw data for the continuous contract calculation is from the Chicago Mercantile Exchange, where the futures are traded. We extract the daily settlement price (series 'settle'), which is given as 100 minus the 3-month London interbank offered rate for spot settlement on the 3rd Wednesday of the contract month, between 1990-01-02 to 2016-09-16.

Construction of the Monetary Surprise Components

We now explain how the elements of the data matrix X in equation (2) are constructed. The rows correspond to the 237 FOMC meeting dates between January 1990 and September 2016.

Figure 6 continued

(a) Corporate Bonds BAA 10Y

(b) GC Repo 3M

(c) Certicate of Deposit 3M
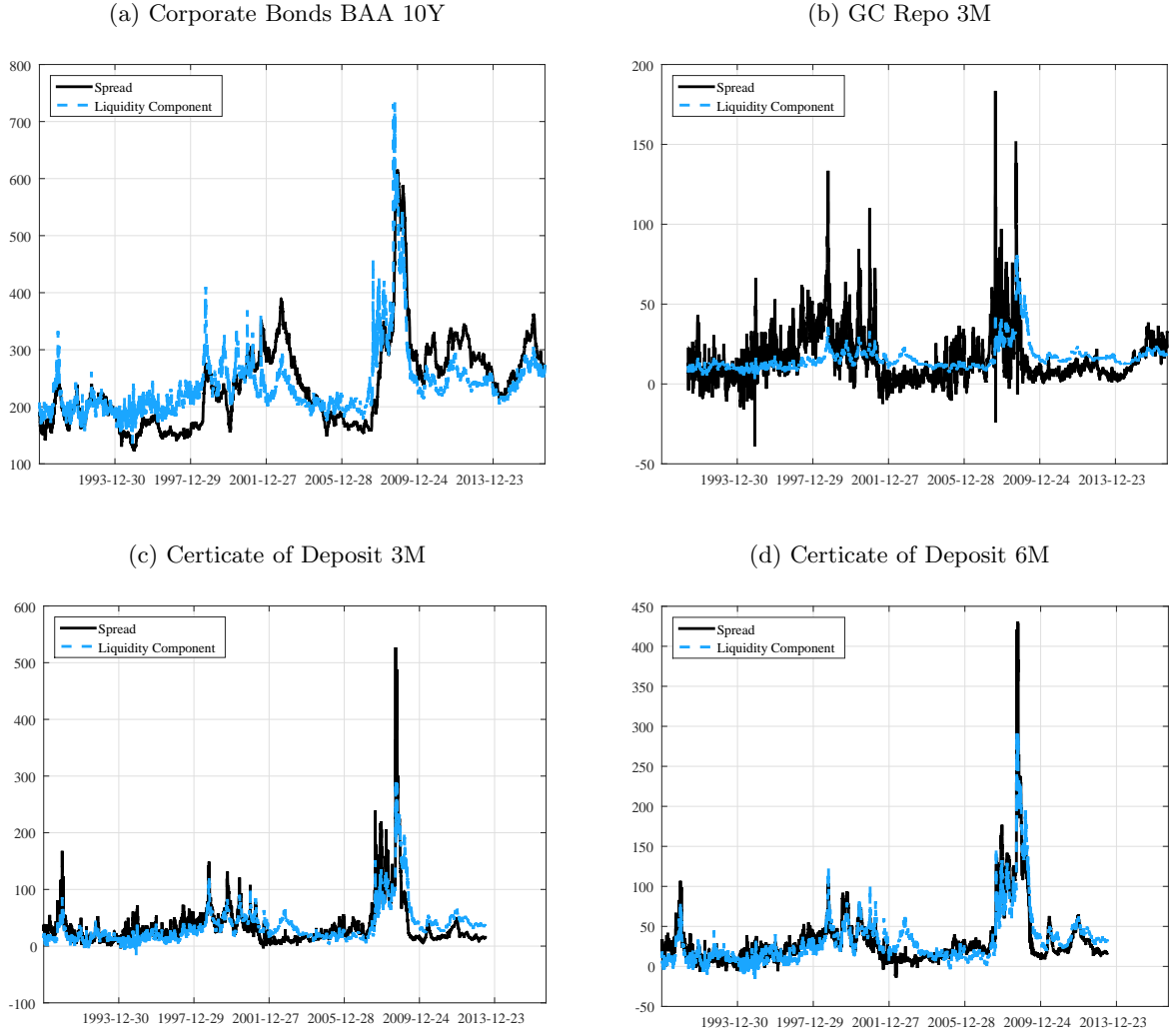
(d) Certicate of Deposit 6M

Notes: Figure shows daily time series of liquidity spreads (black lines) along with their linear projections on the common factor and a constant (blue lines).

The five columns of X refer to the different futures contracts. The third to fifth column gives the one-day change of the Eurodollar futures contracts with 6, 9, and 12 months until delivery around the FOMC meetings. Due to the spot settlement of these contracts, this difference directly gives a measure for the change in expectations about interest rates in 6, 9, and 12 months, respectively. The first two columns entail the surprise changes of expectations using mainly the 1- and the 3-month federal funds futures, whose calculation is more involved, since these contracts settle on the average federal funds rate in the delivery month. The following exposition is based on Gürkaynak et al. (2005) and Gürkaynak (2005).

Given the specification of the federal funds future contracts, the current month future

Table 4: Summary Statistics of Liquidity Spreads

Spread	Time Range	Mean	Std. Dev.
Commercial Paper 3M	1997-01-02 to 2016-09-16	21.82	24.79
Corporate Bonds 3Y	1997-01-02 to 2016-09-16	110.99	120.10
Corporate Bonds 5Y	1997-01-02 to 2016-09-16	108.89	60.61
Corporate Bonds AAA 10Y	1990-01-02 to 2016-09-16	141.55	47.74
Corporate Bonds BAA 10Y	1990-01-02 to 2016-09-16	238.00	77.47
Certificate of Deposit 3M	1990-01-02 to 2013-06-28	35.69	40.97
Certificate of Deposit 6M	1990-01-02 to 2013-06-28	31.83	37.49
GC Repo 3M	1991-05-21 to 2016-09-16	16.04	16.24
Liquidity Premium (Factor)	1990-01-02 to 2016-09-16	53.47	49.45

Notes: Mean and Standard Deviation (Std. Dev.) given in basis points.

settlement rate at the day before the FOMC meeting in t, $ff^1_{t-\Delta 1}$, can be written as

$$ff^1_{t-\Delta 1} = \frac{d_1}{m_1} r_{t-\Delta 1} + \frac{m_1 - d_1}{m_1} E_{t-\Delta 1}(r_t) + \varpi^1_{t-\Delta 1}, \tag{37}$$

where $r_{t-\Delta 1}$ is the average federal funds rate that has prevailed in this month until the day before the meeting (i.e., day $t - \Delta 1$), $E_{t-\Delta 1}(r_t)$ is the expectation at $t - \Delta 1$ about the federal funds rate for the rest of the month, d_1 the day of the FOMC meeting t in the current month with length m_1, and $\varpi^1_{t-\Delta 1}$ any potentially present term or risk premia. Analogously, the settlement rate at the day of the meeting itself reads

$$ff^1_t = \frac{d_1}{m_1} r_{t-\Delta 1} + \frac{m_1 - d_1}{m_1} r_t + \varpi^1_t. \tag{38}$$

Defining the surprise change in the target of the federal funds rate after the current meeting as $mp^1_t \equiv r_t - E_{t-\Delta 1}(r_t)$, allows its calculation according to

$$mp^1_t = \left(ff^1_t - ff^1_{t-\Delta 1}\right) \frac{m_1}{m_1 - d_1}, \tag{39}$$

which assumes that term and risk premia ϖ^1 do not change significantly between t and $t - \Delta 1$, which Gürkaynak et al. (2005) argue to be in line with empirical evidence. The change in the futures rates is scaled with the factor $m_1 / (m_1 - d_1)$, since the surprise change of the federal funds rate only applies to the remaining $m_1 - d_1$ days of the month. For meeting dates very close to the end of the month, the scaling factor becomes relatively big, which can be problematic when there is too much noise in the data. We therefore follow Gürkaynak (2005) and use the

unscaled change in the futures that are due in the next month, $mp_t^1 = \left(ff_t^2 - ff_{t-\Delta1}^2\right)$, when the meeting is within the last 7 days of the month. Another special case are FOMC meetings at the first day of the month. In this case, the monetary surprise has to be calculated as $mp_t^1 = \left(ff_t^1 - ff_{t-\Delta1}^2\right)$.

In a next step, we determine the change of expectations about the federal funds rate that will prevail after the second FOMC meeting $(t+1)$ from the perspective of $t - \Delta1$, r_{t+1}. These values form the entries in the second column of X. Since there are 8 regularly scheduled FOMC meetings per year, the next meeting $(t+1)$ will be in $j = \{1, 2\}$ months.[24] At date $t - \Delta1$, the futures rate that covers the second meeting from now is then given by

$$ff_{t-\Delta1}^{1+j} = \frac{d_{1+j}}{m_{1+j}} E_{t-\Delta1}\left(r_t\right) + \frac{m_{1+j} - d_{1+j}}{m_{1+j}} E_{t-\Delta1}\left(r_{t+1}\right) + \varpi_{t-\Delta1}^{1+j}, \tag{40}$$

where ff^{1+j} refers to the futures contract that expires in $1+j$ months, while d_{1+j} and m_{1+j} refer to the day and the length of the month of the second FOMC meeting from now, respectively. Analogously to the procedure above, we calculate the change in the expected target of the federal funds rate after the next meeting as

$$mp_t^{1+j} \equiv E_t\left(r_{t+1}\right) - E_{t-\Delta1}\left(r_{t+1}\right) = \left[\left(ff_t^{1+j} - ff_{t-\Delta1}^{1+j}\right) - \frac{d_{1+j}}{m_{1+j}} mp_t^1\right] \frac{m_{1+j}}{m_{1+j} - d_{1+j}}. \tag{41}$$

We apply the same corrections as above in case the meeting $t+1$ is on the first day or within the last week of the month.

Factor Estimation and Transformation

We normalize each column of X to have a zero mean and a unit variance before extracting the first two principal components. As there is a very small number of missing values for the 12-month Eurodollar future, we apply the method of Stock and Watson (2002). This gives us the two factors F_1 and F_2, which we again normalize to have a unit variance. Next, we determine the elements of the $[2 \times 2]$ transformation matrix U to obtain $\widetilde{F}_1$ and $\widetilde{F}_2$ in (3). The matrix U is given by the four elements

$$U = \begin{bmatrix} a_1\, b_1 \\ a_2\, b_2 \end{bmatrix},$$

whose identification requires four restrictions that we adopt from Gürkaynak et al. (2005).

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[24]In case of additional unscheduled meetings, the next meeting can also be in the same month. 23 of the 237 FOMC meetings in our sample are unscheduled intermeeting moves. Most of these observations occured in the early 1990s and some happened after surprising financial turmoil, e.g. 2001 and 2007/8. Following Gürkaynak (2005), we assume that on every FOMC meeting, future intermeeting moves are assumed to occur with zero probability.

We normalize the columns of U to unit length, which leads to the conditions

$$a_1^2 + a_2^2 = 1, \tag{42}$$

$$b_1^2 + b_2^2 = 1. \tag{43}$$

This assumption implies that the variance of $\widetilde{F}_1$ and $\widetilde{F}_2$ is unity. The next restriction demands that $\widetilde{F}_1$ and $\widetilde{F}_2$ remain orthogonal to each other, i.e., $E\left(\widetilde{F}_1, \widetilde{F}_2\right) = 0$. This can be shown to imply that the scalar product of the columns of U equals zero,

$$\langle U \rangle = a_1 b_1 + a_2 b_2 = 0. \tag{44}$$

The final restriction is that the second factor $\widetilde{F}_2$ does not affect the current monetary policy surprise, mp_t^1, that forms the first column of X. This is implemented as follows. Starting from $F = \widetilde{F}U^{-1}$, we write F_1 and F_2 as functions of $\widetilde{F}_1$ and $\widetilde{F}_2$, which yields

$$F_1 = \frac{1}{\det(U)} \left(b_2 \widetilde{F}_1 - a_2 \widetilde{F}_2 \right), \tag{45}$$

$$F_2 = \frac{1}{\det(U)} \left(a_1 \widetilde{F}_2 - b_1 \widetilde{F}_1 \right). \tag{46}$$

The current monetary surprise can be written as

$$mp_t^1 = \lambda_1 F_1 + \lambda_2 F_2,$$

where λ_1 and λ_2 are elements of the estimated loading matrix Λ in (2). Using (45) and (46), mp_t^1 can be rearranged to

$$mp_t^1 = \frac{1}{\det(U)} \left[(\lambda_1 b_2 - \lambda_2 b_1) \widetilde{F}_1 + (\lambda_2 a_1 - \lambda_1 a_2) \widetilde{F}_2 \right]. \tag{47}$$

Setting the coefficient of $\widetilde{F}_2$ in (47) to zero, then implements the restriction as

$$\lambda_2 a_1 - \lambda_1 a_2 = 0. \tag{48}$$

Using (42)-(44) and (48), we can solve for the elements of U to obtain the series for the target and the path factor, $\widetilde{F}_1$ and $\widetilde{F}_2$.

A.4 Additional Results

Tables 5 and 6 are the counterparts to Tables 2 and 3 for the sample 1990-2008. Results for this sample excluding the recent zero lower bound episode are similar to those for the total sample.

Table 5: Response of Asset Returns to Changes in Monetary Policy in a Sample Ending 2008-12-16

	Treasuries					GC
	3M	1Y	3Y	5Y	10Y	3M
Change in Federal Funds Rate $\widetilde{F}_1$	0.65***	0.60***	0.32***	0.20***	0.042	0.31***
	(0.080)	(0.059)	(0.040)	(0.040)	(0.041)	(0.078)
Change in Forward Guidance $\widetilde{F}_2$	0.18***	0.48***	0.74***	0.77***	0.66***	-0.001
	(0.054)	(0.050)	(0.069)	(0.067)	(0.058)	(0.057)
R^2	0.55	0.82	0.82	0.84	0.79	0.24
Number of Observations T	175	175	175	175	175	152
	Commercial Paper / Corporate Bonds					CD
	3M	3Y	5Y	10Y(A)	10Y(B)	3M
Change in Federal Funds Rate $\widetilde{F}_1$	0.27***	0.38***	0.15**	-0.033	-0.0047	0.37***
	(0.097)	(0.11)	(0.064)	(0.040)	(0.031)	(0.14)
Change in Forward Guidance $\widetilde{F}_2$	-0.003	0.62***	0.58***	0.37***	0.36***	0.18*
	(0.12)	(0.13)	(0.083)	(0.046)	(0.045)	(0.10)
R^2	0.11	0.44	0.61	0.53	0.54	0.22
Number of Observations T	73	103	103	175	175	175

Notes: Table shows responses of asset returns to changes in the federal funds rate, measured by the target factor, and to changes in forward guidance, measured by the path factor, at FOMC meetings between January 1990 and December 2008. Constant included in all regressions. Heteroskedasticity-robust (White) standard errors in parentheses. Asterisks mark significance at 10% (*), 5% (**), 1% (***). Maturity is measured either in months (M) or in years (Y). Corporate Bond 10Y(A) and (B) refer to long-term bonds with AAA and BAA rating, respectively. CD: Certificate of Deposit; GC: General Collateral Repo.

Table 6: Response of Liquidity Spreads to Changes in Monetary Policy in a Sample Ending 2008-12-16

	Liquidity Premium LP	Commercial Paper / Corporate Bond spread				
		3M	3Y	5Y	10Y(A)	10Y(B)
Change in Federal Funds Rate $\widetilde{F}_1$	-0.41***	-0.28***	0.154*	0.031	-0.075	-0.047
	(0.13)	(0.10)	(0.090)	(0.060)	(0.061)	(0.045)
Change in Forward Guidance $\widetilde{F}_2$	-0.32***	-0.15	-0.063	-0.14***	-0.29***	-0.30***
	(0.081)	(0.12)	(0.076)	(0.047)	(0.042)	(0.034)
R^2	0.30	0.09	0.05	0.10	0.43	0.53
Number of Observations T	175	73	103	103	175	175

	GC spread		CD spread	
	3M		3M	6M
Change in Federal Funds Rate $\widetilde{F}_1$	-0.36**		-0.27*	-0.35*
	(0.15)		(0.15)	(0.19)
Change in Forward Guidance $\widetilde{F}_2$	-0.20**		-0.0014	-0.13
	(0.088)		(0.11)	(0.16)
R^2	0.21		0.08	0.10
Number of Observations T	152		175	175

Notes: Table shows responses of liquidity spreads to changes in the federal funds rate, measured by the target factor, and to changes in forward guidance, measured by the path factor, at FOMC meetings between January 1990 and December 2008. Constant included in all regressions. Heteroskedasticity-robust (White) standard errors in parentheses. Asterisks mark significance at 10% (*), 5% (**), 1% (***). Maturity is measured either in months (M) or in years (Y). Corporate Bond 10Y(A) and (B) refer to long-term bonds with AAA and BAA rating, respectively. CD: Certificate of Deposit; GC: General Collateral Repo. All spreads are calculated relative to Treasuries of the same maturity.

B   Definition of Equilibrium

Definition 1 *A rational expectations equilibrium is a set of sequences $\{c_t,\ y_t,\ n_t,\ w_t,\ \lambda_t,\ m_t^R,\ m_t,\ b_t,\ b_t^T,\ mc_t,\ Z_{1,t},\ Z_{2,t},\ Z_t,\ s_t,\ \pi_t,\ R_t^{IS}\}_{t=0}^\infty$ satisfying*

$$c_t = m_t + m_t^R, \ if \ R_t^{IS} > 1, \quad or \ c_t \leq m_t + m_t^R, \ if \ R_t^{IS} = 1, \tag{49}$$

$$b_{t-1}/\left(R_t^m \pi_t\right) = m_t - m_{t-1}\pi_t^{-1} + m_t^R, \ if \ R_t^{IS} > R_t^m, \tag{50}$$

$$or \ b_{t-1}/\left(R_t^m \pi_t\right) \geq m_t - m_{t-1}\pi_t^{-1} + m_t^R, \ if \ R_t^{IS} = R_t^m,$$

$$m_t^R = \Omega m_t, \tag{51}$$

$$b_t = b_t^T - m_t, \tag{52}$$

$$b_t^T = \Gamma b_{t-1}^T / \pi_t, \tag{53}$$

$$\theta n_t^{\sigma_n} = u_{c,t} w_t / R_t^{IS}, \tag{54}$$

$$1/R_t^{IS} = \beta E_t \left[u_{c,t+1}/\left(u_{c,t}\pi_{t+1}\right)\right], \tag{55}$$

$$w_t/\left(\alpha n_t^{\alpha-1}\right) = mc_t, \tag{56}$$

$$\lambda_t = \beta E_t \left[u_{c,t+1}/\pi_{t+1}\right], \tag{57}$$

$$Z_{1,t} = \lambda_t y_t mc_t + \phi\beta E_t \pi_{t+1}^\varepsilon Z_{1,t+1}, \tag{58}$$

$$Z_{2,t} = \lambda_t y_t + \phi\beta E_t \pi_{t+1}^{\varepsilon-1} Z_{2,t+1}, \tag{59}$$

$$Z_t = \left[\varepsilon/\left(\varepsilon-1\right)\right] Z_{1,t}/Z_{2,t}, \tag{60}$$

$$1 = (1-\phi)Z_t^{1-\varepsilon} + \phi\pi_t^{\varepsilon-1}, \tag{61}$$

$$s_t = (1-\phi)Z_t^{-\varepsilon} + \phi s_{t-1}\pi_t^\varepsilon, \tag{62}$$

$$y_t = n_t^\alpha / s_t, \tag{63}$$

$$y_t = c_t, \tag{64}$$

(where $u_{c,t} = c_t^{-\sigma}$), the transversality conditions, a monetary policy $\{R_t^m \geq 1\}_{t=0}^\infty$, $\Omega > 0$, $\pi \geq \beta$, and a fiscal policy $\Gamma \geq 1$, for given initial values $M_{-1} > 0$, $B_{-1} > 0$, $B_{-1}^T > 0$, and $s_{-1} \geq 1$.

Given a rational expectations equilibrium as summarized in Definition 1, the equilibrium sequences $\{R_t,\ R_t^D,\ R_{t+1}^q,\ R_t^L\}_{t=0}^\infty$ can be determined by

$$R_t = E_t[u_{c,t+1}\pi_{t+1}^{-1}]/[E_t \left(R_{t+1}^m\right)^{-1} u_{c,t+1}\pi_{t+1}^{-1}], \tag{65}$$

$$\lambda_t/R_t^D = \beta E_t[(u_{c,t+1} + (1-\mu)\lambda_{t+1})/\pi_{t+1}], \tag{66}$$

$$1 = \beta E_t \left[\left(R_{t+1}^q/\pi_{t+1}\right)\left(\lambda_{t+1}/\lambda_t\right)\right], \tag{67}$$

$$1/R_t^L = E_t \left[1/R_{t+1}^{IS}\right], \tag{68}$$

If the money supply constraint (12) is not binding, which is the case if $R_t^m = R_t^{IS}$ (see 27), the model given in Definition 1 reduces to a standard New Keynesian model with a cash-in-advance constraint, where government liabilities can be determined residually.

Definition 2 *A rational expectations equilibrium under a non-binding money supply constraint (12) is a set of sequences $\{c_t,\ y_t,\ n_t,\ w_t,\ \lambda_t,\ mc_t,\ Z_{1,t},\ Z_{2,t},\ Z_t,\ s_t,\ \pi_t,\ R_t^{IS}\}_{t=0}^\infty$ satisfying $R_t^{IS} = R_t^m$, (54)-(64), the transversality conditions, and a monetary policy $\{R_t^m \geq 1\}_{t=0}^\infty$, $\pi \geq \beta$, for a given initial value $s_{-1} \geq 1$.*

C   Appendix to Section 4

C.1   Analytical Results

Proof of Proposition 1.   To establish the claims made in the proposition, the model given in Definition 1 for the version with $R_t^m < R_t^{IS}$, i.e., (31)-(35), is further simplified by substituting out $\widehat{R}_t^{IS}$ and $\widehat{R}_t^m$. For the purpose of this analysis, we restrict ourselves to $K = 1$ in (35):

$$\widehat{\pi}_t = \delta E_t \widehat{\pi}_{t+1} + \widehat{c}_t + \widehat{b}_t - \widehat{\varepsilon}_{t+1,t}^m, \tag{69}$$

$$\widehat{c}_t = \widehat{b}_{t-1} - (1 + \rho_\pi)\widehat{\pi}_t - \widehat{\varepsilon}_{t,t-1}^m, \tag{70}$$

$$\widehat{b}_t = \widehat{b}_{t-1} - \widehat{\pi}_t, \tag{71}$$

where $\delta = \beta - \chi \rho_\pi > 0$. We assume that (36) is satisfied, which ensures existence and uniqueness of a locally stable solution. We begin with analyzing the effects of a policy rate reduction in period t, i.e., $\widehat{\varepsilon}_t^m < 0$, by applying the following solution form for the system (69)-(71):

$$\widehat{\pi}_t = \gamma_{\pi b} \widehat{b}_{t-1} + \gamma_{\pi\varepsilon}^m \widehat{\varepsilon}_t^m, \tag{72}$$

$$\widehat{b}_t = \gamma_b \widehat{b}_{t-1} + \gamma_{b\varepsilon}^m \widehat{\varepsilon}_t^m, \tag{73}$$

$$\widehat{c}_t = \gamma_{cb} \widehat{b}_{t-1} + \gamma_{c\varepsilon}^m \widehat{\varepsilon}_t^m. \tag{74}$$

Substituting out the endogenous variables in (69)-(71) with the generic solutions in (72)-(74), leads to the following conditions for $\gamma_{\pi b}$, γ_{cb}, γ_b, $\gamma_{\pi\varepsilon}^m$, $\gamma_{c\varepsilon}^m$, and $\gamma_{b\varepsilon}^m$:

$$\gamma_{\pi b} = \delta \gamma_{\pi b} \gamma_b + \chi \gamma_b + \chi \gamma_{cb}, \; 1 = (1 + \rho_\pi) \gamma_{\pi b} + \gamma_{cb}, \; 1 = \gamma_b + \gamma_{\pi b}, \tag{75}$$

$$\gamma_{\pi\varepsilon}^m = (\delta \gamma_{\pi b} + \chi) \gamma_{b\varepsilon}^m + \chi \gamma_{c\varepsilon}^m, \; \gamma_{c\varepsilon}^m = - (1 + \rho_\pi) \gamma_{\pi\varepsilon}^m - 1, \; \gamma_{b\varepsilon}^m = -\gamma_{\pi\varepsilon}^m. \tag{76}$$

Using the three conditions in (75) and substituting out $\gamma_{\pi b}$ with $\gamma_{\pi b} = 1 - \gamma_b$, gives $0 = (\delta \gamma_b - 1)(1 - \gamma_b) + \chi \gamma_b + \chi \gamma_{cb}$, $1 = (1 + \rho_\pi)(1 - \gamma_b) + \gamma_{cb}$, and further eliminating γ_{cb}, leads to $0 = (\delta \gamma_b - 1)(1 - \gamma_b) + \chi \gamma_b + \chi (1 - (1 + \rho_\pi)(1 - \gamma_b))$, which is a quadratic equation in γ_b that reads $\gamma_b^2 - (\delta + \chi + \chi (\rho_\pi + 1) + 1) \delta \gamma_b + (\rho_\pi \chi + 1) \delta = 0$. Condition (36) ensures that there exists exactly one stable and positive solution (see proof of Lemma 1 in Bredemeier et al., 2017). Assigning the stable root to $\gamma_b \in (0, 1)$, such that $\gamma_{\pi b} = 1 - \gamma_b \in (0, 1)$, we can easily identify the effects of the monetary policy shock $\widehat{\varepsilon}_t^m$ on inflation and consumption in t, i.e., $\gamma_{\pi\varepsilon}^m$ and $\gamma_{c\varepsilon}^m$: Combining the three conditions in (76) yields

$$\gamma_{\pi\varepsilon}^m = -\frac{\chi}{1 + \delta \gamma_{\pi b} + \chi (2 + \rho_\pi)} < 0, \tag{77}$$

where we used $\gamma_{\pi b} > 0$. Inflation in t, thus, increases in response to an expansionary conventional monetary policy shock. The effect on consumption can be obtained by using (77) in $\gamma_{c\varepsilon}^m = - (1 + \rho_\pi) \gamma_{\pi\varepsilon}^m - 1$, which gives

$$\gamma_{c\varepsilon}^m = \frac{\chi (1 + \rho_\pi)}{1 + \delta \gamma_{\pi b} + \chi (2 + \rho_\pi)} - 1 < 0. \tag{78}$$

Hence, consumption in t also increases in response to the conventional monetary policy shock, $\gamma_{c\varepsilon}^m < 0$. To identify the effects of the monetary policy shock on the liquidity premium $\widehat{R}_t^{IS} - \widehat{R}_t^m$, we use the generic solutions (72)-(74) for the equilibrium conditions (32) and (35), leading to

$$\widehat{R}_t^{IS} = [\gamma_{cb}(\gamma_b - 1) + \gamma_{\pi b}\gamma_b]\,\widehat{b}_{t-1} + [\gamma_{cb}\gamma_{b\varepsilon}^m - \gamma_{c\varepsilon}^m + \gamma_{\pi b}\gamma_{b\varepsilon}^m]\,\widehat{\varepsilon}_t^m, \tag{79}$$

$$\widehat{R}_t^m = \rho_\pi\gamma_{\pi b}\widehat{b}_{t-1} + (1 + \rho_\pi\gamma_{\pi\varepsilon}^m)\,\widehat{\varepsilon}_t^m. \tag{80}$$

Therefore, the response of the liquidity premium to the monetary policy shock is

$$\partial(\widehat{R}_t^{IS} - \widehat{R}_t^m)/\partial\widehat{\varepsilon}_t^m = (\gamma_{cb}\gamma_{b\varepsilon}^m - \gamma_{c\varepsilon}^m) + \gamma_{\pi b}\gamma_{b\varepsilon}^m - \rho_\pi\gamma_{\pi\varepsilon}^m - 1 = \rho_\pi\gamma_{\pi b}\gamma_{\pi\varepsilon}^m < 0, \tag{81}$$

where we used $\gamma_{c\varepsilon}^m = -(1 + \rho_\pi)\gamma_{\pi\varepsilon}^m - 1$, $\gamma_{b\varepsilon}^m = -\gamma_{\pi\varepsilon}^m$, $1 = (1 + \rho_\pi)\gamma_{\pi b} + \gamma_{cb}$, and $\gamma_{\pi b} > 0$. Hence, the liquidity premium rises in response to the expansionary monetary policy shock, establishing the claims made in part 1. of the proposition.

We now identify the responses in periods t and $t + 1$ to a negative monetary policy shock in $t + 1$ that is announced in t, $\widehat{\varepsilon}_{t+1,t}^m < 0$. To account for policy announcements, we apply the solution form

$$\widehat{\pi}_t = \gamma_{\pi b}\widehat{b}_{t-1} + \gamma_{\pi\varepsilon}\widehat{\varepsilon}_{t+1,t}^m + \gamma_{\pi\varepsilon}'\widehat{\varepsilon}_{t,t-1}^m, \tag{82}$$

$$\widehat{b}_t = \gamma_b\widehat{b}_{t-1} + \gamma_{b\varepsilon}\widehat{\varepsilon}_{t+1,t}^m + \gamma_{b\varepsilon}'\widehat{\varepsilon}_{t,t-1}^m, \tag{83}$$

$$\widehat{c}_t = \gamma_{cb}\widehat{b}_{t-1} + \gamma_{c\varepsilon}\widehat{\varepsilon}_{t+1,t}^m + \gamma_{c\varepsilon}'\widehat{\varepsilon}_{t,t-1}^m, \tag{84}$$

for the system (69)-(71), where $\gamma_{\pi\varepsilon}$, $\gamma_{b\varepsilon}$, and $\gamma_{c\varepsilon}$ measure the effects of the announcement on the endogenous variables in t, while $\gamma_{\pi\varepsilon}'$, $\gamma_{b\varepsilon}'$, and $\gamma_{c\varepsilon}'$ show the effect in $t + 1$. Following the procedure from above and substitute for the variables in (69)-(71) using the generic solutions in (82)-(84), leads to the conditions

$$\gamma_{\pi b} = \delta\gamma_{\pi b}\gamma_b + \chi\gamma_b + \chi\gamma_{cb}, \; 1 = (1 + \rho_\pi)\gamma_{\pi b} + \gamma_{cb}, \; 1 = \gamma_b + \gamma_{\pi b}, \tag{85}$$

$$\gamma_{\pi\varepsilon}' = (\delta\gamma_{\pi b} + \chi)\gamma_{b\varepsilon}' + \chi\gamma_{c\varepsilon}', \; \gamma_{c\varepsilon}' = -(1 + \rho_\pi)\gamma_{\pi\varepsilon}' - 1, \; \gamma_{b\varepsilon}' = -\gamma_{\pi\varepsilon}', \tag{86}$$

$$\gamma_{\pi\varepsilon} = (\delta\gamma_{\pi\varepsilon}' - \chi) + (\delta\gamma_{\pi b} + \chi)\gamma_{b\varepsilon} + \chi\gamma_{c\varepsilon}, \; \gamma_{c\varepsilon} = -(1 + \rho_\pi)\gamma_{\pi\varepsilon}, \; \gamma_{b\varepsilon} = -\gamma_{\pi\varepsilon}. \tag{87}$$

First note that lines (85) and (86) correspond to (75) and (76) with $\gamma_{x\varepsilon}'$ replacing $\gamma_{x\varepsilon}^m$ for a generic variable $x = \pi, b, c$. The conditions in (85) and (86) feature the six unknown coefficients $\gamma_{\pi\varepsilon}'$, $\gamma_{b\varepsilon}'$, $\gamma_{c\varepsilon}'$, $\gamma_{\pi b}$, γ_b, and γ_{cb}, while the corresponding conditions (75) and (76) feature $\gamma_{\pi\varepsilon}^m$, $\gamma_{b\varepsilon}^m$, $\gamma_{c\varepsilon}^m$, $\gamma_{\pi b}$, γ_b, and γ_{cb}. While $\gamma_{\pi b}$, γ_b, and γ_{cb} are unchanged, $\gamma_{\pi\varepsilon}'$, $\gamma_{b\varepsilon}'$, and $\gamma_{c\varepsilon}'$, are identical with $\gamma_{\pi\varepsilon}^m$, $\gamma_{b\varepsilon}^m$, and $\gamma_{c\varepsilon}^m$, respectively.

We start by identifying the effects of a change in the policy rate in $t + 1$ announced in t on inflation and consumption in period t, i.e., $\gamma_{\pi\varepsilon}$ and $\gamma_{c\varepsilon}$. Combining the three conditions in (87) yields

$$\gamma_{\pi\varepsilon} = \frac{\delta\gamma_{\pi\varepsilon}' - \chi}{1 + \delta\gamma_{\pi b} + \chi(2 + \rho_\pi)} < 0, \tag{88}$$

46

where we used that $\delta > 0$ and $\gamma'_{\pi\varepsilon} < 0$. For the consumption response in period t we apply the condition $\gamma_{c\varepsilon} = -(1 + \rho_\pi)\gamma_{\pi\varepsilon}$ from (87), which implies $\gamma_{c\varepsilon} > 0$. In response to the forward guidance shock, consumption falls and inflation rises in period t. For the liquidity premium $\widehat{R}_t^{IS} - \widehat{R}_t^m$, we use the generic solutions (82)-(84) in the equilibrium conditions as above to write the two rates as

$$\widehat{R}_t^{IS} = [\gamma_{cb}(\gamma_b - 1) + \gamma_{\pi b}\gamma_b]\widehat{b}_{t-1} + [\gamma_{cb}\gamma_{b\varepsilon} + \gamma'_{c\varepsilon} - \gamma_{c\varepsilon} + \gamma_{\pi b}\gamma_{b\varepsilon} + \gamma'_{\pi\varepsilon}]\widehat{\varepsilon}_{t+1,t}^m$$
$$+ [\gamma_{cb}\gamma'_{b\varepsilon} - \gamma'_{c\varepsilon} + \gamma_{\pi b}\gamma'_{b\varepsilon}]\widehat{\varepsilon}_{t,t-1}^m, \tag{89}$$

$$\widehat{R}_t^m = \rho_\pi\gamma_{\pi b}\widehat{b}_{t-1} + \rho_\pi\gamma_{\pi\varepsilon}\widehat{\varepsilon}_{t+1,t}^m + (1 + \rho_\pi\gamma'_{\pi\varepsilon})\widehat{\varepsilon}_{t,t-1}^m, \tag{90}$$

respectively. Hence, the reaction of $\widehat{R}_t^{IS} - \widehat{R}_t^m$ to the announcement $\widehat{\varepsilon}_{t+1,t}^m$ is given by

$$\partial(\widehat{R}_t^{IS} - \widehat{R}_t^m)/\partial\widehat{\varepsilon}_{t+1,t}^m = \gamma_{cb}\gamma_{b\varepsilon} + \gamma'_{c\varepsilon} - \gamma_{c\varepsilon} + \gamma_{\pi b}\gamma_{b\varepsilon} + \gamma'_{\pi\varepsilon} - \rho_\pi\gamma_{\pi\varepsilon}$$
$$= \rho_\pi\gamma_{\pi b}\gamma_{\pi\varepsilon} + \gamma'_{c\varepsilon} + \gamma'_{\pi\varepsilon} < 0, \tag{91}$$

where we used $\gamma_{cb} = 1 - (1 + \rho_\pi)\gamma_{\pi b}$ from (85) and $\gamma_{c\varepsilon} = -(1 + \rho_\pi)\gamma_{\pi\varepsilon}$ and $\gamma_{b\varepsilon} = -\gamma_{\pi\varepsilon}$ from (87), and where the sign follows from $\gamma_{\pi\varepsilon}, \gamma'_{\pi\varepsilon}, \gamma'_{c\varepsilon} < 0$ and $\rho_\pi, \gamma_{\pi b} > 0$. Hence, the liquidity premium rises on impact in response to the negative forward guidance shock. This completes the proof of the claims made in part 2a. of the proposition.

Finally, we identify the responses of consumption, inflation, and the liquidity premium in period $t + 1$ to the announced policy change $\widehat{\varepsilon}_{t+1,t}^m$. For these reactions, we have to take into account that period $t+1$ is already entered with a state variable $\widehat{b}_t \neq 0$ which reflects the effects of the announcement in period t. Specifically, by forward iteration of the generic solutions (82) and (84), the responses of $\widehat{\pi}_{t+1}$ and $\widehat{c}_{t+1}$ to $\widehat{\varepsilon}_{t+1,t}^m$ are given by

$$\partial\widehat{\pi}_{t+1}/\partial\widehat{\varepsilon}_{t+1,t}^m = \gamma'_{\pi\varepsilon} + \gamma_{\pi b}\gamma_{b\varepsilon} \text{ and } \partial c_{t+1}/\partial\widehat{\varepsilon}_{t+1,t}^m = \gamma'_{c\varepsilon} + \gamma_{cb}\gamma_{b\varepsilon},$$

where we have used $\partial\widehat{b}_t/\partial\widehat{\varepsilon}_{t+1,t}^m = \gamma_{b\varepsilon}$ according to (83). Using $\gamma'_{\pi\varepsilon} = \gamma_{\pi\varepsilon}^m$, $0 < \gamma_{\pi b} < 1$ and $\gamma_{b\varepsilon} = -\gamma_{\pi\varepsilon}$ from above, it is sufficient to show that $\gamma_{\pi\varepsilon} > \gamma_{\pi\varepsilon}^m$ to prove that $\partial\widehat{\pi}_{t+1}/\partial\widehat{\varepsilon}_{t+1,t}^m < 0$. Using (77) and (88), we can express $\gamma_{\pi\varepsilon} = \gamma'_{\pi\varepsilon} + \frac{\chi\delta}{(1+\delta\gamma_{\pi b}+\chi(2+\rho_\pi))^2}$ where $\frac{\chi\delta}{(1+\delta\gamma_{\pi b}+\chi(2+\rho_\pi))^2} > 0$ such that $\gamma_{\pi\varepsilon} > \gamma_{\pi\varepsilon}^m$ and, hence, $\partial\widehat{\pi}_{t+1}/\partial\widehat{\varepsilon}_{t+1,t}^m < 0$. Turning to the consumption response, the claim that $\partial c_{t+1}/\partial\widehat{\varepsilon}_{t+1,t}^m < 0$ is equivalent to

$$1 + \delta\gamma_{\pi b} > \rho_\pi\gamma_{\pi b}\delta\gamma'_{\pi\varepsilon} - \rho_\pi\gamma_{\pi b}\chi - \chi, \tag{92}$$

which uses $\gamma_{b\varepsilon} = -\gamma_{\pi\varepsilon}$, (78), (88) and $\gamma_{cb} = 1 - (1 + \rho_\pi)\gamma_{\pi b}$. Since $\rho_\pi, \gamma_{\pi b}, \delta, \chi > 0$ and $\gamma'_{\pi\varepsilon} < 0$, the condition (92) is indeed satisfied and, hence, $\partial\widehat{\pi}_{t+1}/\partial\widehat{\varepsilon}_{t+1,t}^m < 0$. Finally, the response of the premium is governed by

$$\partial(\widehat{R}_{t+1}^{IS} - \widehat{R}_{t+1}^m)/\partial\widehat{\varepsilon}_{t+1,t}^m = [(\gamma_{cb}\gamma_{b\varepsilon} + \gamma'_{c\varepsilon} - \gamma_{c\varepsilon}) + \gamma_{\pi b}\gamma_{b\varepsilon} + \gamma'_{\pi\varepsilon} - (1 + \rho_\pi\gamma'_{\pi\varepsilon})]$$
$$+ [\gamma_{cb}(\gamma_b - 1) + \gamma_{\pi b}\gamma_b - \rho_\pi\gamma_{\pi b}] \cdot \gamma_{b\varepsilon},$$

47

which follows from forward iterations of (89) and (90). Substituting out $\gamma_{b\varepsilon}$, $\gamma_{c\varepsilon}$, $\gamma'_{c\varepsilon}$, $\gamma_{\pi b}$, and γ_{cb} with the conditions in (85), (86), and (87) and rearranging, we can simplify this derivative to

$$\partial(\widehat{R}^{IS}_{t+1} - \widehat{R}^m_{t+1})/\partial\widehat{\varepsilon}^m_{t+1,t} = -2\left(\gamma'_{\pi\varepsilon} + 1\right) + \left(2 - \gamma^2_b\right)\rho_\pi\gamma_{\pi\varepsilon},$$

which is unambiguously negative since $\gamma'_{\pi\varepsilon} = -\frac{\chi}{1+\delta\gamma_{\pi b}+\chi(2+\rho_\pi)} > -1$, $\gamma_{\pi\varepsilon} < 0$ and $\gamma_b \in (0,1)$. ∎

C.2 Calculation of Anticipated Monetary Policy Shocks

In this appendix, we describe how to calculate the sequence of current and anticipated policy shocks $\boldsymbol{\varepsilon}^m_{T+1} = \left\{\varepsilon^m_{T+1}, \varepsilon^m_{T+1+k,T+1}\right\}^K_{k=1}$ of length $H = K + 1$, which are announced in period $T + 1$ for all periods until $T + H$ that yields a desired interest rate path $\left\{R^m_{T+h}\right\}^H_{h=1}$ that we want to study in a policy experiment about forward guidance.

We solve our model using standard perturbation techniques, yielding policy functions of the type

$$Y_{T+1} = g_c + g_p\widehat{\mathbf{s}}_T + g_\varepsilon\boldsymbol{\varepsilon}^m_{T+1} \tag{93}$$

for a generic endogenous variable Y_t, such as the policy rate, that depends on a constant (steady state) value g_c, a vector of state variables $\widehat{\mathbf{s}}_T = \mathbf{s}_T - \mathbf{s}$ that is formulated in deviations from steady state $\mathbf{s}$ with dimension $[S \times 1]$, and the corresponding coefficient vector g_p $[1 \times S]$. $\boldsymbol{\varepsilon}^m_t$ $[H \times 1]$ is a vector of one current and K anticipated policy shocks for period from $T+1$ to $T + H$ with the corresponding coefficients vector g_ε $[1 \times H]$. Analogously, the vector of policy functions for the state variables reads

$$\mathbf{s}_{T+1}\left[S \times 1\right] = g_{sc}\left[S \times 1\right] + g_{sp}\left[S \times S\right]\widehat{\mathbf{s}}_T\left[S \times 1\right] + g_{s\varepsilon}\left[S \times H\right]\boldsymbol{\varepsilon}^m_{T+1}\left[H \times 1\right] \tag{94}$$

with the coefficient matrices g_{sc}, g_{sp}, and $g_{s\varepsilon}$. The coefficient matrices and the steady state are all known objects. Using (93) and (94) and assuming that $\boldsymbol{\varepsilon}^m_{T+1}$ has non-zero entries only in the initial period $T + 1$ (i.e., forward guidance is only provided in $T + 1$ until $T + H$) allows us to write down solutions for the policy rate for H periods ahead that depend on the steady state of the state variables (in period T) and the policy shocks that are announced in $T + 1$ only:[25]

$$R_{T+1}\left(\widehat{\mathbf{s}}_T, \boldsymbol{\varepsilon}^m_{T+1}\right) = g_c + g_p\widehat{\mathbf{s}}_T + g_\varepsilon\boldsymbol{\varepsilon}^m_{T+1}$$
$$R_{T+2}\left(\widehat{\mathbf{s}}_T, \boldsymbol{\varepsilon}^m_{T+1}\right) = g_c + g_pg_{sp}\widehat{\mathbf{s}}_T + g_pg_{s\varepsilon}\boldsymbol{\varepsilon}^m_{T+1}$$
$$\cdots$$
$$R_{T+H}\left(\widehat{\mathbf{s}}_T, \boldsymbol{\varepsilon}^m_{T+1}\right) = g_c + g_pg^{H-1}_{sp}\widehat{\mathbf{s}}_T + g_pg^{H-2}_{sp}g_{s\varepsilon}\boldsymbol{\varepsilon}^m_{T+1}.$$

This constitutes a system of H linear equations in H unknown elements of $\boldsymbol{\varepsilon}^m_{T+1}$ for a given

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[25]The procedure can obviously be applied to any other endogenous variable also, e.g. the policy rate in real terms.

sequence $\left\{R^m_{T+h}\right\}^H_{h=1}$, which can be rewritten as

$$b = M\varepsilon^m_{T+1}, \tag{95}$$

where

$$b\,[H \times 1] = \begin{bmatrix} R_{T+1} \\ R_{T+2} \\ \ldots \\ R_{T+H} \end{bmatrix} - g_c \begin{bmatrix} 1 \\ 1 \\ \ldots \\ 1 \end{bmatrix} - \begin{bmatrix} g_p \\ g_p g_{sp} \\ \ldots \\ g_p g^{H-1}_{sp} \end{bmatrix} \widehat{\mathbf{s}}_T,$$

and

$$M\,[H \times H] = \begin{bmatrix} g_\varepsilon \\ g_p g_{s\varepsilon} \\ \ldots \\ g_p g^{H-2}_{sp} g_{s\varepsilon} \end{bmatrix}.$$

Rearranging (95) then allows to back out the H shocks as

$$\varepsilon^m_{T+1} = M^{-1}b.$$

C.3 Additional Numerical Results

Figure 7 complements our analysis by repeating the comparison of Figure 2, but now the central bank provides forward guidance about the real instead of the nominal policy rate. In this case, the real rate is announced to be reduced by 25 basis points for 4 quarters. We conduct this analysis because central banks in the end aim at steering real rates that are directly relevant for intertemporal consumption decisions. Moreover, we make our analysis thereby comparable to the analysis of McKay et al. (2016), who focus solely on real policy rates. It turns out that whether guidance is in terms of the real instead of the nominal rate does not make much of a difference for the model with the endogenous liquidity premium. The corresponding responses for output, inflation, and the liquidity premium in Figures 2 and 7 line up almost completely. The difference is larger for the conventional New Keynesian model, as the exacerbating effect via higher inflation that endogenously lowers real rates is now absent. The responses of real activity and inflation are nevertheless still much stronger than in the model with the liquidity premium.

Figure 7: Comparison with a model version without liquidity premium – Real Policy Rate
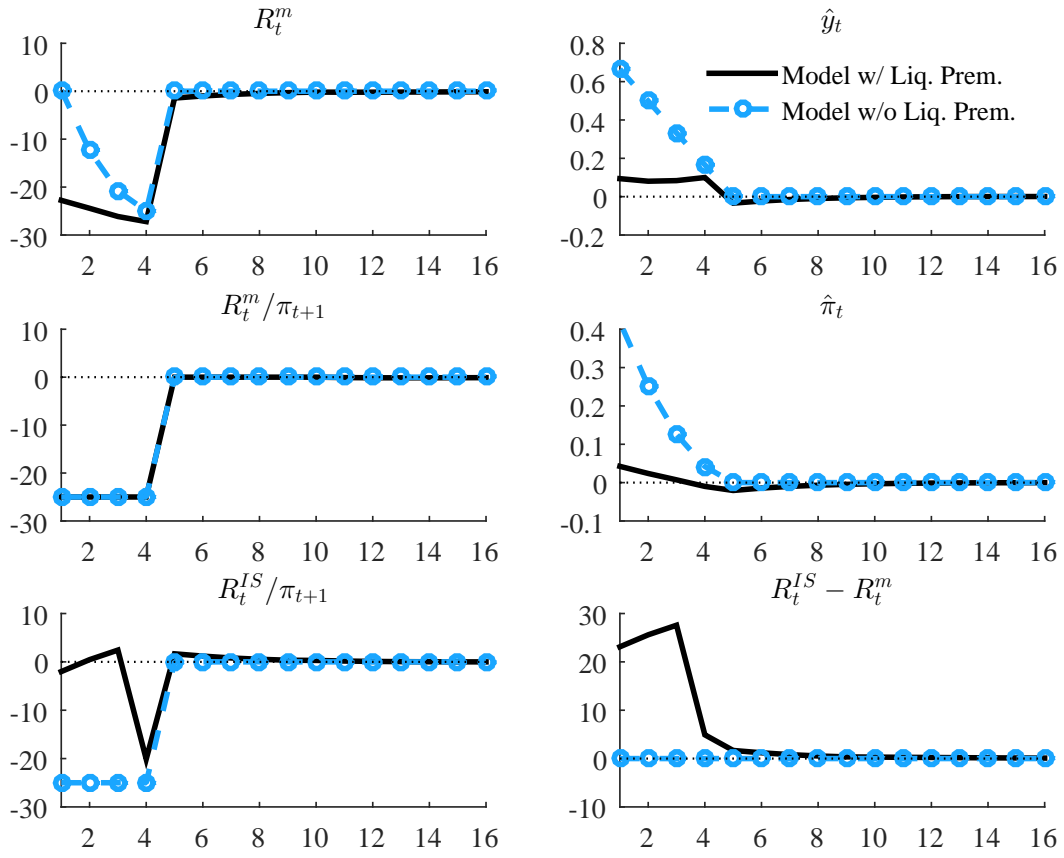
Notes: Impulse responses to *real* policy rate (R_t^m/π_{t+1}) reduction of 25 basis points in quarters 1 to 4, announced before quarter 1: production y_t, inflation π_t, policy rate R_t^m, private-sector real rate R_t^{IS}/π_{t+1}, liquidity premium $R_t^{IS} - R_t^m$. Y-axis: Deviations from steady state in percent ($\hat{y}_t$, $\hat{\pi}_t$) or in basis points (else). X-axis: quarters. Black line: Baseline model with endogenous liquidity premium. Blue circled line: Conventional New Keynesian model.