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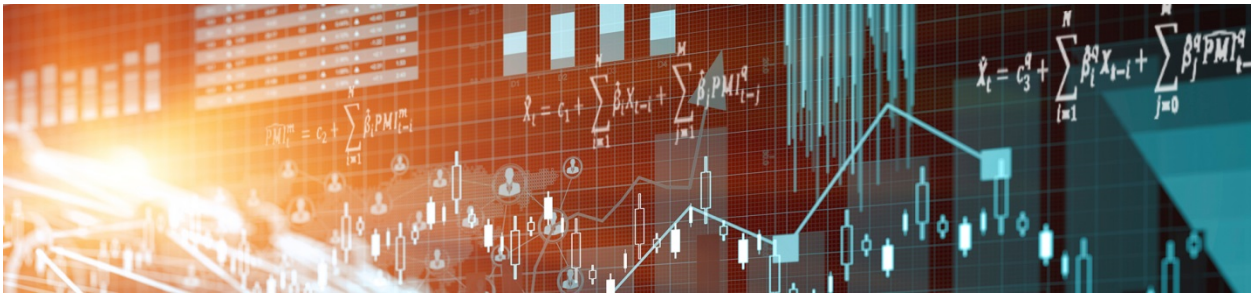

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# Assessing the Impact of Demand Shocks on the US Term Premium

**by**

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# Abstract

During and after the Great Recession of 2008–09, conventional monetary policy in the United States and many other advanced economies was constrained by the effective lower bound (ELB) on nominal interest rates. Several central banks implemented large-scale asset purchase (LSAP) programs, more commonly known as quantitative easing or QE, to provide additional monetary stimulus. Gauging the effectiveness of LSAPs is important, since the ELB may be a constraint on conventional monetary policy more frequently in the future than it was in the past. In this paper we analyze two distinct periods where we observe exogenous demand shocks for 10-year US Treasury bonds to assess their impact on the term premium. Our results show that official sector demand factors, measured by purchases of securities by the foreign official sector and the Federal Reserve's asset purchase program, are important drivers explaining movements in the term premium. They suggest that asset purchases (QE) can help provide additional monetary stimulus even once the policy rate has reached its ELB. Robustness tests also suggest that the estimated impact of official sector demand factors is the most robust driver of the term premium across alternative specifications, while the estimates on risk factors appear more sensitive to the choice of term premium specification. Based on external projections and authors' assumptions, our results suggest that the US term premium will rise gradually from an average of about -20 basis points in the fourth quarter of 2016 to around +10, 32 and 60 basis points by the end of 2017, 2018 and 2019, respectively, before stabilizing around 100 basis points in the medium term.



*Bank topics: Financial markets; Interest rates; Monetary policy framework; Monetary policy implementation; Transmission of monetary policy*
*JEL codes: E, E4, E43, E5, E52, E58, E6, E61, E65, G, G1, G12*



# Résumé

Pendant et après la Grande Récession de 2008-2009, la politique monétaire traditionnelle des États-Unis et de nombreux autres pays avancés s'est trouvée restreinte par la valeur plancher des taux d'intérêt nominaux. Plusieurs banques centrales ont mis en œuvre des programmes d'achat massif d'actifs – regroupés plus communément sous l'appellation d'« assouplissement quantitatif » – pour accroître la détente monétaire. Il importe d'évaluer l'efficacité de ces programmes, car la valeur plancher pourrait imposer une contrainte à la conduite de la politique monétaire

traditionnelle plus souvent que par le passé. Nous analysons deux périodes distinctes où la demande d'obligations du Trésor américain à 10 ans subit des chocs exogènes, afin de jauger les effets de ces chocs sur la prime de terme. D'après nos résultats, les facteurs de demande du secteur officiel – mesurés par les achats de titres auxquels procèdent les autorités étrangères et la Réserve fédérale dans le cadre de son programme d'achat d'actifs – expliquent dans une large mesure les variations de la prime de terme. Les résultats portent à croire que les achats d'actifs (l'assouplissement quantitatif) peuvent concourir à augmenter la détente monétaire même lorsque le taux directeur a atteint sa valeur plancher. Par ailleurs, les tests de robustesse donnent à penser que l'incidence estimative des facteurs de demande du secteur officiel est le principal déterminant de la prime de terme parmi différentes formulations, alors que les estimations des facteurs de risque semblent plus sensibles au choix de la formulation de la prime de terme. Dans le cadre d'un scénario fondé sur des projections externes et les hypothèses des auteurs, nos résultats indiquent que la prime de terme américaine augmentera peu à peu, d'une moyenne d'environ -20 points de base au quatrième trimestre de 2016 jusqu'à une moyenne d'environ +10, 32 et 60 points de base d'ici la fin de 2017, 2018 et 2019 respectivement, avant de se stabiliser autour de 100 points de base à moyen terme.

*Sujets : Marchés financiers; Taux d'intérêt; Cadre de la politique monétaire; Mise en œuvre de la politique monétaire; Transmission de la politique monétaire*
*Codes JEL : E, E4, E43, E5, E52, E58, E6, E61, E65, G, G1, G12*

## I. Overview and main findings

Monetary policy affects economic activity not just by moving short-term interest rates but also through its impact on the whole yield curve. Because many consumer and business borrowing rates are tied to longer-term government bond yields, understanding movements in the entire yield curve is important for assessing the economic outlook. Movements in US long-term interest rates are viewed as particularly important since US Treasury bonds are widely seen as a global benchmark. This note focuses on the drivers behind the term premium component of the US 10-year Treasury bond yield, which we define as the excess yield that investors require to hold a long-term bond instead of a series of shorter-term bonds.

During and after the Great Recession of 2008–09, conventional monetary policy in the United States and many other advanced economies was constrained by the effective lower bound (ELB) on nominal interest rates. Several central banks implemented large-scale asset purchase (LSAP) programs, more commonly known as quantitative easing or QE, to provide additional monetary stimulus. These programs involved purchasing longer-term bonds with the objective of reducing the supply of these assets on the market, thus raising their price and lowering their yields. Gauging the effectiveness of LSAPs is important, since the ELB may be a constraint on conventional monetary policy more frequently in the future than it was in the past.[1] By studying the impact of LSAPs and other exogenous demand factors on the term premium, this paper finds that demand shocks are an important driver of long-term interest rates.

Unfortunately, estimating the importance of LSAPs and other drivers of the term premium is complicated by the fact that the term premium is not directly observable but instead must be estimated. We remain agnostic on the appropriate method for estimating the term premium; instead, we use several well-known estimates from different estimation procedures. For each term premium estimate, we examine the explanatory power of a common set of drivers. The drivers examined in our analysis are (i) the Federal Reserve's LSAP and maturity extension program, (ii) foreign official sector demand for US Treasury securities, (iii) inflation uncertainty, (iv) US government debt-to-GDP ratio, (v) a measure of the business cycle and (vi) measures of risk tolerance.

Overall, we find that the two demand factors (LSAPs and foreign official) are important in explaining movements across all the term premium estimates examined. Our analysis suggests that the significant increase in demand in the 2000s for long-term securities by the foreign official sector lowered the term premium on US Treasury securities by over 100 basis points. More recently, the Federal Reserve's LSAPs are estimated to have reduced US 10-year bond rates in

[1] Dorich et al. (2016) argue that the fall in the neutral rate of interest will cause the frequency of ELB episodes to rise.

the range of 198 to 234 basis points by lowering both the US term premium through the portfolio rebalancing effect (26 to 124 basis points) and the expected path of future short-term interest rates via the signalling effect (106 to 172 basis points).

Going forward, most drivers are expected to put upward pressure on the US 10-year term premium. For example, based on external projections and authors' assumptions, our results suggest that the US term premium will rise gradually from an average of about -20 basis points in the fourth quarter of 2016 to around +10, 32 and 60 basis points by the end of 2017, 2018 and 2019, respectively, before stabilizing around 100 basis points in the medium term.[2] This terminal point will be modestly higher than the average level of the term premium seen over the course of the previous US economic expansion, where it averaged roughly 80 basis points.

## II. What is the term premium?

The term premium is the excess yield that investors require to hold a long-term bond instead of a series of shorter-term bonds. For example, suppose that the interest rate on a 10-year US government bond is 5 per cent, while the interest rate on a one-year US government bond, reinvested over 10 years, is expected to average 4 per cent. In both cases, the time horizon of the investment is the same, but the total return is different. In this case, the term premium on the 10-year bond would be 1 per cent, or 100 basis points.

This can be generalized using the following equation:

$$i_{\tau t} = \frac{1}{\tau}\sum_{k=0}^{\tau-1} E_t\, i_{1,t+k} + tp_{\tau t}$$

The first term on the right-hand side represents the expected average yield on the one-year bond reinvested for 10 years. The second term on the right-hand side is the term premium.

The term premium reflects the fact that the risks associated with holding a long-term bond are not the same as those associated with a series of short-term bonds. Sources of such differences in risks could include unexpected changes in short-term interest rates and inflation, the possibility of default or the chance that the bond cannot be resold after its initial purchase (liquidity risk). Historically, term premiums have usually been positive, but high levels of demand for longer-term bonds can cause term premiums to become negative. As a result, both the sign and the magnitude of the term premium are ultimately empirical questions.

[2] Projections for the main drivers are either based on the authors' assumptions or come from external sources, such as the Congressional Budget Office, and are cited throughout this paper.

Theoretically, demand factors can influence the term premium if bonds of different maturities are not perfect substitutes. These are sometimes referred to as preferred-habitat models of the term structure of interest rates (Vayanos and Vila 2009). Take for example a pension fund that wishes to match the duration of its assets with its liabilities by locking in a safe and liquid, fixed nominal rate of return for a long period of time. If the relative supply of longer-term bonds were to fall, the pension fund might be willing to pay a higher price for the bonds (accepting a lower yield) rather than substituting shorter-term bonds. Moreover, some financial institutions have mandates to trade in specific instruments and therefore are required to hold certain types of assets (for example, government bond funds). If, in addition, financial market participants are risk averse, then changes in investors' demand for bonds can affect the term structure of interest rates, constituting an additional determinant of bond prices other than current and expected future short rates.[3]

## III. Literature review

There are several factors that could influence the evolution of the US term premium. In this paper, we provide a quick overview of the literature on official sector demand factors (LSAPs, foreign demand for Treasury securities) and risk-related factors (US government debt, inflation uncertainty, the business cycle and asset market volatility).[4]

### A. Official sector demand factors

#### i) Large-scale asset purchases

To stabilize US output and inflation, the Federal Reserve purchased roughly $4.2 trillion in long-term assets between November 2008 and October 2014, including Treasury securities.[5] These LSAPs, also known as QE, were intended to ease lending pressures through multiple channels. One was to reduce bond yields by lowering term premiums (a.k.a. the portfolio rebalancing channel), while another was to lower expectations of future short-term interest rates (a.k.a. the

[3] Christensen and Krogstrup (2016) also build a portfolio model that generates asset price effects from central bank asset purchases.

[4] There are also some demographic and institutional factors, such as population aging and increased financial sector regulation, that could affect the demand for the 10-year Treasury yield going forward. However, their impacts are difficult to measure and are therefore not included in our estimation.

[5] In the United States, the Federal Reserve's QE program was rolled out across four rounds. QE1 (November 2008 to March 2010) consisted of $1.75 trillion in purchases of mortgage-backed securities (MBS), agency debt and treasury bonds. QE2 (November 2010 to June 2011) consisted of $0.6 trillion in purchases of Treasury securities and saw the continued reinvestment of proceeds from QE1. The maturity extension program (September 2011 to December 2012) saw the Federal Reserve sell $0.67 billion in shorter-term Treasury securities and use the proceeds to buy longer-term Treasuries. QE3 (December 2013 to October 2014) was an open-ended commitment to purchase MBS and Treasury securities that resulted in $1.5 trillion in purchases.

signalling channel). Given the context of this paper, below we focus on some key studies that look specifically at the impact of LSAPs on the 10-year Treasury term premium.

Gagnon et al. (2010) use an event study analysis to show that the first round of QE mainly affected long-term yields through the term premium. Additionally, they also perform a time series regression analysis to quantify the impact of LSAPs, using Kim and Wright's (2005) estimate of the term premium (see section IV) as a dependent variable. Their results suggest that $1 trillion in asset purchases reduces the term premium on 10-year Treasuries by 31 basis points.

Li and Wei (2013) extend a standard Gaussian affine no-arbitrage term structure model to allow Treasury and MBS supply variables to affect Treasury term premiums. In their model, yields are driven by both yield-specific factors and Treasury and agency MBS supply factors. Their results suggest that the first two rounds of the Federal Reserve's LSAP program (QE1 and QE2) reduced the 10-year Treasury term premium by 125 basis points, or by roughly 54 basis points per $1 trillion in purchases.

Ihrig et al. (2012) take Li and Wei's (2013) framework but refine it in important ways. First, they more carefully distinguish between changes to the LSAP program as it was being implemented. Second, they use survey data from Blue Chip Economic Indicators to build in expectations for when these assets will be sold back onto the market. Engen, Laubach and Reifschneider (2015) later extend this analysis to incorporate unconventional policy actions through to the end of 2013. Their results suggest that the Federal Reserve's asset purchases had reduced the term premium by roughly 120 basis points by the middle of 2013.

Using data from the New York Federal Reserve's Survey of Primary Dealers, Wu (2014), like Ihrig et al. (2012), also creates an LSAP measure that captures not only the total size of purchases but also the duration of time that these purchases are expected to be held off the market. At any point in time, Wu's measure represents a present discounted value of all future LSAP holdings as a percentage of potential GDP. Depending on the definition of the term premium and the control variables used, Wu (2014) finds that $1 trillion in LSAPs held for one year reduces the term premium by roughly 17 to 38 basis points.

### ii) Foreign official sector demand for 10-year Treasury bonds

In the first decade of the 2000s, foreign official sector demand for US Treasury securities rose dramatically across the world, especially in Asian emerging-marking economies (EMEs) following the Asian financial crisis. This demand was mainly the result of policy decisions by foreign central banks, as seen in the large run-up in foreign official sector purchases over this period.[6] Former

[6] Between 2000 and 2010, China's share of total foreign holdings of US Treasuries rose from 8 to 33 per cent. Rising oil prices also helped boost foreign official sector holdings, as many emerging-market countries looked for

Federal Reserve chairman Ben Bernanke (2005) referred to this episode as a "global savings glut" and suggested that it was putting downward pressure on long-term interest rates.[7] While foreign official purchases have declined slightly as a percentage of marketable bonds since 2010, they still represent a large fraction of demand for Treasury securities.

Studies that seek to quantify the impact of these purchases have found large effects. Warnock and Warnock (2009) look at the impact of 12-month *flows* from foreign official purchases into 10-year Treasury yields and find that for the 12 months ending in May 2005, foreign inflows reduced US long-term yields by 80 basis points. Other studies that focus on the *stock* of foreign official purchases have also found substantial impacts per dollar of foreign purchases. Bertaut et al. (2011) use a single-equation ordinary least squares (OLS) specification and find that $1 trillion in purchases reduces yields by roughly 110 to 150 basis points. Beltran et al. (2013) use a vector error-correction model and find that the impact is roughly 170 to 200 basis points.

These impacts are generally much larger than what has been found in studies on LSAPs. At first glance this is puzzling since both actions reduce the stock of outstanding assets in a similar manner. One possible explanation, as postulated by Beltran et al. (2013), is that the LSAP program was designed as a temporary stimulus. By contrast, foreign purchases, which have been rising steadily, are likely to be perceived as more permanent.

### B. Risk factors

#### i) Inflation uncertainty

Unexpected inflation is generally thought to be the most important risk affecting the 10-year Treasury yield. Some studies have found a strong positive relationship between the level of expected inflation and the degree of inflation uncertainty (Mankiw, Reiss and Wolfers 2003; Ball, Mankiw and Romer 1988). However, why the *level* of inflation should affect risk is not exactly clear. By contrast, Wright (2008) looks at several alternative measures of inflation risk, including survey density forecasts (i.e., how confident individual forecasters are in their inflation forecasts) and dispersions around 10-year-ahead inflation forecasts (i.e., the degree of agreement on inflation projections across forecasters). Using a panel data regression on 10 industrialized countries between 1990 and 2008, he tests how important these factors are across two different term premium measures. Wright concludes that a large portion of the decline in long-term interest rates over the past two decades reflects a secular decline in the term premium, which in

safe havens to invest their excess petrodollars and maintain their existing exchange rate pegs to the US dollar. Taken together, the foreign official sector (which is composed mainly of foreign central banks) saw its share of total foreign purchases rise from 57 to 79 per cent over the same period (Bertaut and Judson 2014).

[7] Also see Alan Greenspan's 2005 semiannual Monetary Policy Report to the Senate's Committee on Banking, Housing, and Urban Affairs. He referred to this episode as a "bond market conundrum."

turn reflects greater monetary policy transparency and credibility, which has reduced longer-term inflation uncertainty.[8]

### ii) US Debt to GDP

The level of government debt is often used as a gauge of a country's fiscal position. In the past, some countries with high levels of government debt have often reduced the real value of their debt through higher rates of inflation. As a result, markets often demand to be compensated for this risk through higher term premiums, especially for longer-dated bonds.

A few ways of proxying for this risk have been proposed in the literature. If we accept that higher debt levels increase the risk on a country's longer-dated securities, then one simple way is to use the US federal government's debt-to-GDP ratio. However, the contemporaneous debt-to-GDP ratio can be heavily influenced by the business cycle, potentially biasing the results away from finding a link between government debt and 10-year Treasury yields. Laubach (2009) and Engen and Hubbard (2004) address this concern by taking the expected debt-to-GDP ratio five years ahead and looking at its impact on the five-year-ahead, 10-year forward rate of US Treasury yields (a.k.a. the five-year forward rate). In theory, these measures should represent a period far enough in the future when the effects of the present business cycle are greatly reduced. Results from these papers show that a 1 per cent increase in the debt-to-GDP ratio, on average, raises long-term yields by 3 to 4 basis points. However, these estimates are for the total 10-year Treasury yield, and thus they capture not only the effect on the term premium but also the effect on the future expected path of short-term interest rates.

A case has also been made that once government debt levels pass a certain threshold, they can lead to an outsized impact on interest rates because of growing doubts on the part of lenders (Greenlaw et al. 2013). However, these concerns are likely smaller in a context where the private sector is deleveraging and interest rates are hovering around the zero lower bound (Krugman 2013).

### iii) Business cycle

Term premiums are generally found to be countercyclical as investors become less risk averse during economic booms and the opposite during economic contractions (Wu 2014; Bauer and Diez de los Rios 2012). This suggests that since the financial crisis, the term premium on the 10-year yield has been elevated relative to what it would be if the US economy were operating at its potential.

[8] For example, his estimates suggest that a 1 percentage point decline in long-term inflation dispersion could reduce the term premium by 2.5 to 5 percentage points.

### iv) Asset market volatility

Uncertainty regarding future monetary policy should increase the volatility of Treasury securities, and thus also increase their term premium. One measure of bond market volatility is the Merrill Lynch Option Volatility Estimate (MOVE) index. This index is a market-based measure of uncertainty over the future course of interest rates based on interest rate options. Higher values of the MOVE indicate times when traders are willing to pay more for protection against unexpected interest rate movements. Bernanke (2015) and Abrahams et al. (2015) show evidence that the MOVE correlates with certain estimates of the US 10-year term premium.

Note that some types of uncertainty could lower the 10-year Treasury term premium. Treasury securities are generally considered to be safe, liquid assets, especially in times of crisis. One measure of asset market volatility outside of bonds is the VIX (a.k.a. the Chicago Board Options Exchange Volatility Index). This index measures the implied volatility of S&P 500 index options.[9]

[9] Note that these volatility measures will not be truly independent from the other demand drivers we have listed here. For instance, the effects of the Federal Reserve's LSAP program and similar purchases by other central banks should have implications for bond market volatility. Nevertheless, we continue to include these measures as they proxy for a wide variety of macroeconomic and financial factors and thus should still help explain some of the variation in our variables of interest.

## IV. Methodology

In this section, we examine the explanatory power of a common set of official sector demand and risk factors on the US term premium. Specifically, we focus on (i) the Federal Reserve's LSAP program, (ii) foreign official sector demand for US Treasury securities, (iii) inflation uncertainty, (iv) US government debt-to-GDP ratio, (v) the state of the business cycle and (vi) measures of risk tolerance. Unfortunately, estimating the importance of these drivers is complicated by the fact that the term premium is not directly observable but instead must be estimated. Therefore, in this section we examine the impact of official sector demand and risk factors across several different term premium estimates.

### i) Data

*a. Term premium estimates*

A variety of methods have been developed over time to estimate the term premium on US 10-year Treasuries. In our empirical analysis, we focus on the following four estimates.[10]

1. **Survey of Professional Forecasters (SPF).** The survey-based estimate is constructed using data from the SPF by removing the expected average of short-term interest rates over the next 10 years from the 10-year yield.[11]
2. **Bauer and Diez de los Rios (BDR).** Bauer and Diez de los Rios use a multi-country affine term structure model containing unspanned macroeconomic and foreign exchange risks to estimate country-specific term premiums.[12]
3. **Adrian, Crump and Moench (ACM).** Adrian, Crump and Moench estimate the US term premium using a three-step linear regression approach.[13]
4. **Kim and Wright (KW).** Kim and Wright use a three-factor affine term structure model that also incorporates survey forecasts from the Blue Chip Financial Forecasts.[14]

[10] We also experimented with using a vector autoregression (VAR) to estimate the term premium by forecasting the short-term rate over the next 10 years and backing out the term premium. However, given the sensitivity of the results to the specification of the VAR (levels versus deviations from trend, number of lags, etc.), as well as the tendency for the VAR to return the short-term interest rate to its conditional mean, we chose not to present the results.

[11] Note that the Survey of Professional Forecasters surveys participants on their expectations of short-term interest rates over the next 10 years only once a year. The quarterly estimates are constructed by linearly interpolating between survey observations.

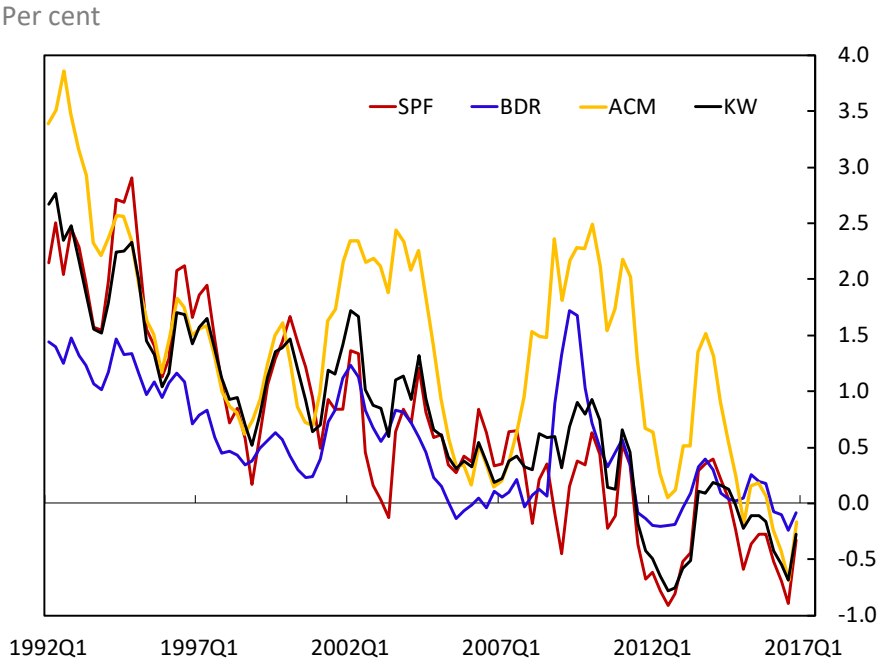
[12] For additional information see Bauer and Diez de los Rios (2012).

[13] For additional information see Adrian, Crump and Moench (2013).

[14] For additional information see Kim and Wright (2005).

From 1992 to 2016, the four term premium estimates share some common elements (**Chart 1**). For instance, all the estimates display a gradual decline over the Great Moderation period that spanned the 1990s to the early 2000s.

**Chart 1: Estimates of the US 10-year term premium**




Sources: Bank of Canada, Federal Reserve, Haver Analytics and authors' calculations

Furthermore, an examination of the changes in the different estimates of the term premium over several time periods indicates that the four measures almost always move in the same direction (**Table 1**). For example, from the first quarter of 1992 to the end of 1999 the four estimates suggest that the US term premium declined by between 71 and 173 basis points. In a more recent example, all four estimates displayed a large increase over 2013, rising by between 60 and 154 basis points between the third quarter of 2012 and the fourth quarter of 2013, which coincides with the increase in bond rates following former chairman Ben Bernanke's May 2013 congressional testimony (also referred to as the "taper tantrum" of 2013).

From the end of 2013, all estimates of the term premium on the 10-year Treasury yield declined, and the term premium remained quite compressed in the fourth quarter of 2016 with the estimates ranging from as low as -33 basis points to as high as only -9 basis points (**Chart 1** and **Table 1**).

**Table 1: Change in US term premium estimates across time**

Measured in basis points

| | SPF | BDR | ACM | KW | Average |
|---|---|---|---|---|---|
| **1992Q2 to 1999Q4** | -71 | -87 | -178 | -128 | -116 |
| **1999Q4 to 2007Q2** | -80 | -47 | -123 | -101 | -88 |
| **2007Q2 to 2008Q3** | -29 | -3 | 110 | 21 | 25 |
| **2008Q3 to 2012Q3** | -127 | -27 | -143 | -137 | -108 |
| **2012Q3 to 2013Q4** | 127 | 60 | 147 | 87 | 105 |
| **2013Q4 to 2016Q4** | -69 | -49 | -169 | -37 | -81 |
| **Level in 2016Q4** | -33 | -9 | -17 | -28 | -22 |

*b. Large-scale asset purchases*

Since 2008 the US Federal Reserve's holdings of long-term Treasuries have increased significantly through the Fed's three rounds of quantitative easing and its maturity extension program (collectively referred to as its LSAPs). To estimate the impact of these purchases on the term premium of 10-year Treasury yields, we construct a present discounted value measure of LSAPs based on Wu (2014). The key advantage of this measure is that it accounts not only for the size of purchases at a point in time but also for the length of time these purchases are expected to stay on the central bank's balance sheet, both of which should impact the term premium.[15] The LSAP measure (**Chart 2**) is constructed using the following formula:

$$LSAP_t = \sum_{t=0}^{\infty} \beta^i E_t \left( \frac{SOMA_{t+i}}{GDP_{t+i}^{POT}} \right) - \frac{LSAP_{t+i}^*}{GDP_{t+i}^{POT}},$$

where $SOMA_{t+i}$ is the market's expectation of the Federal Reserve's holdings of long-term Treasuries at time $t+i$, $GDP_{t+i}^{POT}$ is the Congressional Budget Office's (CBO) estimate of potential nominal GDP at time $t+i$, $\beta^i$ is a standard discount rate assumption of 4 per cent, and $LSAP_t^*$ is the level of long-term asset holdings on the Fed's balance sheet in equilibrium.

To construct $SOMA_{t+i}$, we use information from the New York Federal Reserve's Survey of Primary Dealers. This survey collects financial market participants' future expectations on the economy, monetary policy and financial market developments before each Federal Open Market Committee (FOMC) meeting. For each quarter between the first quarter of 2008 and the second quarter of 2017, we use information from this survey to construct a market-implied forecast of the future evolution of the Federal Reserve's holdings of long-term Treasury assets.[16] In cases where the survey does not ask the relevant questions needed to pin down an exact forecast, we

[15] The authors would like to thank Tao Wu for providing us with guidance on how he computed his measure.

[16] $SOMA_{t+i}$ excludes Treasury bills with less than one year of duration. The forecast for these Treasury bills is constructed by assuming that they stay constant over the forecast horizon at their last observed value.

fill in the necessary information using a series of simplifying assumptions, which are documented in Appendix A.

$LSAP_t^*$ is an equilibrium concept that represents the Federal Reserve's holdings of long-term Treasuries once the US economy is in balance (i.e., when the level of US GDP is equal to its potential output). The level of $LSAP_t^*$ depends on two factors: the equilibrium size of the Federal Reserve's balance sheet and the proportion of that balance sheet that is composed of long-term Treasuries. To pin down the first term, we first note that the Federal Reserve's balance sheet over history was determined mainly by the demand for currency in circulation. Following the methodology of Ferris et al. (2017), we assume that currency in circulation as a percentage of potential GDP continues to grow in line with its trend over the last 10 years. To pin down the second term, we note that prior to the financial crisis, the Federal Reserve held a mix of Treasuries on its balance sheet to avoid distorting the yield curve. This strategy generally meant holding one-third of its assets in short-term bills and the rest in longer-term bonds. For this paper, we assume that this ratio is reasserted in equilibrium.

*c. Foreign official sector demand for Treasury securities*

Foreign official sector demand for US Treasury securities is measured using monthly foreign holdings of US Treasuries, constructed in Bertaut and Tryon (2007) and later refined in Bertaut and Judson (2014) as a share of total marketable securities. Both these studies devise a method to better reconcile and adjust the two main sources of US cross-border data collected by the Treasury International Capital (TIC) system. Comprehensive surveys of US liabilities to foreigners are the first source of information and were available roughly every five years from 1984 to 2000 before becoming an annual survey starting in 2002. The latter source of information from the TIC system captures cross-border purchases and sales of US Treasuries on a monthly basis. To bring these two measures together, the authors must adjust for repayment flows, valuation adjustments and the effect of net purchases through foreign private intermediaries. Bertaut and Judson (2014) are able to control for some of these factors by benchmarking the monthly movements to higher-quality survey data. To avoid any endogeneity-related issues, we focus exclusively on purchases by the foreign *official* sector since their purchases reflect government policy decisions and are, for the most part, not being driven by short-term economic conditions.

As noted earlier, the share of foreign official purchases has declined slightly since 2010 following a significant increase in the previous decade (**Chart 3**). Projecting the future level of foreign official sector demand for US Treasuries is highly uncertain, especially since it is not primarily driven by market forces. As a first-pass assumption, we assume that the fraction of foreign purchases as a percentage of outstanding Treasuries continues to trend slowly downward, returning to its pre-Great Recession level by 2020.

*d. Inflation uncertainty*

Following Wright (2008), we use the dispersion around 10-year-ahead inflation forecasts as our proxy for inflation uncertainty. Specifically, we use the dispersion measure from the SPF, which measures the dispersion of inflation expectations by using the difference between the 25th and the 75th percentile from each survey. Based on the SPF measure, inflation dispersion fell throughout the 1990s before stabilizing over the early to mid 2000s (**Chart 4**). After spiking sharply during the financial crisis of 2009, the rate of dispersion has declined on average in each successive year, excluding 2013. Looking ahead, we assume that the level of dispersion will remain roughly in line with levels observed over the past few years.

*e. US debt to GDP*

We follow Laubach (2009) and use future expectations of the debt-to-GDP ratio (**Chart 5**). Specifically, we use the CBO's five-year-ahead projections of the federal government's debt-to-GDP ratio from each available budget outlook. We also use the same CBO forecasts to compute the projection of the debt-to-GDP ratio out to the end of 2020. The most recent CBO projection has the debt-to-GDP ratio increasing by roughly 10 percentage points from 2016 to 2020, an important increase but still smaller than the 35-percentage-point increase observed between 2007 and 2010.

*f. Business cycle*

To measure the business cycle, we use the CBO's estimate of the "unemployment rate gap" (i.e., the difference between the unemployment rate and the long-term natural rate of unemployment). The unemployment rate gap turned positive (i.e., the unemployment rate was above its natural rate) in the first quarter of 2008—one quarter after the start of the financial crisis—and reached its peak in the fourth quarter of 2009 (**Chart 6**). Since that time, the gap has closed slowly, reflecting the weakness of the US economic expansion since the crisis. The CBO's latest forecast suggests this gap was closed at the end of 2016, after which it should have little impact on movements in the term premium.

*g. Asset market volatility*

We also use the MOVE and VIX to control for asset market volatility (**Chart 7**). The MOVE tends to spike in periods of uncertainty, such as the 2009 financial crisis or the 2013 taper tantrum. More recently, the MOVE also increased, possibly reflecting differing expectations for the pace at which the Federal Reserve was expected to raise short-term interest rates.

Similarly, the VIX tends to spike during periods of financial market stress, such as the 1997–98 Asian financial crisis or US recessions. More recently, the VIX has been hovering around a level consistent with its historical average.

Both measures are assumed to have only a transitory impact on the term premium and thus only impact the short-run dynamics and not where the 10-year term premium is expected to converge over the medium term.

**ii) Estimation**

Formal stationarity tests of the term premium estimates and most of the drivers examined in this paper fail to reject non-stationarity at normal levels of significance. Since we are concerned primarily with how changes in the key drivers are expected to change the fundamental value of the term premium, we model the term premium using a standard two-step error correction framework. First, we construct the long-run level (i.e., structural) specification for each measure of the term premium and then test the residuals for co-integration. Next, we estimate the short-run dynamics using the same drivers to explain quarter-to-quarter movements in the term premium, as well as to assess how quickly typically the term premium converges to its long-run value. By including the long-run drivers in the short-run specifications, we are implicitly incorporating a transitory *flow* effect on top of the permanent *stock* effect. Lastly, as mentioned previously, we only include the measures of asset market volatility into the short-run dynamic equations since they are assumed to have only a transitory impact on the term premium.

To ensure that estimates are asymptotically unbiased and fully efficient, we estimate the long-run relation using fully modified ordinary least squares (FMOLS). Phillips and Hansen (1990) show that this method helps control for serial correlation and endogeneity in the regressors that can result from the existence of a co-integrating relationship. Alternatively, we could have used dynamic OLS (DOLS) to estimate the co-integrating vector. Both FMOLS and DOLS will produce asymptotically unbiased and normally distributed coefficient estimates, although DOLS would reduce the sample size given the inclusions of leads and lags. Given the short sample for some variables, LSAPs, we opted to use FMOLS.[17]

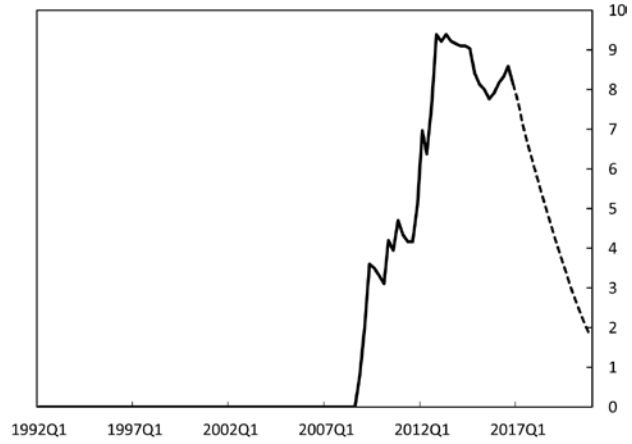
Overall, we have a sample size of 99 observations dating from the second quarter of 1992 to the fourth quarter of 2016. In choosing the variables included in long-run relationships for the four term premium estimates, we began by including each of the potential drivers described above and then excluded drivers where the sign of the coefficient on the variable had the wrong sign relative to prior studies. In all cases, if we excluded a variable because it had the wrong sign relative to prior studies, it was also statistically insignificant, with this criterion applying only to two of the variables included in our analysis. Once the long-run relationship was selected, we tested for co-integration using the Engle-Granger method.

[17] As a robustness check we also produced results using DOLS and found that the overall results were broadly similar. In fact, the DOLS regression produced a slightly better fit with adjusted R-squared higher for all four models.

For the short-run relationship we impose the residuals from the co-integration relationship described above and estimate using OLS with the Newey-West heteroskedasticity- and autocorrelation-consistent method for the standard errors. Once again, we include a lagged dependent variable and most of the drivers discussed above (in first difference) and then exclude those variables where the coefficients had the wrong sign.

**Chart 2: Present discounted value of the Fed's expected LSAP holdings**

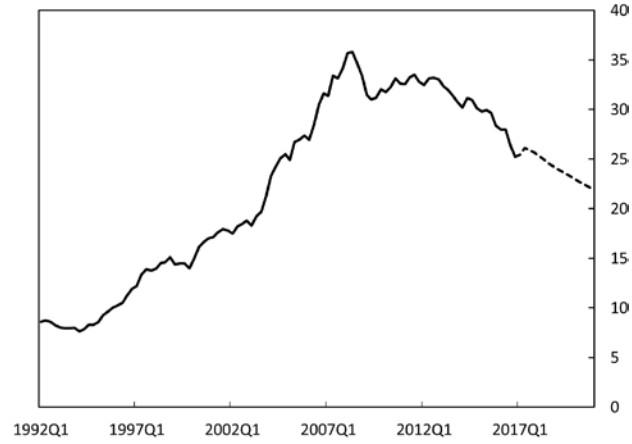
Per cent of US potential GDP




Source: New York Federal Reserve, Congressional Budget Office and authors' calculations

**Chart 3: Foreign official sector holdings of US long-term Treasuries**

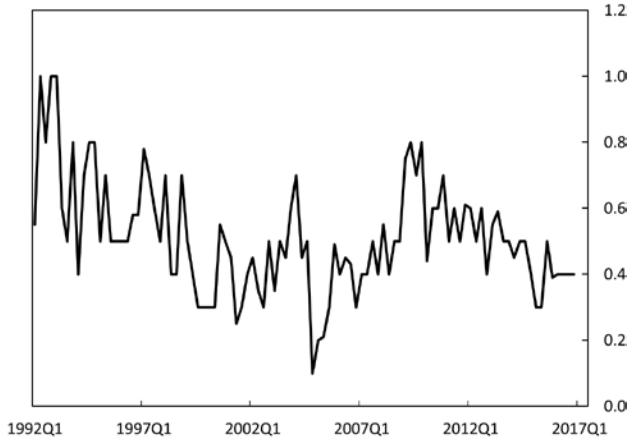
Per cent of marketable bonds




Source: Bertaut and Judson (2014), Haver Analytics and authors' calculations

**Chart 4: Dispersion of the 10-year average CPI forecasts**

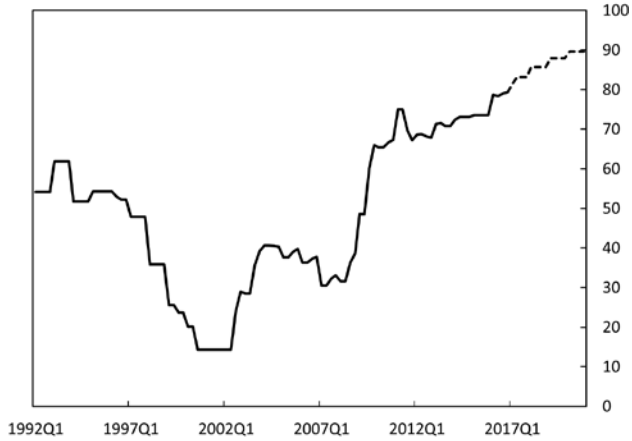
Measured as the 75th percentile minus the 25th percentile




Source: Survey of Professional Forecasters

**Chart 5: Projections of US government debt**

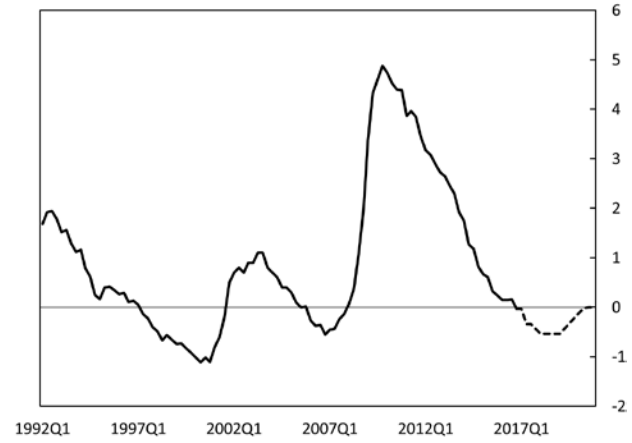
Per cent of GDP, 5 years ahead




Source: Congressional Budget Office

**Chart 6: Unemployment rate gap**

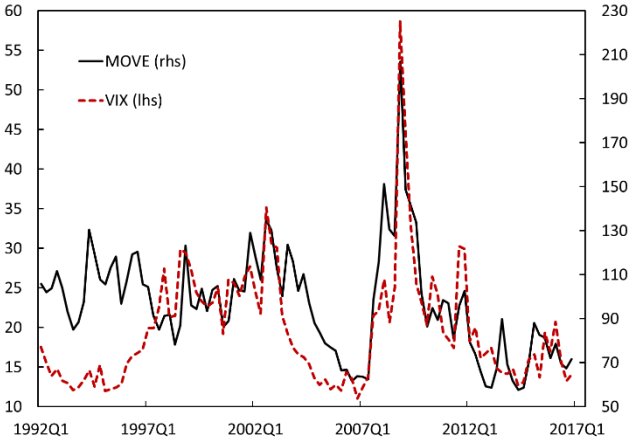
Actual minus long-term natural rate




Source: Congressional Budget Office

**Chart 7: Implied equity and bond market volatility**

Index, January 1992 = 100




Source: Haver Analytics

## V. Results

Our estimation results confirm that there is indeed a long-run relationship between the US term premium and the size of the Fed's holdings of Treasuries, foreign official sector holdings of Treasuries, US government debt, inflation uncertainty and the unemployment rate gap. All four specifications suggest a stable long-run relationship with the US term premium, with three specifications able to reject the null hypothesis of no co-integration at the 15 per cent level of significance, while the fourth (ACM) is almost significant at the 15 per cent level (**Table 2**).

**Table 2: Estimated coefficients of long-run drivers of term premium**

| | SPF | KW | BDR | ACM |
|---|---|---|---|---|
| LSAPs | -0.1119 *** | -0.0988 *** | -0.0281 ** | -0.1312 *** |
| Foreign official sector demand | -0.0537 *** | -0.0539 *** | -0.0391 *** | -0.0502 *** |
| Dispersion of long-term CPI forecasts | 0.8883 * | 0.4950 | 0.2871 | 0.1955 |
| CBO unemployment rate gap | n.a. | 0.1416 *** | 0.1743 *** | 0.4910 *** |
| CBO debt-to-GDP forecast (5 years ahead) | 0.0085 | n.a. | n.a. | n.a. |
| Constant | 1.2788 *** | 1.8511 *** | 1.1999 *** | 2.286 *** |
| Adj. R-squared | 0.7440 | 0.8098 | 0.6781 | 0.7003 |
| **Co-integration test:** | | | | |
| Engle-Granger tau-statistic | -5.640 | -5.395 | -4.127 | -3.976 |
| *p-value* | *(0.003)* | *(0.005)* | *(0.125)* | *(0.166)* |
| Engle-Granger z-statistic | -229.386 | -54.493 | -34.720 | -31.146 |
| *p-value* | *(0.000)* | *(0.000)* | *(0.042)* | *(0.082)* |

*, ** and *** indicate significance at the 10, 5 and 1 per cent level. The sample includes 1992Q2 to 2016Q4.

In general, the coefficients for each explanatory variable have similar magnitudes and the expected sign across the four term premium estimates. All explanatory variables are included in the four co-integrating relationships except for the unemployment rate gap and the CBO debt-to-GDP forecast, which were excluded from the regressions where they had the wrong sign.[18] The overall fit of the long-run relationships ranges from 0.6781 to 0.8098 based on their respective adjusted R-squared.

[18] Note that the excluded coefficients not only had the wrong sign but were also statistically insignificant.

The two most robust results across all four measures of the term premium are related to the official sector demand factors in our analysis.[19] First, the estimated coefficients on the foreign official sector demand are highly statistically significant across all term premium estimates. Moreover, the coefficient estimates on foreign official sector demand are also the most robust across all term premium estimates, with the size and significance being the least sensitive to several robustness checks we performed. Our results suggest that the increase in foreign official sector holdings of the long-term Treasury securities between the first quarter of 2000 and the second quarter of 2008 lowered the US 10-year term premium by between 81 and 112 basis points (**Table 3**). On average, $1 trillion of foreign purchases is estimated to have pushed down the term premium by roughly 10 to 15 basis points over this period.

**Table 3: Impact of a change in specific drivers on the US 10-year term premium**

Measured in basis points

| | SPF | KW | BDR | ACM | Average |
|---|---|---|---|---|---|
| Peak impact from LSAPs (2013Q1) | -105 | -93 | -26 | -123 | -87 |
| Foreign demand (change from 2000Q1 to 2008Q2) | -112 | -112 | -81 | -104 | -102 |
| 10% increase in government debt/GDP | 9 | n.a. | n.a. | n.a. | 9 |

Second, our results confirm that the Fed's LSAPs have had a significant impact on the term premium across the four estimates examined. Our results suggest that in the fourth quarter of 2012, the future discounted value of the Fed's balance sheet reached its peak, reducing the term premium by between 26 and 123 basis points (**Table 3**). The SPF, KW and ACM estimates are broadly in line with those found in the growing literature on LSAPs (see Bonis, Ihrig and Wei 2017), while the small size of the BDR estimate appears to be an outlier. The impact from LSAPs has been stable since the start of 2013 as the present value of the Fed's purchases are estimated to have compressed the term premium by between 23 and 107 basis points lower as of the fourth quarter of 2016.

The wider dispersion of the LSAP impacts on the term premium appears to reflect the methodology used to estimate the term premium. To assess and quantify this effect, we follow

[19] While there is a possibility of endogeneity issues associated with identifying distinct demand factors for the term premium, we believe these have been minimized. First, the foreign demand we focus on is from the foreign official sector, which is far less influenced by short-term economic conditions and often focused on other considerations or goals. Second, while the LSAPs were an endogenous response to the financial crisis and ensuing deleveraging we have controlled for the state of the business cycle in our estimation by including the CBO's unemployment rate gap. Finally, by using FMOLS, which controls for serial correlation and endogeneity, our estimates are asymptotically unbiased and fully efficient.

Wu (2014) and estimate the impact of the LSAPs on the expected short-term interest rates from the four methodologies examined (i.e., the signalling effect). Specifically, we estimate the respective short-term rate expectations on our measure of LSAPs, long-term inflation expectations, the CBO's estimate of potential output growth and the CBO's unemployment rate gap to control for the state of the business cycle.[20] All four measures show that LSAPs had a sizable and statistically significant impact on expected short-term interest rates (**Table 4**). Note that our estimates, like Wu's, are likely an upper bound since we have not controlled for the introduction of forward guidance, which often took place with LSAP announcements. However, controlling for forward guidance does not appear to be that straightforward, particularly to the degree that these policies were typically announced together and could be mutually self-reinforcing, and so is left to future work.

Interestingly, the dispersion of the impact of LSAPs on expected short-term rates, like the term premium, is quite wide ranging, from -110 basis points to -172 basis points. However, when the results are combined, the total estimated impact of LSAPs on the US 10-year bond rate is quite similar and the dispersion much smaller across the four estimates examined, ranging from -198 to -234 basis points (**Table 4**). Overall, $1 trillion of asset purchases is estimated to have reduced the US 10-year bond rate by approximately 44 to 52 basis points.[21]

**Table 4: Impact of LSAPs on the 10-year government bond yield**

Measured in basis points

| Impact from | SPF | KW | BDR | ACM | Average |
|---|---|---|---|---|---|
| Term premium | -105 | -93 | -26 | -123 | -87 |
| Expected short-term rates | -128 | -120 | -172 | -110 | -133 |
| **Total** | **-234** | **-213** | **-198** | **-233** | **-220** |

While the results for measures of official sector demand are quite consistent, the results for the risk factors are more mixed.

First, while the coefficients on the dispersion of long-term inflation expectations all have the correct sign across the four measures, it is only statistically significant for the survey-based

[20] The full estimation results are not presented but are available upon request.

[21] These estimates roughly line up with the numbers discussed in Bernanke (2012) that suggest that, on average, $1 trillion in purchases under LSAP1, LSAP2 and the maturity extension program reduced US long rates by between 30 and 45 basis points.

measure.[22] Second, the coefficients on the business cycle had the correct sign and were statistically significant for three of four measures of the term premium consistent with the view that the term premium exhibits some countercyclical movements. Lastly, the coefficient on the government debt-to-GDP ratio had the correct sign for only one of the measures (SPF), but even this result was not statistically significant at the 15 per cent confidence interval. Moreover, the coefficient was much smaller than typically found in the literature, which could be due to a large portion of the sample overlapping with a period when interest rates were at the zero lower bound (Krugman 2013).

**Table 5: Estimated coefficients of short-run drivers of term premium**

| | SPF | KW | BDR | ACM |
|---|---|---|---|---|
| Error correction term | -0.4006 *** | -0.3897 *** | -0.2182 *** | -0.2034 *** |
| Lagged dependent variable | 0.3732 *** | 0.4062 *** | 0.5421 *** | 0.4614 *** |
| Change in the MOVE index | 0.004 | 0.0064 *** | 0.0047 *** | 0.0119 *** |
| Change in the VIX | -0.0193 ** | -0.0169 *** | n.a | -0.0161 * |
| Change in LSAPs | -0.1184 *** | -0.1039 ** | n.a. | n.a. |
| Change in foreign demand | -0.0523 | n.a. | -0.0575 ** | n.a. |
| Adj. R-squared | 0.2895 | 0.3249 | 0.4302 | 0.3420 |

*, ** and *** indicate significance at the 10, 5 and 1 per cent level. The sample goes from 1992Q3 to 2016Q4.

### Estimating the importance of short-term drivers of the term premium

Next, we estimate the error-correction portion of our models by estimating the change in the term premium to examine how quickly we would expect the term premium to return to its long-run fundamentals when they deviate, as well as other potential short-run drivers of the term premium such as changes in market uncertainty.

Overall, all four models suggest that the term premium returns to fundamentals fairly quickly, with the adjustment coefficients ranging from -0.195 (ACM) to -0.468 (KW), suggesting a half-life of between one and four quarters for a deviation of the term premium from its long-run fundamentals (**Table 5**). All four measures also exhibit some persistence in the change in the

[22] The coefficient estimates on the dispersion of long-term inflation expectations was the one component where the choice of estimation method appeared to make a meaningful difference. In contrast to the FMOLS results reported, had we instead used DOLS, the estimated impact of the dispersion of long-term inflation expectations on the term premium would have almost doubled, on average, across the different measures.

term premium with the coefficient on the lag ranging from 0.362 to 0.568. Changes in implied bond market volatility had the correct sign across all four models (i.e., term premiums increased when implied bond market volatility increased) and were statistically significant for three of the measures. Changes in implied stock market volatility had the correct sign and were statistically significant in three of the models, suggesting that 10-year US government bonds are a safe haven in turbulent markets. Finally, the results of swings in LSAP purchases and foreign official sector demand for US treasuries were more mixed, showing up with the correct sign in only half the models.

## VI. Term premium projected to rise gradually

While the term premium is currently quite low, or even negative based on some estimates, how it evolves over the next few years could have an important impact on the outlook for the US economy. Moreover, the expected level of the term premium over the medium term once all shocks have dissipated will have important implications for pension funds and the government's debt-servicing costs. Using the models described above, we construct hypothetical scenarios for each term premium estimate based on assumptions and external projections of the key drivers. We also construct alternative scenarios based on different assumptions about key drivers to provide insight into the sensitivity of key assumptions about the future level of the term premium.[23]

Overall, official sector demand factors are expected to be the main driver of the term premium over the medium term, with the evolution of both foreign official sector demand and the Federal Reserves' LSAPs expected to support an increase in the term premium. Specifically, the present value of the Federal Reserves' LSAPs is projected to continue to decline (**Chart 2**), and we have assumed that the share of US long-term marketable securities held by the foreign official sector will continue to follow its recent downward trend (**Chart 3**). Together these two factors account for over 90 per cent of the expected increase in the term premium in the medium scenario, which, based on our projections, will rise from about -20 basis points at the end of 2016 to around +10, 32 and 60 basis points by the end of 2017, 2018 and 2019, respectively. Our results are broadly in line with Bonis, Ihrig and Wei (2017), although they estimate that the overall composition of the balance sheet will normalize more slowly than its size, holding down the term premium for longer than our balance sheet assessment would suggest. In the medium term, the term premium is projected to stabilize around 50 to 130 basis points, averaging about 100 basis points across the four estimates examined (**Table 6**). The expected evolution of the dispersion of long-term inflation expectations as well as the CBO's

[23] Note that these alternative scenarios should not be interpreted as confidence intervals since each projection is subject to its own confidence interval based on the uncertainty around the evolution of the drivers, as well as parameter uncertainty that is unique to each model.

projections of the government debt-to-GDP ratio and the unemployment rate gap are expected to have only a minor impact on the term premium.

We also construct two alternative scenarios, high and low. In the high scenario we assume that the share of US long-term marketable securities held by the foreign official sector declines by a greater amount, returning to roughly where it was at around the middle of 2000. This scenario also assumes that the debt-to-GDP ratio ends up 10 percentage points higher than in the medium scenario and that the dispersion of inflation expectations is 0.1 percentage points greater. In contrast, the low scenario assumes that the debt-to-GDP ratio and the dispersion of inflation expectations are, respectively, 10 and 0.1 percentage points lower than in the medium scenario and that the share of US long-term marketable securities held by the foreign official sector remains around its 2016 average value over the projection horizon. These alternative assumptions suggest that the term premium could be roughly 30 to 35 basis points higher or lower, on average, depending on the path of each key driver.[24]

**Table 6: Long-run projections of the US term premium**

Measured in basis points

| | SPF | KW | BDR | ACM | Average |
|---|---|---|---|---|---|
| High | 174 | 124 | 73 | 165 | 134 |
| Medium | 130 | 89 | 47 | 128 | 99 |
| Low | 86 | 60 | 28 | 111 | 71 |

## VII. Conclusion

In this paper we analyzed two distinct periods where we observed exogenous demand shocks for 10-year US Treasury bonds to assess the impact of official sector demand factors on the term premium. Our results suggest that official sector demand, measured by purchases of the foreign official sector, and the Federal Reserve's asset purchase program are important for explaining movements in the term premium. Specifically, our analysis suggests that the significant increase in demand in the 2000s by the foreign official sector lowered the term premium on US Treasury securities by over 100 basis points. More recently, the Federal Reserve's LSAPs are estimated to have reduced US 10-year bond rates by over 200 basis points by lowering both the US term premium through the portfolio rebalancing effect and the expected path of future short-term interest rates via the signalling effect. This suggests that asset purchases can help provide

[24] Note that in these alternative scenarios we have not considered cases where the Fed's balance sheet runs off faster or slower than expected. Factoring this into the analysis would widen the difference between the two alternative scenarios and the medium scenario.

additional monetary stimulus even once the policy rate has reached its effective lower bound. Moreover, robustness tests suggest that official sector demand factors are the most robust variables across alternative specifications, while the estimates on risk factors appear more sensitive to the final specification.

All the estimates of the US term premium analyzed suggest that the US term premium remained quite compressed as of the fourth quarter of 2016. However, over the next few years, the two official sector demand factors analyzed are expected to put some upward pressure on the US 10-year term premium, particularly as the Federal Reserve's balance sheet normalization proceeds. For example, based on external projections and authors' assumptions, our results suggest that the term premium will rise gradually from an average of about -20 basis points in the fourth quarter of 2016 to around +10, 32 and 60 basis points by the end of 2017, 2018 and 2019, respectively, before stabilizing around 100 basis points in the medium term.

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# IX. Appendix A

To construct the profile of $SOMA_{t+i}$, we use information from the New York Federal Reserve's Survey of Primary Dealers. In some cases, some additional simplifying assumptions are used that are catalogued below.

Asset purchases are divided into three periods. The timing and quantities purchased over these periods are based on the Federal Reserve Bank of New York's frequently asked questions (FRBNY FAQs) and the Federal Open Market Committee's (FOMC) press releases.

**QE1 (December 2008 to March 2010)**

1. December 2008 to February 2009 vintages: $600 billion in MBS and Treasury purchases completed by the end of the second quarter of 2009 (June 2009).

   FOMC release available here:
   https://www.federalreserve.gov/newsevents/pressreleases/monetary20081125b.htm

   FRBNY FAQs available here:
   https://web.archive.org/web/20090224222229/http:/newyorkfed.org/markets/mbs_faq.html

2. March 2009 to September 2009 vintages: An additional $1.15 trillion of purchases are completed by December 2009. Another $1.475 trillion is added to March 2009 levels to account for $275 trillion already purchased between December 2008 and March 2009.

   FOMC release available here:
   https://www.federalreserve.gov/newsevents/pressreleases/monetary20090318a.htm

   FRBNY FAQs available here:
   https://web.archive.org/web/20090429024347/http:/www.newyorkfed.org/markets/mbs_faq.html

3. September 2009 to March 2010 vintages: Purchases are extended to the end of the first quarter of 2010 (March 2010).

   FRBNY FAQs available here:
   https://web.archive.org/web/20100404153532/http:/www.newyorkfed.org/markets/mbs_faq.html

   FOMC release available here:
   https://www.federalreserve.gov/newsevents/pressreleases/monetary20090923a.htm

4. November 2009 vintage: We do not account for purchases of agency debt being reduced to $175 billion. Levels of all other purchases are held at the last available level until June 2010 and run down to their pre-crisis share of potential GDP in January 2016 following the process outlined in Chung et al. (2011) Appendix A2.

   FOMC release available here:

   https://www.federalreserve.gov/newsevents/pressreleases/monetary20091104a.htm

5. April 2010 to October 2010 vintages: Levels of purchases are held flat until June 2012 and then run down to their pre-crisis share of potential GDP by June 2017. This rundown is consistent with Chung et al. (2012).

**QE2 (November 2010 to June 2011)**

6. November 2010 and December 2010 vintages: $75 billion in purchases are added per month for an additional seven months until June 2011 for a total of $600 billion in purchases.

   FOMC release available here:
   https://www.federalreserve.gov/newsevents/pressreleases/monetary20101103a.htm

7. January 2011 to June 2011 vintages: Data from the Survey of Primary Dealers are used to provide year-end levels for the total size of the System Open Market Account balance sheet. Movements between year-end values are interpolated linearly (i.e., constant pace of purchases/sales throughout the calendar year). Note that these values are not necessarily consistent with the pace of announced purchases.

**Maturity Extension Program (a.k.a. Operation Twist)**

8. September 2011 to June 2012 vintages: Methodology is the same as QE2 vintages from January 2011 forward. For periods where there is no survey, we take the quarterly value by averaging over the survey periods that exist.

   FOMC release available here:
   https://www.federalreserve.gov/newsevents/pressreleases/monetary20110921a.htm

9. June 2012 to December 2012 vintages: Remaining short-term duration notes are sold off by December 2012. Note that T-Bill holdings reach zero in August 2012.

   FOMC release available here:
   https://www.federalreserve.gov/newsevents/pressreleases/monetary20120620a.htm

**QE3 (October 2012 to October 2014)**

10. October 2012 to October 2014 vintages: Data are extrapolated using survey data from the Survey of Primary Dealers, which always provide estimates for the level of the balance sheet at year end and sometimes for other time periods as well (next quarter, next half year, etc.). The level of holdings is linearly extrapolated between these points.

11. December 2012 to March 2013 vintages: Rates of change in asset purchases are taken from the April 2013 survey. They are calculated by taking the rate of change between the questions that ask the level of the balance sheet in the second half of 2017 and 2018.

    FOMC release available here:
    https://www.federalreserve.gov/newsevents/pressreleases/monetary20120913a.htm

12. January 2014 to October 2014 vintage: Taper of $10 billion is enacted at each meeting until purchases end.

    FOMC release available here:
    https://www.federalreserve.gov/newsevents/pressreleases/monetary20131218a.htm

13. Vintages from December 2014 to present: The level of the balance sheet is held constant until the passive runoff start date is identified in the survey. The pace of runoff is taken from the January 2015 Survey of Primary Dealers. Surveys after this date merely act to change the start of the runoff date, but the pace remains the same. Passive runoff occurs until the level of excess holdings as a percentage of potential GDP equals $\frac{LSAP^{*}_{t+i}}{GDP^{POT}_{t+i}}$.