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# Bond supply expectations and the term structure of interest rates

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ABSTRACT

This paper investigates the influence of forward-looking government bond supply information on changes in the term structure of interest rates. While traditional arbitrage-free models suggest that bond supply should not impact bond yields, models accounting for preferred-habitat investors and imperfect asset substitutability raise this possibility. By analysing debt supply expectations derived from Germany's Treasury press releases, we find that news about expected bond supply affects bond yields, supporting the notion that supply expectations influence current interest rates. Our study also extends macro-finance models, highlighting the significant role of supply expectations in term structure dynamics. Additionally, we provide insights into the puzzle of German government bond yields falling below the ECB deposit rate.

## 1. Introduction

Does forward-looking information on the supply of government bonds drive changes in the term-structure of interest rates? According to arbitrage-free models and the expectations hypothesis bond supply should not affect bond yields (Cox et al., 1985). However, models that consider the presence of preferred-habitat investors and imperfect substitutability between assets raise this possibility Vayanos and Vila (2009, 2021). To the best of our knowledge, we are the first to explore the empirical relationship between interest rates and debt supply expectations derived from Treasury press releases. Understanding the channels through which expected bond supply may influence interest rates clarifies the interconnection between monetary policy and fiscal policy, and the resulting implications for economic growth and the business cycle.

Our work fits within a growing body of literature that examines the relationship between interest rates and bond supply. The foundations of this literature were laid by Tobin (1958, 1969), who proposed that a shock to the stock of available assets has to change the asset expected returns to restore equilibrium. Another early contribution from Modigliani and Sutch (1966) relates to the

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existence of preferred-habitat investors in certain segments of the yield curve. The influential work of Vayanos and Vila (2009, 2021) formalises a no-arbitrage model of the yield curve in which two types of agents trade across the term-structure: preferred-habitat investors who demand only bonds with specific maturities and risk-averse arbitrageurs who trade along the entire yield curve making it arbitrage-free. In this setup, changes in supply affect the required rate of return requested by arbitrageurs to absorb a change in quantities and duration risk. We focus mainly on aggregate measures of bond supply, as those are the ones mainly used in the literature to assess the impact of a change in duration risk on interest rates at the aggregate level.[2]

We contribute to the literature in three main ways. First, we construct a measure of supply expectations for Germany, and test whether expected supply indeed influences the country's yield curve. Existing literature examined the link between interest rates and bond supply changes caused by central banks' large-scale asset purchase programmes (quantitative easing) that took place in western economies after the Great Financial Crisis. Most of these studies distinguish between announcement and auction effects. Announcement effects are defined as long-lasting effects on yields determined by bond purchase programme announcements, while auction effects relate to the changes in prices due to the actual purchases via reverse auctions by the Central Bank.[3] Instead, in our paper we study the supply effects of press releases issued by the Treasury department.[4] We focus on Germany because it is the main European economy by GDP and it has one of the largest and most liquid bond markets in the Eurozone. Further, the German bond market is also considered as the "safe haven" of Europe, as its bonds are the risk-free benchmark for all other Euro area yields. Most importantly, Germany produces very accurate press releases about future bond supply and thus it is the ideal candidate for assessing the effects of bond supply expectations on yields. We use the German Treasury press releases combined with data on outstanding government bonds to build a new proxy variable for the expected supply of German Treasury bonds. This new proxy is used to assess whether the expected bond supply has relevant information for the German yield curve.

Our findings confirm that it does. Our work aligns with the theoretical intuition of Greenwood et al. (2015). Their theory, which builds on the preferred-habitat framework of Vayanos and Vila (2009, 2021) by incorporating supply expectations to the model, suggests that bond risk premia across the yield curve are influenced by expectations about future changes in debt supply. If financial market participants are forward-looking, accurate information regarding expectations of future supply should be embedded into interest rates straight away and thus influence current prices more than current supply.[5] For example, if investors knew that the overall bond supply would increase in the near-term, they would request higher expected returns today. However, previous literature has focused on the impact of current, rather than expected supply, on interest rates. Greenwood and Vayanos (2014) find that the current supply impacts both the spot rate and future excess bond returns through a risk premium channel. Krishnamurthy and Vissing-Jorgensen (2012) find that the overall current supply of Treasury bonds affects their safety and liquidity attributes, which ultimately influence their yields and the spread between Treasuries and corporate bonds.[6]

Our second contribution is an extension of the literature on macro-finance models of interest rates. This is achieved by exploring the role of expected supply as a macro-factor in a Gaussian dynamic term structure model. Several macro variables have been employed in previous research, such as output growth and inflation (Smith and Taylor (2009), Ang and Piazzesi (2003), Ang et al. (2007), Rudebusch and Wu (2008), Cieslak and Povala (2015), Ireland (2015)). Kim and Orphanides (2005) focus on surveys on short-term interest rates as a pricing factor while Li and Wei (2013) estimate the impact of current bond supply on interest rates in the US. Dai and Philippon (2005) study how budget deficits shape the yield curve in the US thanks to a term-structure model. By contrast, we estimate a macro term-structure model (MTSM) to study how the expected supply can influence interest rates when a no-arbitrage restriction is imposed on bond yields. We find that supply expectations play a significant role in the time variation of bond risk premia.

Our third contribution relates to the term structure literature. We consider the puzzling behaviour of German government bond yields falling consistently below the (negative) ECB deposit rate for an extended period and offer a supply-side explanation to this behaviour. Banks, which are among the main investors in government bonds, would not be expected to purchase this asset class if it yields less than the ECB deposit rate. However, banks may be forced to purchase government bonds through liquidity and capital regulations. Local central bank purchases, due to monetary policy interventions or quantitative easing, can provide a further explanation for this counter-intuitive behaviour of government bond yields. However, in addition to demand-side effects, downward pressure on yields may also result from contractions in supply expectations. We estimate that a one percent decrease in expected short-term debt supply relative to GDP (around €35 billions at 2019 prices) decreases the spread between German bond yields and the ECB deposit rate (i.e., it increases it, in absolute value) by around 10-15 basis points, whenever such spread is negative.

[2] Some papers focus on the local supply channel by looking at the impact of bond-level supply on bond-level yields. See, for example, D'Amico and King (2013) and D'Amico and Kaminska (2019).

[3] Among others, D'Amico and King (2013), Krishnamurthy and Vissing-Jorgensen (2011), Gagnon et al. (2011) Berndt and Yeltekin (2015), Krishnamurthy et al. (2018) and Joyce et al. (2011) estimate the impact of these programmes in the U.S and United Kingdom with an event-study approach. The literature regarding the impact of the Quantitative Easing in Europe is more limited, because the European Central Bank lagged among its peers in adopting a similar policy. However, a growing number of studies on the ECB's Asset Purchase Programme (APP) have been published in the last few years. For example, see Altavilla et al. (2015), De Santis and Holm-Hadulla (2017), Gambetti and Musso (2017), Koijen et al. (2016), Blattner and Joyce (2016), Wieladek and Garcia Pascual (2016), Lemke and Werner (2020), Altavilla et al. (2019) and Eser et al. (2019) for studies on how the APP affected financial and macroeconomic variables.

[4] Some of the existing research, such as Lou et al. (2013), Sigaux (2018), Beetsma et al. (2016) and Keloharju et al. (2002) focuses on interest rate movements around bond auction dates. While we indeed use data related to bond auctions, we mainly focus on the long-term impact of changes in bond supply on interest rates.

[5] Several papers study the forward-looking behaviour of financial markets. See, among others, Beaudry and Portier (2006), Chahrour and Jurado (2018), Ederington and Lee (1993), Patell and Wolfson (1979).

[6] Related to our work, several research papers examine the impact of different factors on sovereign yield spreads. Among others, Beetsma et al. (2013), De Grauwe and Ji (2012), Monfort and Renne (2014), De Santis (2012), Gerlach et al. (2010), Falagiarda and Gregori (2015), Corsetti et al. (2014), Schwarz (2019) and Bahaj (2020) find that various macroeconomic and financial determinants have affected sovereign spreads since 2009, such as liquidity, risk aversion, fiscal policy announcements, contagion and country-specific effects.

The rest of the paper is organised as follows. Section 2 describes how we construct the supply variables used in our study. Section 3 illustrates our baseline identification strategy and its results. Section 4 focuses on scarcity effects. Section 5 shows the robustness tests we conduct to validate our findings. Section 6 reports and discusses our results from our MTSM. Section 7 concludes the paper.

## 2. Bond supply measures

We download data on bond supply from the German Treasury website. Our sample covers the period from January 2006 to December 2017. We collect detailed information on each fixed-rate and zero-coupon government bond issued during this period (ticker, issue date, maturity date, coupon rate, auction average price, bid-to-cover ratio and face value outstanding). Thus, we can reconstruct the total amount of bond supply at each point in time during our sample.

Following Greenwood and Vayanos (2014) we construct a maturity weighted measure of debt:[7]

$$MWD_t = \frac{\sum_{\tau=0}^{30} D_t^\tau \tau}{GDP_t}$$

where

$$D_t^\tau = Pr_t^\tau + C_t^\tau.$$

$Pr_t^\tau$ and $C_t^\tau$ are the aggregate principal and coupon payments that are due $\tau$ years from time $t$. We choose this as our main measure of supply because, according to Greenwood and Vayanos (2014), maturity-weighted Debt-to-GDP dominates several other measures of debt when forecasting bond returns. Moreover, as a robustness test, we instrument maturity-weighted Debt-to-GDP with the standard $D/GDP$ ratio, in which we only sum up principal payments and exclude coupon payments in line with Krishnamurthy and Vissing-Jorgensen (2012).

We also formulate a new measure of future expected supply. To the best of our knowledge, we are the first to study the relationship between interest rates and a future expected supply derived from Treasury press releases. We assume that agents incorporate all the publicly available forward-looking information into asset prices. We define the future expected value of supply as:

$$E[MWD_{t+k}] = \frac{\sum_{\tau=0}^{30} E[D_{t+k}^\tau \tau | I_t]}{GDP_t}$$

where $E[D_{t+k}^\tau \tau | I_t]$ is the expected value of total principal and coupon payments due in $\tau$ years from $t+k$ months ahead conditional on the information available at time $t$, $I_t$. We build the best possible proxy for expected supply given the information known by investors at each point in time. To estimate this variable, we examine how the German Treasury department organises press releases regarding their bond issuance plan. Our supply measures are "net" indicators that include all outstanding debt, new debt issues and upward revisions of existing debt's principal payments. Redemptions, downward revisions of existing debt's principal amounts and coupon payments are deducted from the measures when they occur.

The German Treasury issues several communications throughout the year.[8] The first release takes place each December, when the Treasury states the issuance plans for the next calendar year, including the expected notional amount of every auction for each bond. There are also communications at the end of every quarter that announce changes in the upcoming auctions. In Figs. B.1 and B.2 in the Appendix, we show two examples of these events. Fig. B.1 is a press release of September 2016 that describes how the funding requirements for the German government have decreased. As a consequence, the German Treasury cut the bond issuance volumes for the following quarter by seven billion euros. Fig. B.2 reports the issuance outlook for bond supply in 2016, which was released in December 2015. This outlook details the government plans about bond auctions for each maturity throughout the following year. Thus, investors do not have information about auctions that will take place after the end of the current calendar year and for these they would need to wait until the new annual auction schedule is released.

We use the following approach for constructing a proxy for the expected supply conditional on all the information available at time $t$, $E[D_{t+k}^\tau \tau | I_t]$.[9] This proxy is defined as the amount of maturity-weighted supply that would be outstanding at the end of the year, according to the information available at each point in time and taking into consideration all future issuance, cash-flows and redemptions. We download every press release to estimate the amount of supply that would be outstanding at the end of each year if there were no changes to the Treasury's plan in the next $k$ months, with $k$ shrinking throughout each calendar year (with $k=12$ each December, 11 in January and so on). Whenever a new press release regarding changes to planned auctions becomes public, we adjust the supply measure to account for the changes in supply due to cancelled auctions, new auctions that were not announced or changes in the notional amount offered on planned auctions. We also assume that the amount of coupon payments due in the future and starting $t+k$ months ahead will be based on market conditions that are observable at time $t$. In our robustness tests, we also take into account our shrinking forecast horizon by removing a possible seasonal component in $E[D_{t+k}^\tau \tau | I_t]$ with an ARIMA filter.

[7] Some papers (see for example Eser et al. (2019)) try to distinguish between the supply held by arbitrageurs and preferred-habitat investors. In these papers, only the relative ratio of supply held by arbitrageurs over total supply has an impact on interest rates through the duration risk channel. However, our data does not allow to make this distinction.

[8] All the press releases for the German Treasury can be downloaded at https://www.deutsche-finanzagentur.de/en/press/press-releases/.

[9] In our expected supply variable, any future change in supply that has been communicated to the public would be reflected in a change to the variable today, even if auctions related to that communication have yet to happen.

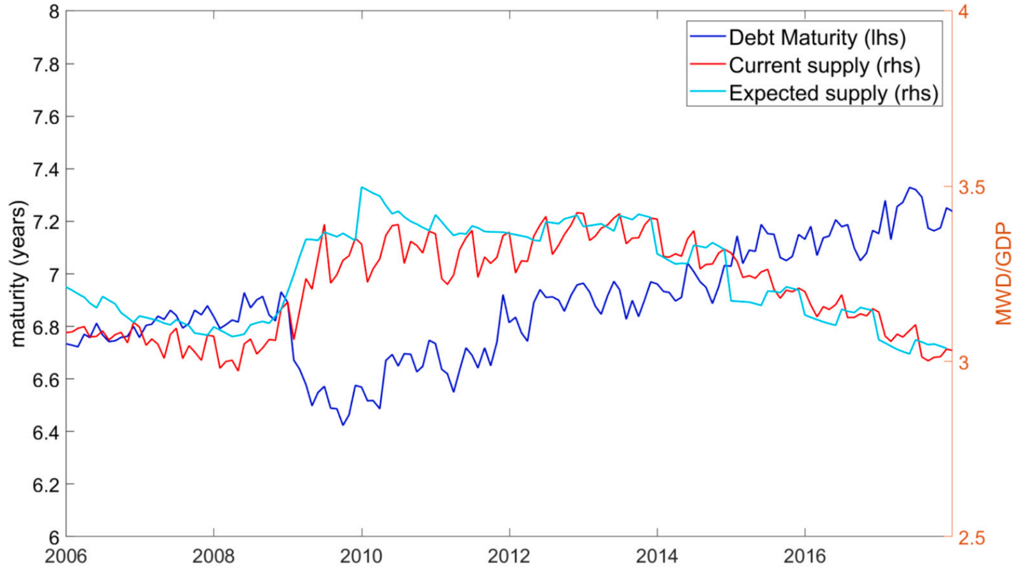


**Fig. 1. Measures of German debt supply and maturity**. The blue line represents the overall maturity of German debt, while the red and light-blue lines show the current and expected maturity weighted debt over GDP, respectively. (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

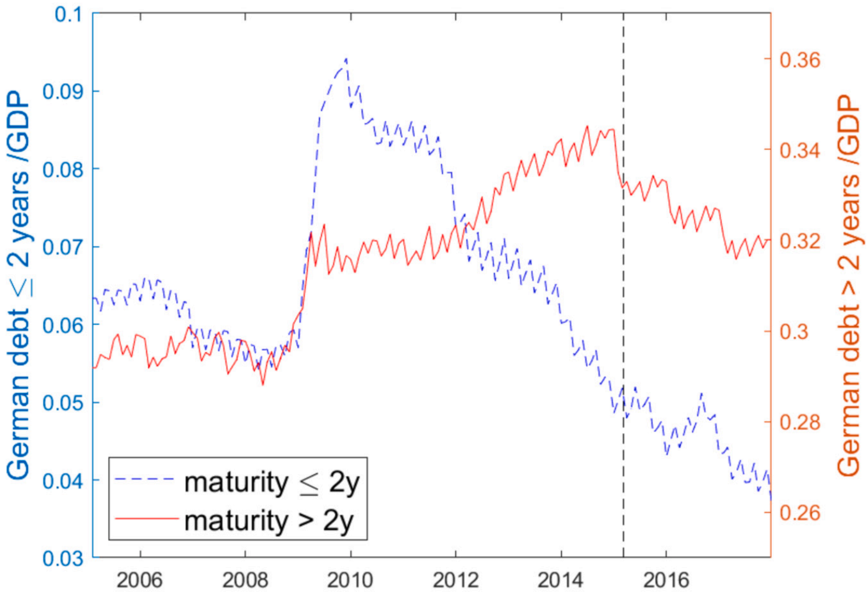


**Fig. 2. German short-term and long-term debt**. The figure plots the amount of outstanding German debt divided into two sub-groups. The blue line represents the amount of debt with original maturity below two years scaled by GDP, while the red line is all the remaining maturities scaled by GDP. The dashed vertical line represents the start of the Public Sector Purchase Programme (PSPP). In this graph we do not subtract the amount of PSPP purchases from the outstanding amount of debt above two years maturity (the red line).

In Fig. 1, we show both our current and expected supply variables alongside the overall maturity of German debt. Both current and expected supply increased during the Global Financial Crisis, but then started to decline after 2013. The overall maturity of outstanding debt had the opposite dynamics, decreasing during the crisis and then consistently increasing from 2010. This was in line with the German government's strategy, aimed at both reducing the amount of outstanding debt and increasing its overall maturity.

The transition from short- to medium- and long-term debt can also be seen in Fig. 2, which shows separately the short-term and long-term German debt supply curves. The short-term debt increased sharply towards the end of 2009 and then steadily decreased reaching very low levels in October 2017. The contraction is even more dramatic if we examine bonds with less than one year to maturity, because the total amount outstanding decreased from around €100bn before 2010 to about €10bn at the end of 2017.

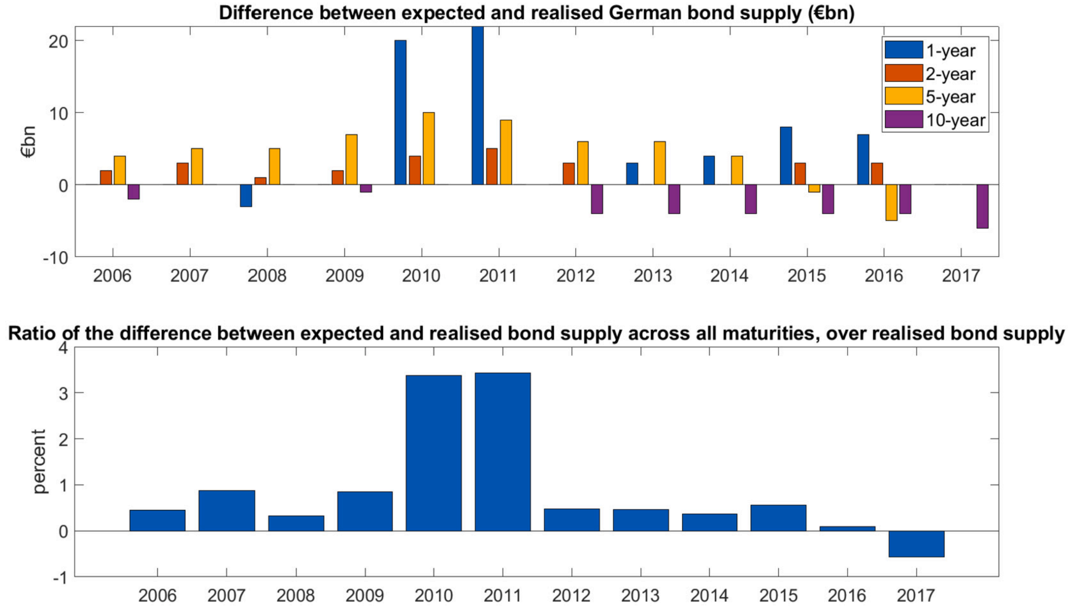


**Fig. 3. Bond supply prediction error**. The top panel shows the amount in €bn by which the 12-month ahead expected supply exceeds the realised supply (prediction error). Expected supplies are computed in December of every year. Each coloured bar represents a specific maturity. The bottom panel reports, for each sample year, the sum of all prediction errors scaled by total German bond supply.

Some other related research focuses on extrapolating information about future outstanding debt from long-term historical projections of Debt-to-GDP or fiscal deficits provided by the Treasury.[10] However, these studies are few and focus mainly on the US. Given that we do not have access to this type of data, we build our expected supply variables using Treasury press releases. In this context, it is important to assess the alignment between these press releases and subsequently realized debt patterns. In Fig. 3 we show the difference between each 12-month-ahead supply expectation, measured in December, and the corresponding realised supply. The upper panel shows the deviation in billions of Euros for different maturity buckets, while the lower panel shows the cumulative sum of these deviations across all maturities in relation to the overall supply levels. This chart shows that press releases are quite accurate in predicting future bond supply realisations. The prediction error is larger in absolute terms for short-term maturity bonds and during certain years within our sample (as indicated by the blue bars in the upper panel). However, the ratio of the prediction error aggregated across maturities and the total supply remains negligible throughout our entire sample period.

We additionally retrieve data concerning German government bond purchases by the European Central Bank during the public sector purchase programme (PSPP) that started in March 2015.[11] This encompasses information about the overall purchases made and the average remaining duration of the ECB's bond holdings. Subsequently, we devise a maturity-weighted metric for German debt held by the European Central Bank, which can be expressed as follows:

$$MWQE_t = \frac{\sum_{t=0}^{n} Holdings_t * \bar{M}_t}{GDP_t}$$

where $\sum_{t=0}^{n} Holdings_t * \bar{M}_t$ is the sum of all the PSPP holdings multiplied by their average residual maturity.

We express our supply variables in face values for two reasons. First, as Greenwood and Vayanos (2014) point out, interest rate changes have a mechanical effect on the overall supply if this is expressed in market values. A decrease in bond prices would decrease maturity-weighted debt, thus creating a spurious negative relationship between yields and supply. Second, we could theoretically estimate a market value of expected debt based on interest rates observed ex-post, but those same interest rates would not be available in the market at the time when details about the future value of outstanding debt become available to investors.

Finally, we are interested in studying potential scarcity effects at the short-end of the German term structure of interest rates. To capture these effects we define the expected amount of short-term bonds outstanding as follows:

$$E[STD_{t+k}] = \frac{\sum_{\tau=0}^{2} E[D^{\tau}_{t+k} | I_t]}{GDP_t}$$

where $\sum_{\tau=0}^{2} E[D_{t+k} | I_{i,t}]$ is the sum of the expected outstanding amount of German bonds at the end of the year with an original maturity under two years, based on the information available at time $t$. We also take advantage of some specific features of the PSPP

[10] See, for example, Laubach (2009), Bernoth et al. (2012) and Thomas and Wu (2009).

[11] Bond purchases in the context of the PSPP were undertaken by Euro Area national central banks, but are still reported on the ECB balance sheet.

**Table 1**

**Summary statistics**. This table shows summary statistics (mean, standard deviation, minimum and maximum values) for the main variables used in the analysis. ECB Dep. Rate is the interest of deposits at the European Central Bank. 2y, 5y, 10y, 30y are zero-coupon yields on 2, 5, 10 and 30-year bonds. $MWD$ is the Maturity-Weighted Debt scaled by GDP. $E[MWD|I_t]$ is the future expected value of Maturity-Weighted Debt scaled by $GDP$. $MWQE$ is the amount of Maturity-Weighted Purchases by the ECB during the Public Sector Purchase Programme (PSPP) scaled by $GDP$. $E[STD]$ is the expected outstanding amount of German short-term bonds scaled by GDP. Liquidity Risk is the time-weighted bond bid-ask spread calculated from the Mercato dei Titoli di Stato (MTS) platform. We average across all maturities the intra-day bid-ask spread of each bond displayed in the order book, weighted by the length of time each spread is displayed. Credit Risk is the log of the five-year US dollar-denominated Sovereign CDS Spread. Inflation is the year-on-year inflation growth. Inflation Risk is the standard deviation of the year on year inflation over the past twelve months. Output Growth is the difference between log real GDP in the current quarter and log real GDP in quarter t-4. Stock market volatility is the log of the Vstoxx index. Crisis dummy is a dummy that assumes the value of 1 between October 2010 and September 2012.

| Sample: 2006-2017 (Monthly Data - 156 Observations) | | | | |
|---|---|---|---|---|
| Yields | $\mu$ | $\sigma$ | Min | Max |
| ECB Dep. Rate | 0.007 | 0.008 | -0.004 | 0.0325 |
| 2y | 0.012 | 0.016 | -0.009 | 0.044 |
| 5y | 0.016 | 0.016 | -0.006 | 0.045 |
| 10y | 0.023 | 0.014 | -0.002 | 0.045 |
| 30y | 0.029 | 0.012 | 0.004 | 0.047 |
| Supply | | | | |
| $MWD$ | 3.199 | 0.133 | 2.97 | 3.4 |
| $E[MWD\|I_t]$ | 3.236 | 0.146 | 3.022 | 3.501 |
| $MWQE$ | 0.129 | 0.293 | 0.000 | 1.021 |
| $D/GDP$ | 0.384 | 0.021 | 0.351 | 0.420 |
| $E[STD]$ | 0.061 | 0.016 | 0.037 | 0.096 |
| Other Variables | | | | |
| Liquidity Risk | 0.106 | 0.060 | 0.029 | 0.376 |
| Credit Risk | 2.821 | 1.034 | 0.752 | 4.72 |
| Inflation | 0.001 | 0.004 | -0.012 | 0.012 |
| Inflation Risk | 0.004 | 0.001 | 0.003 | 0.005 |
| Output Growth | 0.005 | 0.012 | -0.065 | 0.02 |
| Stock Market Vol. | 22.810 | 8.201 | 11.991 | 60.686 |
| Crisis Dummy | 0.150 | 0.361 | 0 | 1 |

to make sure that our measure is a reliable estimate of the net outstanding amount of short-term debt. Notably, at the start of the programme, the ECB could purchase neither bonds with remaining maturity below two years nor bonds that traded below the deposit rate. Since short-term German bonds had been trading below this threshold consistently since the start of the PSPP, we know that our measure of short-term supply is a good estimate of the total amount of bonds available to investors. Even if the PSPP implementation slightly changed in January 2017, when the ECB was eventually allowed to buy bonds with yields below the deposit rate, we believe the purchases in this maturity bucket were limited.[12] Nonetheless, in our robustness tests we restrict our sample and define expected short-term debt supply differently to check the consistency of our results. We split the bonds into two maturity buckets (less than one year and between one and two years) and regress the Bund yield minus the ECB deposit rate on these two maturity-specific supply variables. Results are not affected by these different specifications.

Table 1 provides summary statistics for yields, various supply proxies and other variables used in the empirical analysis. Table B.1 in the Appendix details the sources for the main variables used in our empirical analysis and Table B.2 in the Appendix shows the correlations in levels and first difference between the main variables in our study. The latter table shows that our measure of expected supply has higher correlation with 10- and 5-year spreads than current supply, both in levels and in first differences.

## 3. Baseline identification

To gauge the effect of Treasury press releases on interest rates, we first run simple event-study regressions. This allows us to assess how unexpected changes in expected supply affect German bonds on and around press release dates. First, we focus on those dates when the Treasury reduced the expected volume of planned issuances in the forthcoming months. This is because decreases are more prevalent in our sample period. We also consider the difference between the "newly" announced expected supply and the one

[12] As stated by the ECB (see https://www.ecb.europa.eu/mopo/implement/omt/html/pspp-qa.en.html): "Purchases of securities with a yield to maturity below the interest rate on the ECB deposit facility continue to be undertaken to the extent necessary after the restart of net purchases. For each jurisdiction, priority is given to purchases of assets with yields above the DFR. This means that some jurisdictions with eligible assets with yields below the DFR may require purchases at yields below the DFR and others may not, depending on the amount of assets with yields above the DFR available to fulfil the total PSPP volume for the jurisdiction in question [...]. In this way, the approach minimises purchases of bonds with yields below the DFR within each jurisdiction. This mechanism can be reviewed in the future."

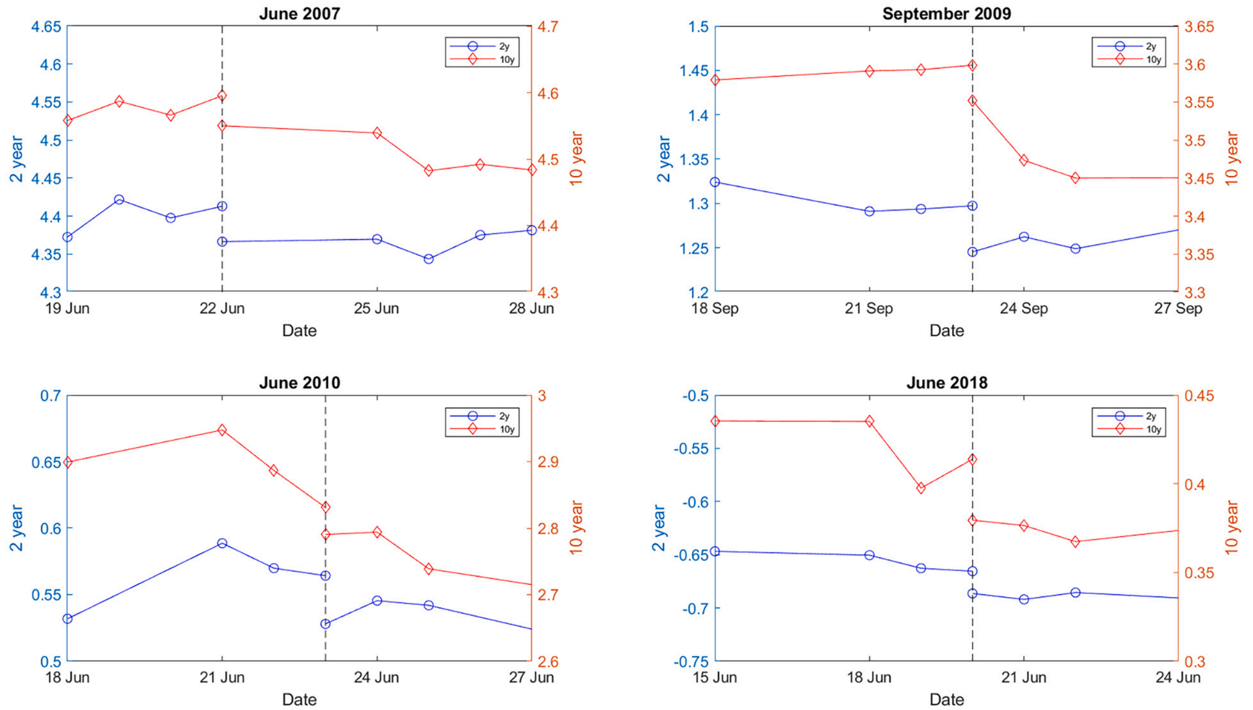


**Fig. 4. German interest rates around treasury press release dates**. The figure represents interest rate movements for 2 and 10-year German bonds on selected dates around press releases about future bond auctions. The dashed vertical line represents the day of the press release. The breaks in the yields represent the effect of the press releases. The events in the figure represent instances in which the Treasury decreased the expected issued amount in different maturity buckets.

previously communicated, which we refer to as the "surprise" change. Fig. 4 illustrates the movements of yields around some of the dates when reductions in expected supply were announced. We estimate the event-study regressions as follows:

$$\Delta y_t^{(\tau)} = \alpha + \beta News_t + \epsilon_{i,t}$$

where $News_t$ is either a dummy variable that has value 1 on days with unexpected reductions in expected supply or is a continuous variable that indicates the overall surprise change in expected supply. The surprise change is positive (negative) when there is an unexpected increase (decrease) in future supply. $\Delta y_t^{(\tau)}$ is the daily yield change for bonds with maturity $\tau$. Therefore, we can interpret the $\beta$ in the regressions as follows. When $News_t$ is a dummy, it captures the average effect of decreased bond supply on yield changes across all news events. When it is a continuous variable, it indicates the effect of a €1bn positive surprise change. Given that $News_t$ represents negative surprises with a value of 1 when it is a dummy, we should expect its coefficient to have the opposite sign than when $News_t$ is a continuous variable. We estimate the regression with heteroskedasticity-robust standard errors.

Further, we use the variables that we have described in the previous section to estimate the following monthly regressions of yield spread changes on current and expected future supply separately:

$$\Delta(y_t^{(\tau)} - y_t^{(1)}) = \alpha + \beta_1 \Delta MWD_t + \beta_2 \Delta MWQE_t + \epsilon_t \quad \forall \tau > 1 \tag{1}$$

$$\Delta(y_t^{(\tau)} - y_t^{(1)}) = \alpha + \beta_1 \Delta E[MWD_{t+k}|I_t] + \beta_2 \Delta MWQE_t + \epsilon_t \quad \forall \tau > 1 \tag{2}$$

where $\Delta(y_t^{(\tau)} - y_t^{(1)})$ is the monthly change in the spread between the $\tau$-year and the 1-year bond. We also run horse-race regressions in which we jointly estimate the contribution of both current and future expected supply to the yield spread change:

$$\Delta(y_t^{(\tau)} - y_t^{(1)}) = \alpha + \beta_1 \Delta MWD_t + \beta_2 \Delta E[MWD_{t+k}|I_t] + \beta_3 \Delta MWQE_t + \epsilon_t \quad \forall \tau > 1. \tag{3}$$

Yield spread variability may depend on other variables besides current and/or expected supply. Thus, throughout the paper, statistical significance is always determined on the basis of robust t-tests calculated using auto correlation and heteroskedasticity-robust standard errors (Newey and West (1987)). Given the high persistence of the variables in our sample, we consider them in first-differences. Indeed, when we perform an augmented Dickey-Fuller test, we cannot reject the null hypothesis of the presence of a unit root in the data both for our dependent and independent variables in levels (the results of this test are reported in Table B.3 in Appendix B).

**Table 2**
**Event study: Treasury announcements of future bond supply**. This table reports daily event study regressions of yield changes on expected supply surprises for the period between January 2006 and December 2017: $\Delta y_t^{(\tau)} = \alpha + \beta News_t + \epsilon_t$ where $News_t$ is either a dummy equal to 1 whenever the German Treasury communicated a reduction in expected bond supply in future auctions (top panel), or the difference between the newly announced expected supply and the previously communicated one (i.e. the "surprise" amount) in each press release (bottom panel). The dependent variables are 1 and 2-day changes in the 2, 5 and 10-year German yields. T-stats in brackets are based on robust standard errors. *** p<0.01, ** p<0.05, * p<0.1.

| Reduced Supply Events | | | | |
|---|---|---|---|---|
| Bond | $\beta_{1day}$ | t-stat | $\beta_{2days}$ | t-stat |
| 2year | **-1.6**** | [2.1] | **-0.82*** | [2] |
| 5year | **-2.4***** | [2.2] | **-1.1**** | [2.1] |
| 10year | **-2.2**** | [2.2] | **-1.2**** | [2.4] |
| Obs | 2860 | | 2860 | |
| All Events - Surprise Amounts | | | | |
| Bond | $\beta_{1day}$ | tstat | $\beta_{2days}$ | t-stat |
| 2year | **0.4***** | [3.6] | **0.3*** | [1.8] |
| 5year | **0.6***** | [4.6] | **0.5***** | [2.5] |
| 10year | **0.7***** | [5] | **1.1***** | [5.5] |
| Obs | 2860 | | 2860 | |

### 3.1. Linear regressions results

We start the empirical analysis with our event-study regressions and report our estimated results in Table 2. We run regressions with daily yield changes for 2-year, 5-year and 10-year German bonds. We use two alternative definitions of the event window. The first definition considers only day 't', which represents the date of the press release concerning future supply. The second definition includes the period from day t-1 to day t+1. We select short event windows because we want to reduce the probability of having multiple events in the same window. Coefficients across all maturities are statistically significant for both event windows and all specifications. For example, the 10-year bond yield displays an abnormal negative change of 2.2 basis points during press release days that announce reductions in expected supply (top panel), while a negative surprise of €1bn (equivalent to 0.15 standard deviations of this variable) has an estimated negative effect of 0.7 basis points (bottom panel). This magnitude is in line with Phillot (2021) who focuses on US Treasuries announcements.

Our event study results indicate that interest rates respond to Treasury's press releases. However, these results do not provide insights into the yield effects of current and expected bond supply. Table 3 shows the result of regressions of yield spread changes on current and future expected supply changes. The second column of Panel A and Panel B reports the estimated coefficients of current and expected maturity-weighted supply changes. The coefficients of current supply changes are not significant for any maturity, with the exception of the 30 year bond which is only mildly significant. However, future expected supply changes have highly significant coefficients at all maturities. Further, in line with what we would theoretically expect from Vayanos and Vila (2021)'s framework, the difference between the effects of current and expected supply becomes larger with maturity.

Assessing the economic significance of these findings, a one standard deviation increase in future expected supply would correspond approximately to a 22 basis point increase in the yield spread between the 10- and 1-year German yields (coefficient = 0.014, t = 2.72). To compare these estimates with the impact of the supply reduction caused by the PSPP programme, which the ECB announced in January 2015, we would need to understand the market expectations before the programme's implementation. Specifically, we would need an estimate of the projected volume and mean maturity of purchases that market participants anticipated. This task is complex because it involves determining the point at which agents incorporated information about future purchases into their expectations. For the purpose of this exercise, we assume that the ECB announcement of the programme was completely unanticipated by the markets. With this assumption, we can run a back-of-the-envelope calculation based on the overall amount of German purchases following the ECB capital key.[13] This would amount to around €220 billions in January 2015. If we also assume the average maturity of purchased bonds to be around 5 years (slightly lower than the average euro area debt in 2015) and a GDP of €3.4 trillions based on 2015 data, we would have a decrease in expected maturity-weighted supply of about 0.32 (0.22*5/3.4), which is a change of around 2 standard deviations for the variable. This would imply a total decrease of the yield spread by 48 basis points. Our results are broadly in line with the estimates of Greenwood and Vayanos (2014), and are strikingly similar to what observed in

[13] The ECB capital key is calculated on the basis of a country's shares of population and GDP relative to the EU, equally weighted. If, for instance, a country accounted for 10% of the EU's total population and produced 20% of the EU's GDP, its central bank's share in the ECB's capital would be 15%. Asset purchases were determined for each euro area country according to this capital key.

**Table 3**

**Current and expected debt supply as a determinant of yield spreads**. This table reports monthly regressions (Jan 2006-Dec 2017) of yield spread changes on current and expected future maturity-weighted supply changes for Germany: $\Delta(y_{i,t}^{(\tau)} - y_{i,t}^{(1)}) = \alpha + \beta_1 \Delta MWD_{i,t} + \beta_2 \Delta E[MWD_{i,t+k}|I_{i,t}] + \beta_3 \Delta MWQE_{i,t} + \epsilon_{i,t}$. $\Delta(y_{i,t}^{(\tau)} - y_{i,t}^{(1)})$ is the change in the slope of the yield curve at different maturities $\tau$. $\Delta MWD$ is the change in Maturity-Weighted Debt scaled by $GDP$. $\Delta E[MWD|I_t]$ is defined as the change in maturity-weighted supply, scaled by $GDP$. $\Delta MWQE$ is the amount of maturity-weighted purchases by the ECB during the Public Sector Purchase Programme (PSPP) scaled by $GDP$. Panel A shows the results for the regression of yield spreads on current supply, while Panel B for expected future supply. Panel C reports horse-race regressions in which current and expected supply are estimated together. T-stats are reported in brackets. We estimate all regression models with Newey West standard errors allowing for up to 16 lags. Coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

**Panel A**: Current Supply

| $\Delta(y_{i,t}^{(\tau)} - y_{i,t}^{(1)})$ | $\Delta MWD$ | t-stat | $\Delta MWQE$ | t-stat | $\alpha$ | t-stat | $R^2_{adj}$ |
|---|---|---|---|---|---|---|---|
| 2y | 0.0007 | [0.32] | 0.002 | [0.96] | 0 | [-0.19] | 0 |
| 3y | 0.001 | [0.59] | 0.003 | [1.08] | 0 | [-0.18] | 0 |
| 4y | 0.002 | [0.76] | 0.005 | [1.13] | 0 | [-0.17] | 0 |
| 5y | 0.002 | [0.80] | 0.006 | [1.15] | 0 | [-0.16] | 0 |
| 6y | 0.002 | [0.75] | 0.007 | [1.19] | 0 | [-0.15] | 0 |
| 8y | 0.003 | [0.81] | 0.008 | [1.17] | 0 | [-0.12] | 0 |
| 10y | 0.0025 | [0.61] | 0.001 | [1.16] | 0 | [-0.09] | 0 |
| 30y | **0.005*** | [1.68] | 0.001 | [1.08] | 0 | [0.06] | 0 |

**Panel B**: Expected Supply

| $\Delta(y_{i,t}^{(\tau)} - y_{i,t}^{(1)})$ | $\Delta E[MWD\|I_t]$ | t-stat | $\Delta MWQE$ | t-stat | $\alpha$ | t-stat | $R^2_{adj}$ |
|---|---|---|---|---|---|---|---|
| 2y | **0.005**** | [2.27] | 0.002 | [1.13] | 0 | [-0.12] | 0.02 |
| 3y | **0.007**** | [2.37] | 0.004 | [1.25] | 0 | [-0.12] | 0.02 |
| 4y | **0.01**** | [2.26] | 0.005 | [1.29] | 0 | [-0.12] | 0.03 |
| 5y | **0.012**** | [2.14] | 0.006 | [1.33] | 0 | [-0.11] | 0.03 |
| 6y | **0.013**** | [2.25] | 0.008 | [1.39] | 0 | [-0.10] | 0.04 |
| 8y | **0.014**** | [2.51] | 0.009 | [1.35] | 0 | [-0.07] | 0.03 |
| 10y | **0.014***** | [2.72] | 0.01 | [1.35] | 0 | [-0.03] | 0.03 |
| 30y | **0.018***** | [2.71] | 0.01 | [1.17] | 0 | [0.16] | 0.03 |

**Panel C**: Horse-Race Regressions

| $\Delta(y_{i,t}^{(\tau)} - y_{i,t}^{(1)})$ | $\Delta MWD$ | t-stat | $\Delta E[MWD\|I_t]$ | t-stat | $\Delta MWQE$ | t-stat | $\alpha$ | t-stat | $R^2_{adj}$ |
|---|---|---|---|---|---|---|---|---|---|
| 2y | 0.0002 | [0.15] | **0.003*** | [1.84] | 0.002 | [0.93] | 0 | [-0.38] | 0.02 |
| 3y | 0.0009 | [0.42] | **0.005*** | [1.88] | 0.004 | [1.25] | 0 | [-0.40] | 0.03 |
| 4y | 0.0013 | [0.51] | **0.007*** | [1.85] | 0.006 | [1.32] | 0 | [-0.44] | 0.03 |
| 5y | 0.0016 | [0.55] | **0.008*** | [1.74] | 0.007 | [1.38] | 0 | [-0.47] | 0.04 |
| 6y | 0.0017 | [0.58] | **0.009*** | [1.81] | 0.007 | [1.42] | 0 | [-0.45] | 0.03 |
| 8y | 0.002 | [0.60] | **0.009**** | [1.96] | 0.01 | [1.40] | 0 | [-0.60] | 0.03 |
| 10y | 0.001 | [0.44] | **0.01**** | [2.40] | 0.01 | [1.35] | 0 | [-0.49] | 0.03 |
| 30y | 0.003 | [0.93] | **0.012**** | [2.58] | 0.013 | [1.09] | 0 | [-0.36] | 0.04 |

Lemke and Werner (2020). The latter paper shows that the German Bund yield movements around PSPP related events in the months before the official announcement, and yield movements on announcement day, sum up to around 50 to 60 basis points, an estimate very close to our own.

Column 4 in Panels A and B of Table 3 reports the coefficients related to maturity weighted purchases by the ECB. These estimated coefficients, which measure the impact of actual purchases on yield spreads, are not significant at any maturity. At first sight, this may seem counter-intuitive. However, the existing literature (for example D'Amico and King (2013)) estimates that actual purchases have a limited impact on yields compared to announcement effects. Actual purchases are also transitory and converge to zero a few days after the auctions. Therefore, our monthly time-series regressions may not adequately capture this effect, which could instead be observed at higher frequencies. Panel C of Table 3 reports the results of the horse-race regressions between current and expected maturity-weighted supply. Consistent with our results in Panel A and B of the same Table, our measure of expected supply dominates current supply. We also estimate another variant of these regressions. More specifically, we fit a stochastic ARMA(4,4) process both to current and expected supply changes, and we use the extracted shocks from this process as explanatory variables where yield slope changes are the dependent variables. Table B.4 reports the results of this exercise. The estimated shocks to expected supply are still significant in explaining the change in yield slopes at several maturities, but slightly weaker than our baseline results. At the same time, current supply shocks are not significant at any maturity. These results show that unexpected changes in supply expectations drive interest rates, while unexpected changes in current supply are irrelevant when pricing the contemporaneous yield curve.

After having determined that expected bond supply influences bond yields we test whether the same is true for bond excess returns, similarly to Greenwood and Vayanos (2014). We define the excess return as the log price change of a bond with $\tau$ maturity

**Table 4**
**Bond excess returns regressions**. Regressions of bond excess returns on expected supply: $(p_{t+1}^{(\tau-1)} - p_t^{(\tau)}) - y_t^{(1)} = \alpha + \beta_1 E[MWD|I_t] + \beta_{2,n} X_t + \epsilon_t$ where $p_t^{(\tau)}$ is the log-price of bond with maturity $\tau$ at time t. $(p_{t+1}^{(\tau-1)} - p_t^{(\tau)}) - y_t^{(1)}$ are 2- and 10-year 12-months bond excess returns, $E[MWD|I_t]$ is maturity-weighted expected supply and $X$ a matrix of controls. $y^{(10)} - y^{(1)}$ is the slope of the yield curve, while the level, slope and curvature factors are the first three principal components extracted from the cross-section of interest rates. T-stats are reported in brackets. Sample period is Jan 2006-Dec 2017. Coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

| | 2y excess return | | | 10y excess return | | |
|---|---|---|---|---|---|---|
| $E[MWD\|I_t]$ | **0.063*****<br>[4.47] | 0.0054<br>[0.43] | 0.0047<br>[0.85] | **0.12*****<br>[3.34] | **0.1***<br>[1.70] | **0.083***<br>[1.69] |
| $y^{(10)} - y^{(1)}$ | | 0.15<br>[1.06] | | | **6.44*****<br>[10.6] | |
| Level Factor | | | **0.011*****<br>[15.8] | | | **0.048*****<br>[7.32] |
| Slope Factor | | | **0.011*****<br>[7.36] | | | **-0.085*****<br>[5.71] |
| Curvature Factor | | | **-0.014*****<br>[3.26] | | | 0.055<br>[1.28] |

over the next 12-months minus the one year yield today.[14] We show in Table 4 regressions in which expected supply is used as a factor in order to forecast 2- and 10-year 12 months bond excess returns. Higher expected supply should depress bond prices, raising future expected bond returns. In line with this expectation, the coefficient for expected supply changes is positive in these regressions and it is increasing with maturity. The 2-year excess return is not significant when we control for the first three principal components of the term structure of bond yields. But, the 10-year excess return keeps its statistical significance even after controlling for these factors. Table B.5 in the Appendix shows the same excess return regressions, but with current supply instead of expected supply as a conditioning variable. Consistent with our previous findings, current supply is not significant in any of these specifications.

Moreover, we use the same specifications of equations (1), (2) and (3), but we change how we define current and expected supply. In order to check for local supply effects, we create maturity-specific buckets of current and expected supply and we regress them on the corresponding yield curve slope. We focus on medium- and long-term maturities (5 and 10 years), as we will look into the short-end of the yield curve in Section 5 when we explore scarcity effects. We report the results of these regressions in Table B.6 in Appendix B. Our measures of maturity-specific expected supply are significant at both maturities, while current supply is not significant. This is in line with our other specifications, and points to local supply effects at specific maturity buckets of the German curve.

Finally, we adopt an instrumental variables approach to check whether endogeneity could bias our results. Endogeneity could arise from the fact that the government could choose the structure of its debt to minimise interest payments. The Treasury could have an incentive to shift towards issuing a higher percentage of long-term bonds if the spread between long and short-term interest rates decreased, due for example to a higher demand for bonds with longer maturity. We focus our instrumental variable approach on equation (2), because that specification showed the best fit with the OLS regression. We choose the future expected Debt-to-GDP as an instrument for future expected German supply. Our approach is consistent with the one used by Krishnamurthy and Vissing-Jorgensen (2012) and Greenwood and Vayanos (2014).[15] Table 5 shows the results of our estimation. The t-statistics are computed with Newey and West (1987) standard errors and allow for lags up to 12 months. Column 2 reports the second stage regression estimates for the effect of expected supply changes on the changes in yield spreads. The coefficient on the 10-year spread is 0.02 (0.014 for the baseline regression in Panel B of Table 3) and significant. In Fig. 5 we also report rolling OLS coefficients of our baseline regression (2) showing the time-varying effect of expected supply changes on yield spread changes. Expected supply is significant until mid-2015. We attribute this decreasing significance mainly to the effects of the ECB PSPP. This programme put downward pressure on Euro Area interest rates by reducing the available supply of bonds on the market, which we do not capture with our expected supply variable. King (2019) finds similar results when looking at U.S data and he explains these findings by the reduction in interest-volatility near the zero lower bound.

To understand the statistical significance of expected supply, and the lack of significance of current supply in our baseline regressions, one could refer to the literature investigating central banks' asset purchase programmes (e.g., D'Amico and King (2013)). To a degree, Treasury announcements of expected supply could be seen as the opposite of central banks' announcements regarding asset purchase programmes. In the latter case, central banks announce their plans to buy various assets in the secondary market, which

[14] In these regressions, our independent variables are in levels. This is the approach used in the return-forecasting regression literature (Cochrane and Piazzesi (2005), Greenwood and Vayanos (2014), Joslin et al. (2014), Bauer and Hamilton (2017)). Nonetheless, we test the stationarity of regression residuals. The ADF tests we performed reject the null hypothesis of non-stationarity of the residuals.

[15] Expected debt-to-GDP causes variation in maturity-weighted debt to GDP through two channels. The first is mechanical: holding average maturity constant, expected maturity-weighted debt to GDP varies because it is (approximately) the product of average expected maturity times expected debt to GDP. Second, an increase in expected debt to GDP induces governments to issue a larger fraction of their debt long-term to reduce rollover risk, hence raising average expected maturity.

**Table 5**
**Instrumental variable regressions**. This table shows instrumental variable regressions of current and expected bond supply on yield spreads. $\Delta(y_{i,t}^{(\tau)} - y_{i,t}^{(1)})$ is the change in the slope of the yield curve at different maturities $\tau$. $\Delta E[MWD|I_t]$ is defined as the change in maturity-weighted expected supply scaled by $GDP$. $\Delta MWQE$ is the amount of maturity-weighted purchases by the ECB during the Public Sector Purchase Programme (PSPP) scaled by $GDP$ (its estimated coefficients are not reported in the table). Column 2 reports second stage coefficient for expected supply. T-stats, reported in brackets, are based on Newey-West standard errors with 16 lags. We instrument expected maturity-weighted debt with expected debt to GDP, $E[D]/GDP$. We report the first stage coefficient for this variable, the T-statistic and the $R^2$ in the bottom panel in the table. Sample period is Jan 2006-Dec 2017. Coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

Instrumental Variables - Second Stage

| $\Delta(y_{i,t}^{(\tau)} - y_{i,t}^{(1)})$ | $\Delta E[\widehat{MWD}|I_t]$ | t-stat | $R^2_{adj}$ |
|---|---|---|---|
| 2y | **0.007****** | [3.73] | 0.02 |
| 4y | **0.013****** | [3.64] | 0.04 |
| 5y | **0.015**** | [3.29] | 0.03 |
| 8y | **0.02**** | [4.11] | 0.04 |
| 10y | **0.02**** | [3.30] | 0.04 |
| 30y | **0.02**** | [3.21] | 0.05 |
| First Stage | $\beta$ | t-stat | |
| E[D]/GDP | **3.49****** | [12.85] | |
| MWQE | -0.04 | [-0.35] | |
| $\alpha$ | 0.0003 | [0.16] | |
| Adj. $R^2$ | 0.65 | | |

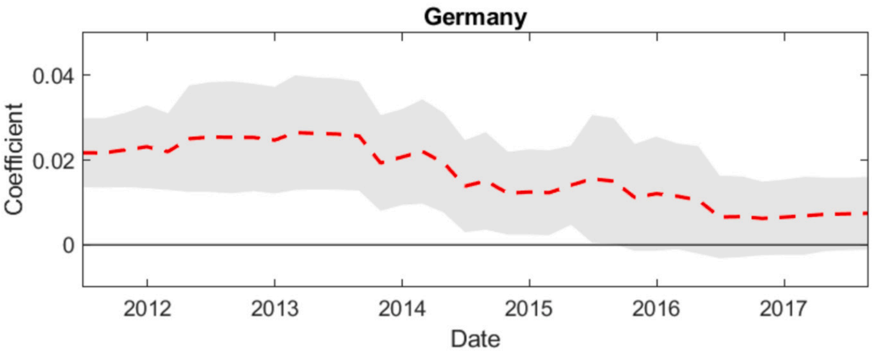


**Fig. 5. Stability of the expected supply coefficient**. The figure shows rolling OLS coefficient estimates of the effect of expected supply changes on the German 10-year yield curve slope changes. The grey shaded area represents 95% confidence intervals.

then translates into a lower expected supply for those purchased assets. These central bank announcements have been found to have strong and persistent effects. In contrast, actual purchases, which are more related to our current supply variable, do not move prices by the same amount comparatively. Thus, supply expectations are found to exert a markedly more robust impact on interest rates than current supply.

## 4. Identification of scarcity effects

We also extend our analysis to the non-linear effects of expected supply on short- and medium-term German bonds. Our objective is to assess whether supply expectations can have a different impact on interest rates when expected supply is scarce. We focus on short- and medium-term interest rates because, as shown in Fig. 2, the German Treasury decreased the overall supply of these bonds starting from 2010, while issuing more long-term bonds. Since we are focusing on shorter-term bonds, we will use the yield spread at these short-term maturities over the short-rate (the ECB deposit facility rate) as a dependent variable.

More specifically, we employ a threshold model where we set the threshold at the bottom 20 percent of the level of current German short-term supply. Our reasoning is as follows: if the current level of supply is low, it is possible that a further expected reduction in supply will lead to a stronger impact on short-term yields compared to periods when the amount of short-term bonds in the market is higher. We estimate the following regressions:

**Table 6**
**Impact of scarce short-term supply on yield spreads over ECB the rate**. In this table, we report regression results in which the dependent variables are 4-week yield spread changes at different maturities. The sample period is from January 2006 to December 2017. E[STD] is expected short-term supply with maturity below 2 years. The two indicators $q > 20$ and $q < 20$ are equal to one whenever the lagged short term supply is above or below the 20% quantile of the short term supply distribution. Credit Risk is the log of the five-year US dollar-denominated Sovereign CDS Spread. Stock market volatility is the log of the Vstoxx index. We model the error process as an AR(1) in Columns 6-9, while we use Newey-West standard errors with up to 16 lags in Columns 2-5. T-stats in brackets are based on robust standard errors. Coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

| VARIABLES | Four Week Changes | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3m | 1y | 2y | 3y | 3m | 1y | 2y | 3y |
| $\Delta_4$E[STD] if $q > 0.20$ | 0.07 | **0.14*** ** | **0.14** ** | **0.13** ** | **0.04*** | **0.09*** ** | **0.07*** | **0.06*** |
| | [1.52] | [3.43] | [2.96] | [2.33] | [1.82] | [3.25] | [1.90] | [1.686] |
| $\Delta_4$E[STD] if $q < 0.20$ | **0.17*** ** | **0.23*** ** | **0.27*** ** | **0.29*** ** | **0.22*** ** | **0.22*** ** | **0.24*** | **0.25*** ** |
| | [4.61] | [7.47] | [6.62] | [6.68] | [4.64] | [4.18] | [1.82] | [4.15] |
| $\Delta_4$ Stock Market Vol | -0.001 | **-0.002** ** | **-0.002*** ** | **-0.002*** ** | **-0.0006** ** | **-0.001*** ** | **-0.001*** ** | **-0.001*** ** |
| | [-1.64] | [-2.54] | [-3.41] | [-3.65] | [-2.13] | [-3.31] | [-4.40] | [-4.70] |
| $\Delta_4$ Credit Risk | **-0.002*** | **-0.001*** | **-0.001** ** | **-0.001*** | -0.0002 | -0.0003 | -0.0004 | 0 |
| | [-1.79] | [-1.77] | [-1.92] | [-1.88] | [-0.46] | [-0.49] | [-1.18] | [-1.65] |
| SE | NW(8) | NW(8) | NW(8) | NW(8) | AR(1) | AR(1) | AR(1) | AR(1) |
| Obs. | 621 | 621 | 621 | 621 | 621 | 621 | 621 | 621 |
| Adj. R-Squared | 0.15 | 0.18 | 0.15 | 0.14 | 0.02 | 0.05 | 0.06 | 0.06 |

$$\Delta_4 s_t^{(\tau)} = \alpha + \beta_1 \Delta_4 E[STD] \mathbb{1}_{STD_q>0.2} + \beta_2 \Delta_4 E[STD] \mathbb{1}_{STD_q<0.2} + \sum_{j=3}^{n} \beta_j \Delta_4 X_{jt} + \epsilon_t \quad (4)$$

where $\Delta_4 s_t^{(\tau)}$ is the 4-weeks change in the yield spread between the $\tau$ yield and the short-rate, $E[STD]$ is the expected supply of government debt with original maturity below 2 years and $X_{jt}$ are control variables. $\mathbb{1}_{STDq>0.2}$ and $\mathbb{1}_{STD<0.2}$ are two indicator functions that are one whenever the lagged supply is above or below the 20% quantile threshold, respectively.

We also estimate this threshold model with a different definition of the threshold where we look at different effects of the change in supply expectations whenever the spread between yields and the ECB deposit rate is either positive or negative:

$$\Delta_4 s_t^{(\tau)} = \alpha + \beta_1 \Delta_4 E[STD] \mathbb{1}_{(s_{t-4}^{(\tau)}>0)} + \beta_2 \Delta_4 E[STD] \mathbb{1}_{(s_{t-4}^{(\tau)}<0)} + \sum_{j=3}^{n} \beta_j \Delta_4 X_{jt} + \epsilon_t \quad (5)$$

where $\mathbb{1}_{(s_{t-4}^{(\tau)}>0)}$ and $\mathbb{1}_{(s_{t-4}^{(\tau)}<0)}$ are two indicator functions that are one whenever the lagged spread is positive and negative, respectively. We estimate this variant of the model to check if expected supply had a role in pushing German short- and medium- interest rates further below the ECB deposit rate.

We estimate our models using robust Newey and West (1987) standard errors and allowing for eight lags. As a robustness check, we also consider an alternative specification and assume an AR(1) process for the regression residuals and estimate the extended model with robust standard errors. We control mainly for flight-to-safety effects, since German government bonds might be prone to increased demand at times of high market stress, given their safe-haven status.

### *4.1. Scarcity effects results*

We show in Table 6 the results of the threshold model of equation (4). These results point to the stronger effect of supply expectations when supply is scarcer. For example, at the 1-year maturity, if current short-term supply is in the bottom 20 percent of the sample distribution, a one percent decrease in expected short-term supply over GDP would decrease the yield spread by 23 basis points (22bps with AR(1) residuals). Even if the coefficient is significant, the impact is halved if supply is not scarce (i.e. not in the bottom 20 percent of the distribution). Also, at the 3-year maturity a decrease of 1% in short-term expected debt over GDP would decrease the spread by 29 basis points (t-stat = 6.68) when supply is scarce, while it would only decrease the spread by 13 basis points (t-stat = 2.33) when supply is not in the lower 20% of the distribution. The result is even more pronounced when looking at AR(1) residuals (columns 6-9 of Table 6) at different maturities.

Furthermore, Table 7 shows the estimates of equation (5), which we use to assess the impact of scarcity effects whenever German short-term bonds trade at lower yields than the ECB deposit rate. Columns 2-6 present the model with Newey and West (1987) standard errors allowing for eight months of lags. Adding more lags does not seem to alter our results. Instead, in columns 7-11 we report estimated coefficients when we assume an AR(1) process for the regression residuals. In this case, we also use robust standard errors. The two alternative estimations deliver similar results. For instance, the coefficient of 0.189 (t = 7.07) in column 3 implies that a one percent decrease in the expected short-term debt to GDP (approximately half of the standard deviation for this variable) makes the spread between the one-year bond and the short rate more negative by 19 basis points.[16] In column 8, we obtain an estimate of

[16] Thinking the other way around, the dependent variable is negative whenever a German bond with $\tau$ maturity has a yield lower than the deposit rate, so an increase in a positive independent variable with a positive coefficient would decrease the spread between the bond and the deposit rate.

**Table 7**

**Impact of scarce short-term supply on yield spreads when yield spreads are positive or negative**. The table reports estimates of a weekly 4-week changes threshold regressions of the form: $\Delta_4 s_t^{(\tau)} = \alpha + \beta_1 \Delta_4 E[STD] \mathbb{1}_{(s_{t-4}^{(\tau)}>0)} + \beta_2 \Delta_4 E[STD] \mathbb{1}_{(s_{t-4}^{(\tau)}<0)} + \sum_{j=3}^{n} \beta_j \Delta_4 X_j + \epsilon_t$ where the dependent variable is the spread between the $\tau$ year bond and the deposit rate of the European Central Bank. $\mathbb{1}_{(s_{t-4}^{(\tau)}>0)}$ and $\mathbb{1}_{(s_{t-4}^{(\tau)}<0)}$ are indicator variables that assume value 1 whenever the spread is positive or negative, respectively. The independent variable $E[STD]$ is the end of year outstanding amount of government debt with original maturity below two years scaled by $GDP$. Stock Market Vol is the log of the Vstoxx index. Credit Risk is the 5-year US dollar denominated sovereign CDS. Columns 2-6 report the coefficients assuming Newey-West standard errors with 8 lags. Columns 7-11 assume an AR(1) process for residuals and robust standard errors. T-stats are reported in brackets. Sample period is Jan 2006-Dec 2017. Coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

| VARIABLES | Four Week Changes | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3m | 1y | 2y | 3y | 4y | 3m | 1y | 2y | 3y | 4y |
| $\Delta_4$E[STD] if Spr>0 | **-0.12**** | -0.005 | 0.063 | 0.088 | **0.164***** | -0.0254 | 0.005 | 0.041 | 0.076 | **0.135***** |
| | [-2.30] | [-0.07] | [0.66] | [0.88] | [2.64] | [-0.56] | [0.11] | [0.70] | [1.32] | [3.45] |
| $\Delta_4$E[STD] if Spr<0 | **0.126***** | **0.189***** | **0.169***** | **0.156***** | **0.091**** | **0.082**** | **0.134***** | **0.09*** | 0.071 | 0.0178 |
| | [4.78] | [7.07] | [7.39] | [6.12] | [2.41] | [1.99] | [2.87] | [1.82] | [1.51] | [0.66] |
| $\Delta_4$ Stock Market Vol. | **-0.0019*** | **-0.002***** | **-0.002***** | **-0.002***** | **-0.002***** | **-0.0007**** | **-0.0011***** | **-0.0014***** | **-0.0015***** | **-0.0018***** |
| | **[-1.80]** | [-2.73] | [-3.68] | [-3.88] | [-4.12] | [-2.22] | [-3.32] | [-4.32] | [-4.90] | [-5.68] |
| $\Delta_4$ Credit Risk | **-0.0023*** | -0.0018 | **-0.0015*** | **-0.0012*** | -0.0009 | -0.0002 | -0.0003 | -0.0004 | -0.0005 | **-0.0007**** |
| | [-1.68] | [-1.63] | [-1.78] | [-1.67] | [-1.28] | [-0.43] | [-0.74] | [-1.22] | [-1.60] | [-2.12] |
| SE | NW(8) | NW(8) | NW(8) | NW(8) | NW(8) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) |
| Obs. | 621 | 621 | 621 | 621 | 621 | 621 | 621 | 621 | 621 | 621 |
| $R^2_{adj}$ | 0.17 | 0.2 | 0.15 | 0.14 | 0.13 | 0.02 | 0.06 | 0.05 | 0.06 | 0.09 |

0.134 (t = 2.87) for the same coefficient. This means that a one percent decrease in expected short-term debt to GDP increases the same spread by 13.4 basis points. Furthermore, the impact of expected short-term debt on the spread between government bonds and the deposit rate is, in most cases, not significant whenever the spread is positive (first row of Table 7). The only maturity in which the expected outstanding amount of short-term debt seems to have a positive impact on the spread is at the four-year maturity. However, this could be due to the limited number of days in which four-year bonds traded below the deposit rate. In our robustness tests, we apply the model to different sample periods and also create maturity-specific measures of expected supply to better isolate local supply effects and sharpen our identification. We discuss this robustness test in the next section. In all our specifications, our conclusions are confirmed. To the best of our knowledge, we are the first to find a link between the expected amount of short-term bond supply and the amount of German bonds trading below the ECB deposit rate.

In our model, we also control for flight-to-safety effects, because an increased demand for German bonds during times of high market stress and risk aversion may drive interest rates downward in safe markets. We add 4-week changes in stock market volatility and in the German CDS spread as controls for flight-to-safety. Indeed, we find a negative relationship between our controls and German yields, confirming the presence of a flight-to-safety effect in our sample. The estimated coefficients in rows 3 and 4 of Table 7 are negative and mostly significant. However, our variable of interest is still significant, even after adding these controls.

## 5. Robustness tests

We perform several robustness tests on our baseline specifications. First, we estimate the same regressions as in Panels A and B of Table 3, but in levels. We compute the t-statistics with Newey and West (1987) standard errors allowing for up to 12 lags. The results in Table B.8 are very similar to our regressions in first-difference, even if somewhat weaker. Next, we add to our baseline regressions several controls. Table B.9 in the Appendix reports the results. First, in column 3 we add controls for credit and liquidity risk. Credit and liquidity conditions may drive interest rates, especially in times of high market stress, for example during the Great Financial Crisis and during the European sovereign debt crisis. Next, in column 4 we add a control for risk aversion in the equity market, proxied with the Vstoxx index, and a dummy for the sovereign crisis. Moreover, in columns 5 and 6 we add two macroeconomic controls: output growth and inflation, which could affect interest rates through the risk premium, as shown in Ludvigson and Ng (2009) and Joslin et al. (2014). Our results remain significant after controlling for all these factors.

Further, we are aware that our main expected supply variable has a shrinking forecasting horizon in each calendar year. This might cause some forecast seasonality that could affect our baseline results. In order to control for this effect, we extract the seasonal component of this variable with an ARIMA filter, and repeat our baseline regressions after we remove the seasonal component. Results are shown in Table B.10. Our expected supply variable remains statistically significant even after this adjustment, with t-statistics that are slightly lower compared to our baseline regressions.

As a further robustness check, we compute an alternative measure of current and expected supply. Following Krishnamurthy and Vissing-Jorgensen (2012) we construct the amount of current and expected long-term debt without maturity weighting as follows:

$$LTD_t = \frac{\sum_{\tau=10}^{30} D_t^{\tau}}{GDP_t}$$

and

$$E[LTD_{t+k}] = \frac{\sum_{\tau=10}^{30} E[D_{t+k}^{\tau}|I_t]}{GDP_t}$$

After computing these measures, we run again our baseline regressions and obtain 2-stage least square estimates by instrumenting both variables with $D/GDP$ and $E[D/GDP]$, respectively. We report the results in Table B.11 in the Appendix. Even with this specification, expected supply dominates current supply and is robust to a set of controls. Current long-term debt is not significant even in this specification. In the same table we also show that the current level of long-term debt is not significant on its own, which confirms our baseline results.

We also check whether the results regarding the impact of expected short-term debt on the spread between German bonds and the deposit rate of the ECB remain significant with different specifications. In columns 2-6 of Table B.12 we modify our measure of expected short term debt. We calculate separately the specific amount of expected supply for bonds with original maturity of less than one year and less than two years, respectively. We regress the three months and the one-year spread on the expected supply of less than one-year bonds, while we regress the two-year spread on the expected supply of bonds with two-year maturity. Since the German government does not issue bonds with three and four years of original maturity, we use the expected supply of two-year bonds as the closest proxy of expected supply for three- and four-year bonds. Furthermore, columns 7-11 show the results when we use a smaller sample period ranging from 2010 to 2017 and omitting the Great Financial Crisis. In fact, the government might have responded endogenously to the decrease in short-term interest rates by issuing a larger fraction of short-term debt. In this specification, the coefficients of expected short term supply when the spread is negative are twice as large as those in Table 7. In Columns 12-16 we omit data for 2017. It is possible, in fact, that the ECB purchased bonds with about two years' maturity and below the deposit rate from January 2017 after it changed the scope of the purchase programme. However, our results are largely unaffected when we omit 2017. Finally, we estimate a horse-race threshold regression between current and expected future short-term supply. We also augment this specification with a control for liquidity risk. Table B.13 shows the estimation results. As in the baseline results, our measure of expected short-term debt is positive and highly statistically significant when the spread is negative while current short-term supply is

**Table 8**
**Estimated risk neutral parameters from the term structure model**. This table presents maximum likelihood estimates of the risk-neutral parameters from our MTSM: the long-run risk-neutral mean $r^Q_\infty$, the eigenvalues of the feedback matrix under $Q$ ($\lambda^Q$) and the parameters governing the macro-spanning equation $\gamma_0$ (scalar) and $\gamma_1$ ($1x3$ vector). We report small-sample standard errors in parentheses and bootstrapped standard errors in brackets. The sample period is from January 2006 to December 2017.

| Risk Neutral Parameters | | | | | | | |
|---|---|---|---|---|---|---|---|
| $r^Q_\infty$ | $\lambda^Q_1$ | $\lambda^Q_2$ | $\lambda^Q_3$ | $\gamma_0$ | | $\gamma_1$ | |
| 0.006 | **0.997*** ** | **0.986*** ** | **0.986*** ** | **-3.81*** ** | **-0.060*** ** | **0.868*** ** | **6.23*** ** |
| (0.002) | (0.001) | (0.004) | (0.010) | (0.144) | (0.011) | (0.057) | (0.216) |
| [0.006] | [0.003] | [0.0053] | [0.041] | [0.759] | [0.017] | [0.179] | [0.541] |

mostly not significant (or with a puzzling negative sign when it is significant at the 4-year maturity). This also confirms our previous findings on the intrinsic value of specific forward-looking information compared to the actual quantities of debt observable in the market.

## 6. Term-structure model results

Given the results in the previous sections, we now turn to estimating a Macro Term Structure Model (MTSM) with expected supply as a pricing factor. Our estimation follows closely Joslin et al. (2011) and Li and Wei (2013). The main ingredients of the model are as follows:

1. The short rate is affine in the pricing factors $Z_t$:

$$r_t = \delta_0 + \delta_1 Z_t, \tag{6}$$

2. $Z_t$ follows a VAR(1) process under the physical (P) and risk-neutral (Q) dynamics:

$$Z_{t+1} = K_0^{Q,P} + K_1^{Q,P} Z_t + \epsilon^{Q,P}_{Z,t+1}, \tag{7}$$

3. Yields for all maturities take an exponentially linear form of $Z_t$ and are expressed as:

$$y_t = A_{n,Z} + B'_{n,Z} Z_t, \tag{8}$$

   where $A$ and $B$ depend on the risk-neutral parameters estimated from the model.
4. Finally, market prices of risk - which govern risk premiums in the model - are also affine and defined as:

$$\begin{aligned} \lambda_0 &= K_0^P - K_0^Q, \\ \lambda_1 &= K_1^P - K_1^Q. \end{aligned} \tag{9}$$

We use 3 pricing factors in our model: the first 2 principal components extracted from the cross-section of interest rates and our expected supply variable. In Appendix A, we describe in detail the model and the estimation procedure. We estimate the MTSM using yields with maturities of 3, 12, 24, 36, 48, 60, 96 and 120 months from January 2006 to December 2017. We also compute a parametric bootstrap to obtain standard errors in the spirit of Bauer and Rudebusch (2016).

In Tables 8 and 9 we report parameter estimates under the risk-neutral and the physical measures. $\lambda^Q$ represents the eigenvalues of the $K_1^Q$ matrix, which governs the $Q$-rates of the factors' mean reversion, while $\lambda^P_{con}$ in Table 9 reports the eigenvalues from the constrained feedback matrix under the physical measures. The eigenvalues of the physical dynamics are close enough to unity to imply that expected future interest rates on longer maturities are not constant, which is in line with survey forecasts as shown in Kim and Orphanides (2005). Low eigenvalues would imply a faster mean reversion process, which would attribute too much of the variation in long-term forward rates to risk premiums. Moreover, the free parameters $\gamma_0$ and $\gamma_1$ that link the yield curve factors to expected supply are all highly significant (see Table 8). Concerning risk premium parameters, Table 10 shows the market prices of risk that capture the excess return required from risk-averse investors. These can be interpreted as excess holding period returns which reflect risk premiums for every segment of the yield curve up to the longest maturity used in the estimation (the 10-year yield in our case). Indeed, market prices of risks affect the intercept and the loadings in Equations (9). The bottom-right coefficient in the matrix (-0.06), which is related to supply expectations, is highly statistically significant. This means that expected supply drives time-variation in risk premia in our model. The negative sign of the coefficient also implies that a positive shock to supply expectations has a positive and increasing impact on longer bond maturities compared to short-term bonds, which is consistent with our baseline regressions in Table 3. In addition, our results are consistent with our excess return regressions in Table 4, in which we show that expected excess returns increase with maturity. Further, in Table 4 we find that a one standard deviation change in expected supply increases the 10-year excess return over the 1-year yield by around 1.2%.[17] The MTSM coefficient implies a similar magnitude, as

[17] The 0.083 coefficient in Table 4 is the effect for a one unit increase in the variable, which is around 6.5 standard deviations.

**Table 9**
**Intercept and feedback matrix under** $P$. This table presents maximum likelihood estimates of $K_0^P$ and $K_1^P$ for our MTSM. The Level and Slope factors are the first two principal components extracted from the cross-section of yields. Expected Supply is the end-of-year maturity weighted supply. $\lambda_{con}^P$ represents the eigenvalues of the constrained feedback matrix under the physical measure $P$. $\lambda_{unc}^P$ represents the eigenvalues of the same matrix when there are no constraints on the coefficients. Small-sample standard errors are reported in parentheses and bootstrapped standard errors in brackets. The sample period is from January 2006 to December 2017.

| Z | $K_0^P$ | $K_1^P$ | | |
|---|---|---|---|---|
| Level | 0.029 | **0.995***** | 0.055 | 0 |
| | (0.089) | (0.01) | (0.05) | |
| | [0.1013] | [0.022] | [0.155] | |
| Slope | -0.04 | -0.0016 | **0.964***** | 0 |
| | (0.0406) | (0.004) | (0.023) | |
| | [0.1593] | [0.004] | [0.034] | |
| Expected Supply | -0.118 | 0 | -0.088 | **0.925***** |
| | (0.043) | | (0.031) | (0.0255) |
| | [0.1249] | | [0.0639] | [0.0516] |
| $\lambda_{con}^P$ | | 0.992 | 0.967 | 0.928 |
| $\lambda_{unc}^P$ | | 0.996 | 0.956 | 0.956 |

**Table 10**
**Risk premium parameters**. This table presents maximum likelihood estimates from our MTSM of the parameters $\lambda_0$ and $\lambda_1$ governing the investors' attitude toward risk (sample period Jan 2006 - Dec 2017). The Level and Slope factors are the first two principal components extracted from the cross-section of yields. Expected Supply is the end of year maturity weighted supply. Market prices of risk are defined as $\Lambda_t = \Sigma_Z^{-1/2}(\lambda_0 + \lambda_1 Z_t)$. Bootstrapped standard errors are reported in square brackets.

| Z | $\lambda_0$ | $\lambda_1$ | | |
|---|---|---|---|---|
| Level | 0.079 | -0.002 | **-0.055***** | 0 |
| | [0.052] | [0.0071] | [0.015] | |
| Slope | 0.017 | -0.001 | -0.022 | 0 |
| | [0.042] | [0.004] | [0.0173] | |
| Expected Supply | -0.17 | 0 | -0.087 | **-0.06***** |
| | [-0.239] | | [0.064] | [0.020] |

a standard deviation change in expected supply increases, on average, expected excess returns for longer-term bonds by around 1% compared to the short-rate.

In Fig. 6 we also plot the estimated one and five-year yields from the model together with observed yields. Our model produces a good fit of the term structure, with an average pricing error of around 10 basis points in the cross-section. Moreover, Fig. 7 shows how our expected supply factor drives excess returns in our sample. In line with the sign of the risk-premium coefficient of Table 10, a shock to supply expectations leads to counter-cyclical movements in the risk premium associated with exposures to expected supply. Expected excess returns implied by the model reached the highest point during the Great Financial Crisis, in which higher supply from the government increased the return requested from investors to hold this specific risk. Not surprisingly, Germany was largely unaffected by the sovereign crisis that reached its peak in the Eurozone between 2010 and 2012 and the excess return from our supply factor does not spike during that period.

We also investigate whether our restricted model performs better than an unrestricted model estimated with a vector autoregressive model under the physical measure $P$ where all parameters are unconstrained. We perform a log-likelihood ratio test between the two log-likelihoods implied by these two models. The t-stat of the test is 0.4, so we cannot reject the null that the restricted model is more efficient. We report the eigenvalues of the unconstrained feedback matrix under $P$ ($\lambda_{unc}^P$) in the last row of Table 9.

The results derived from the MTSM confirm our findings that supply expectations impact interest rates and affect term premium variation in Germany. However, how do these finding compare with a term structure model where current supply is one of the pricing factors instead of expected supply? We show in Table B.7 in the Appendix the risk premium parameters estimated from a term structure model with current supply used as a pricing factor together with the first two principal components extracted from interest rates. This matrix is essentially the difference between physical and risk-neutral parameters and the model is estimated with the same restrictions we used when we employed expected supply as one of the pricing factors. The risk premia parameter linked to current supply (bottom right parameter) is not significant, which means current supply does not have an effect on the time-variation of risk premia in the model. This is different from the model with expected supply, as those estimates point to the importance of

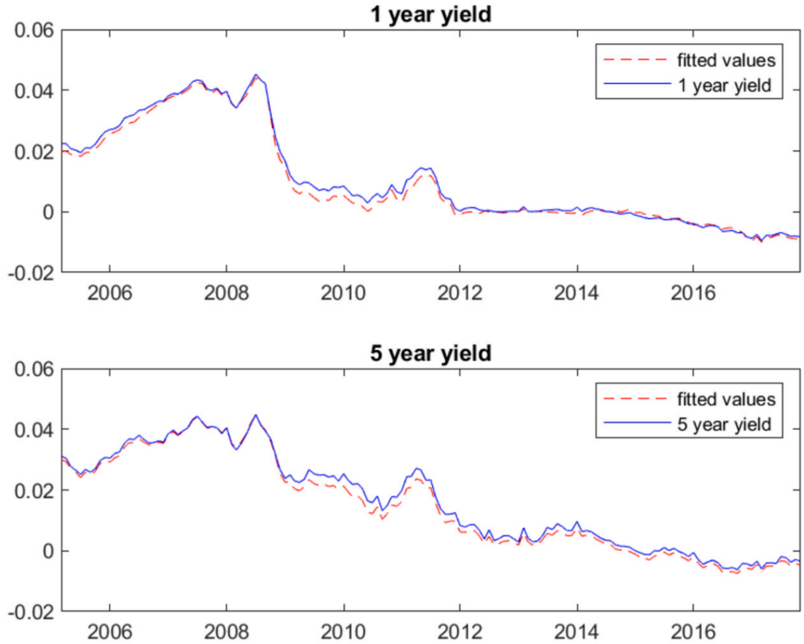


**Fig. 6. Fitted yields from the MTSM compared with observed yields**. The figure shows the fitted 1-year and 5-year German yields derived from the Macro Term Structure Model (MTSM) against the observed German yields.

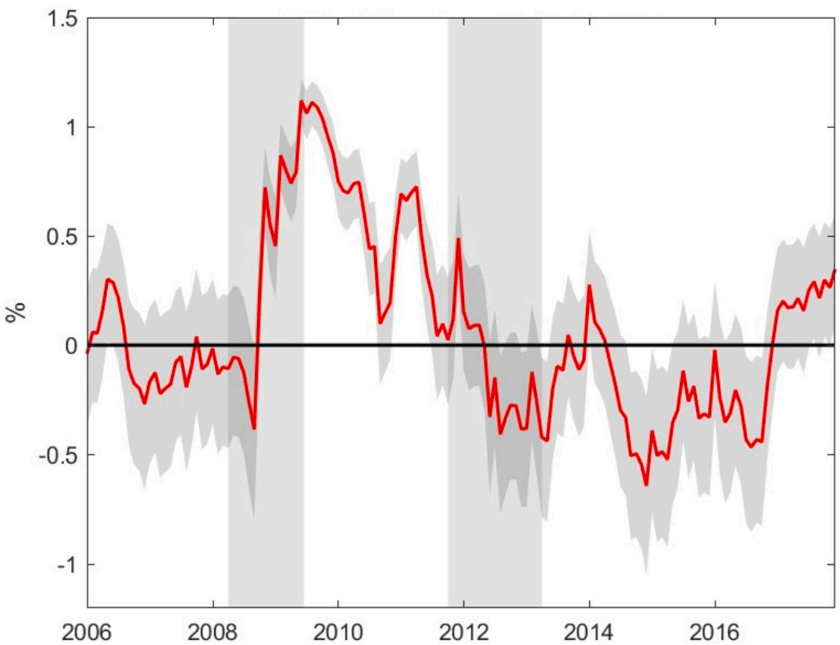


**Fig. 7. Excess returns from the MTSM based on expected supply as a pricing factor**. The figure shows model implied excess returns estimated from the macro term structure model (MTSM) with expected supply as the only time-varying factor. The other two pricing factors, that is the first two principal components of the cross section of interest rates, are held constant. Dark grey areas represent 95% confidence intervals based on bootstrapped standard errors. Grey shaded areas represent recession periods provided by CEPR.

supply expectations on the time-variation of risk premia. Together with the evidence we showed in Section 3, these results confirm the irrelevance of current supply compared to expected supply in pricing the German term structure of interest rates.

## 7. Conclusion

This paper provides evidence on the impact of current debt supply and expected debt supply on government bond yields in the German bond market. We find that, whenever agents have specific information on future issues from the government, the current level of supply that is observable in the market does not affect interest rates. We also find an explanation for the sizable amount of German government bonds trading consistently below the deposit rate of the European Central Bank. Our findings are both statistically and economically significant. For example, an increase by one unit in expected maturity-weighted debt steepens the yield curve by around 140 basis points in Germany. Moreover, a one standard deviation increase in expected short-term supply decreases the spread between short term bond yields and the ECB deposit rate by around 10-15 basis points whenever the spread is negative. We also validate our results with a Macro Term Structure model in which we find supply expectations are indeed a driver of time variation of risk premia for Germany.

We provide empirical support for portfolio rebalance and preferred-habitat theories of the term structure of interest rates. Understanding how the channels through which current and expected supply affect interest rates is useful both for policy makers and Treasury departments. Indeed, specific communications and forward guidance on bond issuance by Treasury departments could influence interest rates and decrease yields' uncertainty. Our findings suggest that supply expectations do have an impact on interest rates and play a prominent role in determining yields unlike current supply. As a consequence, countries that do not follow a specific forward guidance and that do not communicate ahead of time their issuing plans are forfeiting a potentially useful tool to affect their country's yield curve in the desired way. Likewise, the channel of transmission regarding expectations of future supply might be useful for central banks in case new large-scale asset purchase programmes are undertaken in the future.

Finally, we do not argue that the fiscal authority should use this tool for monetary policy purposes. The objectives of the fiscal and monetary authority are inherently different. While central banks' objective is to influence short and long-term yields to converge in the medium term to a predetermined inflation target, fiscal authorities are mainly concerned with minimising debt rollover risks and overall interest payments. Anchoring debt supply expectations with a clear communication strategy could then help the debt management office to control unexpected movements in interest rates that could affect future interest payments.

## CRediT authorship contribution statement

**M. Billio:** Conceptualization, Methodology, Supervision. **F. Busetto:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. **A. Dufour:** Conceptualization, Methodology, Supervision, Writing – review & editing. **S. Varotto:** Conceptualization, Methodology, Project administration, Supervision, Writing – review & editing.

## Appendix A. A term structure model with expected supply

In this section we describe how we estimate our Gaussian dynamic term structure model. We let the short rate be a linear function of state variables $Z_t$:

$$r_t = \delta_0 + \delta_1 Z_t, \tag{A.1}$$

where $\delta_0$ is a constant, $\delta_1$ is a 1x3 row vector and $Z_t$ is a 3x1 column vector containing the first $\psi$ pricing factors ($P_t^{\psi}$) with $\psi = 2$, and $M_t$ is our expected bond supply variable. The additional pricing factors can be either latent or observed portfolios of yields. We use the first two principal components derived from bond yields as our additional pricing factors, commonly known as level and slope factors in the literature. Joslin et al. (2013) show that this model is observationally equivalent to a model with $P_t^N$ pricing factors, with $N = M + \psi$ portfolios of yields and with M = 1 in our setup. We also assume that $M_t$ and the yield portfolios $P_t^{\psi}$ are measured without error, while the remaining yield factors are different from their theoretical values by a zero-mean measurement error $\sigma_e$. It is a well-known fact since Litterman and Scheinkman (1991) that the term structure of interest rates is well defined by a low-dimensional factor structure, so we choose $N = 3$ to obtain estimates that will fit the observed yields without incurring in the risk of over-fitting the model.

More precisely, $Z_t$ follows a VAR(1) process under the risk-neutral dynamics

$$Z_{t+1} = K_0^Q + K_1^Q Z_t + \epsilon_{Z,t+1}^Q, \tag{A.2}$$

where $\epsilon_{Z,t+1}^Q \sim iid\, N(0, \Sigma_Z)$ under the risk-neutral measures and $K_0^Q$ and $K_1^Q$ are an Nx1 vector and a NxN matrix, respectively. $\Sigma_Z$ is a positive definite matrix. In this setup, yields for all maturities take a linear form of $Z_t$ and are expressed as:

$$y_t = A_{n,Z} + B'_{n,Z} Z_t, \tag{A.3}$$

where $A_{n,Z}$ and $B'_{n,Z}$ are dependent on the risk-neutral parameters $\Theta^Q = \{\delta_0, \delta_1, K_0^Q, K_1^Q, \Sigma_Z\}$ and are estimated recursively as:

$$A_{n+1} = A_t + B'_n K_0^Q - \frac{1}{2} B'_n \Sigma_Z B_n + \delta_0, \tag{A.4}$$

$$B'_{n+1} = \delta'_1 + B'_n K_1^Q. \tag{A.5}$$

The state vector also follows a VAR(1) under the physical distribution:

$$Z_{t+1} = K_0^P + K_1^P Z_t + \epsilon_{Z,t+1}^P, \tag{A.6}$$

where $\epsilon_{Z,t+1}^P \sim iid N(0, \Sigma_Z)$ under the physical measure. We use the same normalisation suggested in Joslin et al. (2011) and based on the work of Dai and Singleton (2000) to obtain identification. Thus we estimate the macro term structure model (MTSM) in its canonical form. In this specification, the risk-neutral distribution is characterised by $\Sigma_Z$, the long-run risk-neutral mean $r_\infty^Q$ of the short rate and $\lambda^Q$, the N-vector of real eigenvalues of the feedback matrix $K_1^Q$ that is rotation-invariant. Moreover, as also shown in Joslin et al. (2013) the macro-spanning restriction imposed in this class of term-structure models implies that the information stemming from macroeconomic state variables is already embedded in the information provided by yield-based state variables. An implication of this construct is the observational equivalence of a model with $Z_t$ and $P_t^N$ as pricing factors. This implies that our macro factor (expected supply) is a linear combination of $P_t^N$:

$$M_t = \gamma_0 + \gamma_1 P_t^N. \tag{A.7}$$

That is, our bond supply variable is completely spanned by the first $N$ principal components of bond yields.[18] This means we could theoretically rotate a model with $P_t^N$ as pricing factors to one with $Z_t = [M_t, P_t^\psi]$ by using the following transformation:

$$Z_t = \begin{bmatrix} 0 \\ 0 \\ \gamma_0 \end{bmatrix} + \begin{bmatrix} I_\psi & 0_{\psi x(N-\psi)} \\ & \gamma_1 \end{bmatrix} P_t^N. \tag{A.8}$$

Spanned term-structure models do not imply that macroeconomic information does not matter in order to price the term-structure of interest rates. This class of models implies that if enough information already contained in the yield curve is used to estimate an MTSM, macro factors can be determined by yield-based pricing factors. We also constrain the $K_1^P$ matrix as follows:

$$\begin{bmatrix} k_{11} & k_{12} & 0 \\ k_{21} & k_{22} & 0 \\ 0 & k_{32} & k_{33} \end{bmatrix}$$

These constraints mean that under the physical measure, bond supply does not load on the yield-based pricing factors. Moreover, supply is only affected by the second principal component extracted from observed bond yields (the slope factor). These constraints are similar to those of Li and Wei (2013) and they help to ensure that any evidence in support of supply effects is driven by the data. However, as described in Joslin et al. (2011), restrictions on the $P$ side of the model do not affect the factor loadings that depend only on the estimated risk-neutral parameters. The only advantage that might be obtained by restricting the matrix under the physical distribution is to improve the forecasts of bond portfolios. Nonetheless, we also estimate the model with an unconstrained $K_1^P$ matrix and check whether our constrained model is statistically better than the unconstrained one according to a log-likelihood ratio test. Finally, market prices of risk, which modulate investors' behaviour towards risks, are also affine in our specification and are defined as $\Lambda_t = \Sigma_Z^{-1/2}(\lambda_0 + \lambda_1 Z_t)$ where

$$\begin{aligned} \lambda_0 &= K_0^P - K_0^Q, \\ \lambda_1 &= K_1^P - K_1^Q. \end{aligned} \tag{A.9}$$

To summarise, our entire parameter set is $\Theta = (r_\infty^Q, \lambda^Q, \gamma_0, \gamma_1, \Sigma_Z, K_0^P, K_1^P, \sigma_e)$. We estimate the model using maximum likelihood, following the estimation procedure proposed in Joslin et al. (2011). We also compute a parametric bootstrap to retrieve the standard errors for our parameters. In fact, as also noted in Bauer et al. (2012), estimates from dynamic term structure models can be biased especially in small samples, thus leading to misleading inference on parameter estimates. To address this problem, our simulation design is as follows: using the parameter estimates from our MTSM, we simulate n = 1000 yield and macro factors from the VAR and then construct fitted yields from the factor loadings and the simulated data. We take t = 1 as the starting point of our VAR. We also compute the bootstrap by choosing a random initial point from which we simulate our factors and results are not affected. We also add an i.i.d Gaussian measurement error to obtain simulated yields. We take as measurement error the cross-sectional average of our pricing error in the MTSM. Our simulated samples have the same length as the actual data (T = 144). We then run the model for each simulated sample and obtain maximum likelihood estimates of our parameters from these simulated data.

[18] See also Bauer and Rudebusch (2016) for an in-depth analysis on whether or not to use the spanning restriction in term structure models with macro variables.

## Appendix B. Figures & tables


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Press Release

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Issues planned by the Federal Government in the fourth quarter of 2016

Funding requirements of the Federal Budget and its special funds have decreased since the beginning of the year. Thus, the Federal Government intends to reduce the fourth quarter issuance volumes of both, capital and money market instruments, by € 7 billion compared to the initial plans published in December 2015. Therefore the annual issuance volume is reduced to € 200.5 billion - € 204.5 billion (including inflation-linked Federal Securities).

**Fig. B.1. Sample press release of a debt issuance reduction**. The figure shows a German Treasury press release published on 20 September 2016, in which expected issuance for short-term and long-term debt was decreased by €7bn each.

**Table B.1**
**Description of the variables used in our regression analyses.**

| Sample: 2006-2017 | Source | Ticker |
|---|---|---|
| **Yields** | | |
| ECB Deposit Rate | Bloomberg | EUORDEPO Index |
| 2y | Bloomberg | I04002Y Index |
| 5y | Bloomberg | I04005Y Index |
| 10y | Bloomberg | I04010Y Index |
| 30y | Bloomberg | I04030Y Index |
| Supply | Source | |
| $MWD$ | National Treasuries, Authors' estimate | |
| $E[MWD\|I_t]$ | National Treasuries Press Releases, Authors' estimate | |
| $MWQE$ | European Central Bank, Authors' estimate | |
| $D/GDP$ | National Treasuries, Authors' estimate | |
| $E[ST\,debt]$ | National Treasuries, Authors' estimate | |
| Other Variables | Source | Ticker |
| Liquidity | MTS | Authors' estimate |
| log (CDS) | Bloomberg | GERMAN CDS USD SR D14 Corp |
| Inflation | Bloomberg | GRCP2HMM Index |
| Inflation Risk | Bloomberg, Authors' estimate | GRCP2HMM Index |
| Output Growth | FRED Database, Authors' estimate | CLVMNACSCAB1GQDE |
| Stock Market Vol. | Bloomberg | V2X Index |
| Crisis Dummy | Authors' estimate | |

| Security | Volume | Share in % | 1st quarter | | | 2nd quarter | | | 3rd quarter | | | 4th quarter | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
| Schatz 2 Y | 53 | 26.2 | 5 | 5 | 4 | 4 | 5 | 5 | 4 | 9 | 4 | | 5 | 3 |
| Bobl 5 Y | 41 | 20.2 | | 5 | 8 | | 4 | 4 | 5 | 4 | 4 | 4 | 3 | |
| Bund 10 Y | 51 | 25.2 | 5 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 4 | 6 | |
| Bund 30 Y | 9 | 4.4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | | |
| Capital market | 154 | 76.0 | 11 | 16 | 17 | 9 | 14 | 14 | 15 | 18 | 14 | 9 | 14 | 3 |
| | | | 44 | | | 37 | | | 47 | | | 26 | | |
| Bubill 6 M | 32 | 15.8 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | |
| Bubill 12 M | 16.5 | 8.1 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | |
| Money market | 48.5 | 24.0 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 3.5 | 0 |
| | | | 13.5 | | | 13.5 | | | 13.5 | | | 8 | | |
| **Year total:** | **202.5** | **100** | **15.5** | **20.5** | **21.5** | **13.5** | **18.5** | **18.5** | **19.5** | **22.5** | **18.5** | **13.5** | **17.5** | **3** |
| | | | **57.5** | | | **50.5** | | | **60.5** | | | **34** | | |

**Fig. B.2. German bond issuance outlook for 2016**. The table shows the detailed outlook for German expected supply issuance in 2016 released by the German Treasury in December 2015. Issuance plans in €bn are shown for each maturity and for each month of the upcoming year.

**Table B.2**
**Correlation matrix**. The table shows the correlation matrix between the main variables in our analysis. $E[MWD|I_t]$ is the end of year maturity weighted supply for Germany. *MWD* is the current maturity weighted debt. 10y Spread and 5y Spread are the 10 and 5-year yields minus the 1-year yield, respectively. Credit Risk is the US dollar denominated sovereign CDS. Crisis dummy is a dummy that assumes the value of 1 between October 2010 and September 2012. Output Growth is the difference between log real GDP in the current quarter and log real GDP in quarter t-4. Liquidity Risk is the time-weighted bid-ask spread from Mercato dei Titoli di Stato (MTS). We report the correlations in levels below the diagonal, while above the main diagonal we show the first-difference correlations. We highlight in bold the correlations between current and expected supply and 10 year and 5 year yield spreads in levels and first difference.

| | $E[MWD\|I_t]$ | MWD | 10y | 5y | CDS | Crisis D. | Output Gr. | Liquidity |
|---|---|---|---|---|---|---|---|---|
| $E[MWD]$ | 1 | 0.08 | **0.17** | **0.16** | 0.08 | -0.03 | 0.10 | -0.05 |
| $MWD$ | 0.87 | 1 | **0.06** | **0.07** | 0.08 | -0.06 | 0.08 | 0.16 |
| 10y Spread | **0.76** | **0.64** | 1 | 0.89 | 0.17 | -0.01 | 0.11 | 0.24 |
| 5y Spread | **0.66** | **0.47** | 0.94 | 1 | 0.15 | 0.01 | 0.10 | 0.13 |
| Credit Risk | 0.70 | 0.71 | 0.69 | 0.52 | 1 | 0.16 | -0.09 | 0.27 |
| Crisis D. | 0.44 | 0.38 | 0.32 | 0.27 | 0.57 | 1 | -0.04 | 0.01 |
| Output Gr. | 0.02 | 0.03 | -0.04 | -0.01 | -0.28 | 0.02 | 1 | -0.16 |
| Liquidity Risk | 0.10 | 0.15 | 0.36 | 0.27 | 0.63 | 0.19 | -0.57 | 1 |

**Table B.3**
**Augmented Dickey-Fuller test**. This table shows the test statistics of an Augmented Dickey-Fuller test for yield spreads, current and expected supply. $y_t^{(10)} - y_t^{(1)}$ is the 10-year minus the 1-year yield. $E[MWD|I_t]$ is the end of year maturity weighted supply. $MWD$ is current maturity weighted debt. The third column reports the test critical values. *** p<0.01, ** p<0.05, * p<0.1.

| Test Statistic | | Critical Value |
|---|---|---|
| $y_t^{(10)} - y_t^{(1)}$ | -2.279 | [-2.887] |
| $MWD$ | -1.287 | [-2.887] |
| $E[MWD\|I_t]$ | -1.877 | [-2.887] |

**Table B.4**
**Regression of yield spreads on current and expected supply shocks**. This Table shows coefficients of regressions where yield slope changes are the dependent variable and shocks to current ($\Delta\epsilon_{MWD}$) and expected supply ($\Delta\epsilon_{E[MWD|I_t]}$) changes are independent variables. Shocks to current and expected supply are estimated by fitting an ARMA(4,4) process to both series. T-stats are provided in brackets. Coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

| | $\Delta(y_{i,t}^{(2)} - y_{i,t}^{(1)})$ | $\Delta(y_{i,t}^{(3)} - y_{i,t}^{(1)})$ | $\Delta(y_{i,t}^{(5)} - y_{i,t}^{(1)})$ | $\Delta(y_{i,t}^{(10)} - y_{i,t}^{(1)})$ |
|---|---|---|---|---|
| $\Delta\epsilon_{MWD}$ | -0.0007 | 0.0003 | 0.0008 | 0.0010 |
| | [-0.03] | [0.13] | [0.27] | [0.31] |
| $\Delta\epsilon_{E[MWD\|I_t]}$ | **0.0029*** | **0.0042*** | **0.0071*** | **0.0072*** |
| | [1.8] | [1.93] | [1.74] | [1.79] |

**Table B.5**

**Regression of bond excess returns on current supply**. Coefficients of regressions where 2- and 10-year bond excess returns are the dependent variable and current supply ($MWD$) is an independent variable. $y^{(10)} - y^{(1)}$ is the slope of the yield curve, while the level, slope and curvature factors are the first three principal components extracted from the cross-section of interest rates. Coefficients in bold are significant. T-statistics based on robust standard errors are reported in brackets. *** p<0.01, ** p<0.05, * p<0.1.

| | 2y excess return | | | 10y excess return | | |
|---|---|---|---|---|---|---|
| $MWD$ | 0.04 | 0.002 | 0.001 | 0.08 | 0.01 | 0.12 |
| | [1.52] | [1.1] | [0.07] | [1.08] | [0.13] | [1.37] |
| $y^{(10)} - y^{(1)}$ | | 0.26 | | | 1.99 | |
| | | [0.63] | | | [1.45] | |
| Level factor | | | **0.006***** | | | **0.009**** |
| | | | [9.12] | | | [2.37] |
| Slope factor | | | **0.006**** | | | **-0.03*** |
| | | | [2.31] | | | [-1.68] |
| Curvature factor | | | 0.009 | | | 0.09 |
| | | | [0.15] | | | [0.82] |

**Table B.6**

**Regressions of maturity-specific supply**. This Table shows coefficients of linear regressions in which changes of maturity-specific yield curve slopes are regressed onto the corresponding changes in current supply ($\Delta MWD_{matspecific}$) and expected supply ($\Delta E[MWD|I_t]_{matspecific}$). In brackets, we report t-statistics which are based on Newey and West standard errors computed with up to 16 lags. *** p<0.01, ** p<0.05, * p<0.1.

| | $\Delta(y^{(5)} - y^{(1)})$ | | | $\Delta(y^{(10)} - y^{(1)})$ | | |
|---|---|---|---|---|---|---|
| $\Delta MWD_{matspecific}$ | 0.005 | | 0.005 | 0.015 | | 0.014 |
| | [0.28] | | [0.27] | [1.41] | | [1.38] |
| $\Delta E[MWD\|I_t]_{matspecific}$ | | **0.012**** | **0.012**** | | **0.008**** | **0.0074*** |
| | | [2.24] | [2.23] | | [1.95] | [1.77] |

**Table B.7**

**Risk premium parameters - MTSM with current supply**. This table presents maximum likelihood estimates from our MTSM of the parameters $\lambda_1$ governing investors' attitude toward risk. The Level and Slope factors are the first two principal components extracted from the cross-section of yields. Current supply is the current supply of German government bonds. Market prices of risk are defined as $\Lambda_t = \Sigma_Z^{-1/2}(\lambda_0 + \lambda_1 Z_t)$. Bootstrapped standard errors are reported in square brackets.

| | $\lambda_1$ | | |
|---|---|---|---|
| Level | -0.003 | **-0.069***** | 0 |
| | [0.0092] | [0.013] | |
| Slope | -0.0051 | -0.023 | 0 |
| | [0.063] | [0.018] | |
| Current Supply | 0 | 0.063 | -0.034 |
| | | [0.08] | [0.07] |

**Table B.8**

**Current and expected debt supply as a determinant of yield spreads**. This table reports monthly regressions of yield spreads on current and expected future maturity-weighted supply for Germany: $y_{i,t}^{(\tau)} - y_{i,t}^{(1)} = \alpha + \beta_1 MWD_{i,t} + \beta_2 E[MWD_{i,t+k}|I_{i,t}] + \beta_3 MWQE_{i,t} + \beta_4 t + \epsilon_{i,t}$. $(y_{i,t}^{(\tau)} - y_{i,t}^{(1)})$ is the slope of the yield curve at different $\tau$ maturities. $MWD$ is the Maturity-Weighted Debt scaled by $GDP$. $E[MWD|I_t]$ is defined as the maturity-weighted supply at the end of each calendar year, scaled by $GDP$. $MWQE$ is the amount of maturity-weighted purchases by the ECB during the Public Sector Purchase Program (PSPP) scaled by $GDP$. Panel A shows the results for the regression of yield spreads on current supply, while Panel B for expected future supply. T-stats are reported in brackets. We estimate all regression models with an AR(1) process for residuals and with robust standard errors. Coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

**Panel A**: Current Supply

| Yield Spreads | $MWD$ | t-stat | $MWQE$ | t-stat | $\alpha$ | t-stat | Adj. R-squared |
|---|---|---|---|---|---|---|---|
| 2y | 0.0008 | [0.56] | 0.001 | [0.43] | -0.0006 | [-0.14] | 0.01 |
| 3y | 0.001 | [0.78] | 0.002 | [0.66] | 0.0001 | [0.027] | 0.02 |
| 4y | 0.002 | [0.85] | 0.003 | [0.66] | 0.0009 | [0.12] | 0.02 |
| 5y | 0.002 | [0.90] | 0.004 | [0.70] | 0.001 | [0.15] | 0.02 |
| 6y | 0.002 | [0.83] | 0.005 | [0.76] | 0.003 | [0.32] | 0.02 |
| 8y | 0.003 | [0.90] | 0.006 | [0.79] | 0.004 | [0.39] | 0.03 |
| 10y | 0.002 | [0.70] | 0.007 | [0.77] | 0.007 | [0.59] | 0.02 |
| 20y | 0.004 | [1.06] | 0.007 | [0.64] | 0.007 | [0.48] | 0.03 |
| 30y | 0.004 | [1.15] | 0.007 | [0.69] | 0.005 | [0.33] | 0.04 |

**Panel B**: Expected Supply

| Yield Spreads | $E[MWD|I_t]$ | t-stat | $MWQE$ | t-stat | $\alpha$ | t-stat | Adj. R-squared |
|---|---|---|---|---|---|---|---|
| 2y | **0.005**** | [2.32] | 0.0024 | [1.25] | **-0.013**** | [-2.05] | 0.05 |
| 3y | **0.006**** | [2.16] | 0.0036 | [1.05] | -0.014 | [-1.65] | 0.05 |
| 4y | **0.008**** | [2.35] | 0.0047 | [1.00] | **-0.02*** | [-1.72] | 0.05 |
| 5y | **0.01**** | [2.39] | 0.0055 | [0.97] | **-0.022*** | [-1.71] | 0.06 |
| 6y | **0.01**** | [2.32] | 0.0064 | [0.99] | -0.022 | [-1.56] | 0.06 |
| 8y | **0.011**** | [2.12] | 0.0073 | [0.94] | -0.021 | [-1.25] | 0.05 |
| 10y | **0.011**** | [1.99] | 0.0078 | [0.90] | -0.02 | [-1.12] | 0.05 |
| 20y | **0.013**** | [2.09] | 0.0078 | [0.73] | -0.02 | [-1.06] | 0.05 |
| 30y | **0.013**** | [2.07] | 0.0077 | [0.78] | -0.02 | [-1.14] | 0.06 |

**Table B.9**

**Robustness tests**. In this table we report results for regressions of the form: $\Delta(y_t^{(\tau)} - y_t^{(1)}) = \alpha + \beta_1 \Delta E[MWD_{t+k}|I_t] + \beta_2 \Delta MWQE_t + \sum_{i=3}^{n} \beta_i C_t + \epsilon_{i,t}$. The dependent variables are 2, 5, 10 and 10-year yield spreads. $E[MWD|I_t]$ is defined as the maturity-weighted supply at the end of each calendar year, scaled by $GDP$. $MWQE$ is the amount of maturity-weighted purchases by the ECB during the Public Sector Purchase Programme (PSPP) scaled by $GDP$. Column 2 reports the coefficients of expected supply in our base case, (fully reported in Table 3), where we do not add further controls. Column 3 adds controls for credit risk and liquidity risk. Column 4 adds controls for stock market volatility and a dummy for the sovereign crisis. Columns 5 and 6 add a control for Output Growth and Inflation risk, respectively. Liquidity Risk is the time-weighted bond bid-ask Spread calculated from the MTS platform. Credit Risk is the log of the five-year US dollar-denominated sovereign CDS spread. Stock market volatility is the log of the Vstoxx index. Crisis dummy is a dummy that takes the value of 1 between October 2010 and September 2012. Output Growth is the difference between log real GDP in the current quarter and log real GDP in quarter t-4. Inflation Risk is the standard deviation of the year on year inflation over the past twelve months. All control variables are defined in Table 3. We use Newey-West standard errors allowing for up to 16 lags. T-stats are in brackets and coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

| $\Delta E[MWD|I_t]$ | Base Case | Credit Risk<br>Liquidity Risk | Stock Market Vol.<br>CrisisDummy | Output Growth | Inflation Risk |
|---|---|---|---|---|---|
| 2y | **0.005**** | **0.005**** | **0.004**** | **0.005**** | **0.005**** |
| | [2.27] | [2.28] | [2.16] | [2.13] | [2.09] |
| $R^2_{adj}$ | 0.02 | 0.01 | 0 | 0 | 0 |
| 5y | **0.02**** | **0.01**** | **0.01**** | **0.01**** | **0.01**** |
| | [2.14] | [2.02] | [2.28] | [2.26] | [2.22] |
| $R^2_{adj}$ | 0.03 | 0.04 | 0.03 | 0.05 | 0.04 |
| 10y | **0.014***** | **0.013***** | **0.016***** | **0.015***** | **0.015***** |
| | [2.72] | [2.68] | [3.24] | [3.13] | [2.99] |
| $R^2_{adj}$ | 0.03 | 0.03 | 0.08 | 0.10 | 0.09 |
| 30y | **0.018***** | **0.02***** | **0.02***** | **0.02***** | **0.02***** |
| | [2.71] | [2.68] | [3.27] | [3.25] | [3.12] |
| $R^2_{adj}$ | 0.03 | 0.02 | 0.08 | 0.07 | 0.07 |

**Table B.10**

**Seasonally adjusted expected supply regressions**. This table shows the results for the regressions of yield spread changes on expected supply changes ($\Delta E[MWD_{sa}]$) and maturity weighted QE ($MWQE$) when we seasonally adjust our expected supply variable. We use the X-12 ARIMA filter package of the U.S. Census Bureau to extract the seasonal component from the series. T-stats are reported in brackets. We estimate all regression models Newey-West standard errors up to 16 lags. Coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

| Yield Spread Changes | $\Delta E[MWD_{sa}]$ | t-stat | $MWQE$ | t-stat | $\alpha$ | t-stat |
|---|---|---|---|---|---|---|
| 2Y | **0.018*** | [1.65] | **-0.019*** | [-1.73] | 0.001 | [1.36] |
| 3Y | **0.028*** | [1.90] | **-0.043**** | [-2.27] | 0.002 | [2.13] |
| 5Y | **0.044*** | [1.78] | **-0.11***** | [-3.04] | 0.005 | [2.33] |
| 8Y | **0.064*** | [1.87] | **-0.19***** | [-3.60] | 0.007 | [2.43] |
| 10Y | **0.068**** | [1.98] | **-0.23***** | [-3.85] | 0.008 | [2.34] |

**Table B.11**

**Expected long-term debt impact on yields**. This table shows coefficient estimates of the impact on German yields of an alternative measure of expected supply, defined as the expected amount of long-term bonds available on the market at the end of each calendar year ($E[LTD|It]$). The dependent variable is the 2-year, 5 year or 10-year yield minus the 1-year yield. We instrument expected long-term debt with expected debt/GDP and current long-term debt with debt/GDP. We also control for the change in the current amount of long-term bonds in the market ($\Delta\widehat{LTD}$) and another set of controls. Stock Market Volatility is the log of the Vstoxx index, Liquidity is the time-weighted bid-ask spread of German bonds obtained from the MTS platform, Credit Risk is the log of the 5-year CDS Spread. We report t-statistics based on Newey-West standard errors allowing for up to 16 lags. Adding more lags does not affect our results. *** p<0.01, ** p<0.05, * p<0.1.

Instrumental Variable Regressions

| | 2y | | | 5y | | | 10y | | |
|---|---|---|---|---|---|---|---|---|---|
| $\Delta E[\widehat{LTD}\|I_t]$ | **0.084***** | | **0.082**** | **0.185***** | | **0.17**** | **0.23***** | | **0.24**** |
| | [3.23] | | [2.30] | [2.89] | | [2.06] | [3.29] | | [2.52] |
| $\Delta\widehat{LTD}$ | | 0.04 | 0.027 | | 0.08 | 0.05 | | 0.07 | 0.035 |
| | | [1.11] | [0.67] | | [1.25] | [0.67] | | [1.01] | [0.37] |
| Δ Stock Market Vol. | | | -0.0001 | | | 0.0002 | | | 0.0013 |
| | | | [-0.09] | | | [0.18] | | | [0.82] |
| Δ Liquidity Risk | | | -0.0010 | | | 0.0003 | | | 0.0010 |
| | | | [-0.41] | | | [0.04] | | | [0.11] |
| Δ Credit Risk | | | -0.0002 | | | 0.0007 | | | 0.0010 |
| | | | [-0.97] | | | [1.63] | | | [1.16] |
| $R^2_{adj}$ | 0.04 | 0 | 0.03 | 0.06 | 0.003 | 0.08 | 0.04 | 0.02 | 0.09 |
| QE Purchases | YES | YES | YES | YES | YES | YES | YES | YES | YES |

**Table B.12**

**Scarcity effects with different specifications**. In this Table, Columns 2-6 report the coefficients of the same model described in Table 7, but we define a specific $E[STD]$ for each maturity up to 2 years, conditional on the 4-week lagged spread between the bond yield of a given maturity and the ECB deposit rate being positive, $s_{t-4} > 0$, or negative, $s_{t-4} < 0$. The dependent variables are 4-week yield spread changes at different maturities. More specifically, in Column 2 and 3 we use the amount of bonds with original maturity (Bubills) below 1 year, while in Column 4 we define $E[STD]$ as the amount of bonds with 2-years original maturity (Schatz). Since the German Treasury does not issue 3 and 4-year bonds we use the amount of bonds with 2 year maturity even in Columns 5 and 6. Credit Risk is the log of the five-year US dollar-denominated sovereign CDS spread. Stock market volatility is the log of the Vstoxx index. Columns 7-11 restrict the sample from 2010 to the end of 2017, while Columns 12-16 exclude 2017. We model the error process as an AR(1). T-stats in brackets are based on robust standard errors. Coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

**Yield Spread Changes**

| VARIABLES | Specific Maturities | | | | | 2010-2017 | | | | | 2006-2016 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3m | 1y | 2y | 3y | 4y | 3m | 1y | 2y | 3y | 4y | 3m | 1y | 2y | 3y | 4y |
| $\Delta_4$E[STD] if $s_{t-4}$ >0 | 0.052 | 0.077 | -0.032 | 0.06 | **0.20*** | -0.03 | -0.017 | 0.004 | 0.047 | 0.074 | -0.05 | 0.004 | 0.04 | 0.07 | **0.13***** |
| | [0.89] | [1.18] | [-0.35] | [0.74] | [1.90] | [-0.71] | [-0.45] | [0.09] | [0.85] | [1.18] | [0.10] | [0.70] | [0.70] | [1.60] | [3.43] |
| $\Delta_4$E[STD] if $s_{t-4}$ <0 | **0.089*** | **0.15***** | **0.56***** | **0.64*** | -0.21 | **0.16**** | **0.22***** | **0.25***** | **0.19***** | **0.13*** | **0.13***** | **0.09***** | **0.07*** | 0.01 | 0.02 |
| | [1.94] | [2.82] | [3.08] | [1.69] | [-1.13] | [2.29] | [3.78] | [4.08] | [2.61] | [1.79] | [1.99] | [2.86] | [1.81] | [1.50] | [0.64] |
| $\Delta_4$ Stock Market Vol. | **-0.0006**** | **-0.001***** | **-0.001***** | **-0.001***** | **-0.002***** | -0.0002 | **-0.0005**** | **-0.001***** | **-0.001***** | **-0.0015***** | **-0.001**** | **-0.001***** | **-0.0014***** | **-0.001***** | **-0.002***** |
| | [-2.19] | [-3.34] | [-4.58] | [-4.85] | [-5.68] | [-1.12] | [-2.05] | [-3.21] | [-3.77] | [-4.44] | [-2.09] | [-3.29] | [-4.23] | [-4.81] | [-5.58] |
| $\Delta_4$ Credit Risk | -0.0002 | -0.0003 | -0.0004 | **-0.0005*** | **-0.0006*** | **-0.001***** | **-0.001***** | **-0.001***** | **-0.002***** | **-0.002***** | -0.0002 | -0.0003 | -0.0004 | -0.0005 | **-0.001**** |
| | [-0.43] | [-0.69] | [-1.29] | [-1.68] | [-1.92] | [-3.12] | [-3.02] | [-3.28] | [-3.05] | [-3.37] | [-0.33] | [-0.63] | [-1.14] | [-1.59] | [-2.20] |
| SE | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) | AR(1) |
| Obs. | 621 | 621 | 621 | 621 | 621 | 412 | 412 | 412 | 412 | 412 | 574 | 574 | 574 | 574 | 574 |
| $R^2_{adj}$ | 0.02 | 0.05 | 0.06 | 0.06 | 0.07 | 0.06 | 0.1 | 0.12 | 0.11 | 0.12 | 0.02 | 0.06 | 0.05 | 0.06 | 0.09 |

**Table B.13**

**Expected short-term supply vs. current short-term supply**. In this Table, Columns 2-6 report the coefficients of the same model described in Table 7, but we augment the regression with the outstanding amount of current short-term debt changes and with Liquidity Risk changes. We let current short-term supply have different coefficients according to the threshold we choose (the deposit rate of the ECB). Stock market volatility is the log of the Vstoxx index. Credit Risk is the log of the five-year US dollar denominated sovereign CDS spread. Liquidity Risk is the time-weighted bid-ask spread obtained from the Mercato dei Titoli di Stato (MTS) platform. T-stats are based on Newey-West standard errors allowing for eight lags. Coefficients in bold are significant. *** p<0.01, ** p<0.05, * p<0.1.

| VARIABLES | Yield Spreads Changes | | | | |
|---|---|---|---|---|---|
| | 3m | 1y | 2y | 3y | 4y |
| $\Delta_4$E[STD] if Spr> 0 | **-0.11**** | 0.012 | 0.076 | 0.089 | **0.16***** |
| | [-2.18] | [0.17] | [0.78] | [0.87] | [2.67] |
| $\Delta_4$E[STD] if Spr<0 | **0.13***** | **0.20***** | **0.17***** | **0.16***** | **0.084**** |
| | [4.00] | [6.05] | [6.66] | [5.08] | [2.01] |
| $\Delta_4$[STD] if Spr>0 | -0.053 | -0.058 | -0.042 | 0.001 | 0.011 |
| | [-0.82 | [-1.11] | [-0.86] | [0.03] | [0.19] |
| $\Delta_4$[STD] if Spr<0 | 0.08 | 0.05 | 0.08 | 0.009 | **-0.13**** |
| | [1.31] | [0.65] | [0.79] | [0.08] | [-1.96] |
| $\Delta_4$ Stock Market Vol. | **-0.002*** | **-0.002***** | **-0.002***** | **-0.002***** | **-0.002***** |
| | [-1.88] | [-2.95] | [-3.64] | [-3.61] | [-3.86] |
| $\Delta_4$ Credit Risk | **-0.002*** | -0.002 | **-0.001*** | -0.001 | -0.001 |
| | [-1.73] | [-1.64] | [-1.68] | [-1.47] | [-1.04] |
| $\Delta_4$ Liquidity Risk | **-0.0006*** | **-0.0006*** | -0.000 | -0.000 | -0.000 |
| | [-1.81] | [-1.70] | [-1.55] | [-1.25] | [-0.91] |
| SE | NW(8) | NW(8) | NW(8) | NW(8) | NW(8) |
| Obs. | 621 | 621 | 621 | 621 | 621 |
| $R^2_{adj}$ | 0.23 | 0.22 | 0.16 | 0.14 | 0.13 |

## Data availability

The authors do not have permission to share data.

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