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Dissecting long-term Bund yields in the run-up to the ECB's Public Sector Purchase Programme

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Abstract

Starting in summer 2014, markets began to build up expectations that the European Central Bank (ECB) would embark on large-scale sovereign bond purchases. The ECB's Public Sector Purchase Programme (PSPP) was eventually announced on 22 January 2015 and purchases started in March. Both during the run-up phase to the PSPP announcement day and for the day itself, German government bond yields declined significantly. Using an affine term structure model, we evidence that the yield declines are almost fully attributable to a decline in the term premium as opposed to the expectations component. This speaks in favour of the conjecture that the PSPP transmits to long-term yields mainly via a portfolio re-balancing channel rather than a (policy rate) signalling channel. The results prove robust against changing the number of factors in the model, the estimation sample and the estimation approach.

Keywords: term structure of interest rates, large-scale asset purchases, term premia
JEL: E43, E52

Non-technical summary

Since summer 2014, markets have increasingly anticipated that the ECB would eventually embark on large-scale asset purchases, and German government bond yields have shown a long-stretched decline. On 22 January 2015, the European Central Bank (ECB) announced a large-scale public-sector purchase programme (PSPP). Complementing the purchases of private-sector assets, a series of policy rate cuts and other non-standard monetary policy measures, the PSPP was intended to help bring euro area inflation back to the ECB's desired level of close to, but below, 2%. On 22 January 2015 the ten-year German Bund yield decreased by another 15 basis points – marking the twelfth largest daily decline since the start of Economic and Monetary Union in 1999. PSPP purchases started in March 2015.

This paper intends to help understand via what channels the inception of the PSPP has led to the observed bond yield compression. Under the so-called signalling channel, bond purchases would underline the central bank's commitment to keeping its key interest rates at low levels for an extended period of time. This in turn stabilises market expectations of short-term rates at least for the short- to medium-term horizon. Under the portfolio re-balancing channel, central bank purchases reduce the supply of government bonds available to the private sector and make investors attempt to re-shuffle their own portfolio allocations in response.

In order to detect what channels are at work, it is useful to think about long-term bond yields as being the sum of a so-called expectations component (average expected future interest rates) and a term premium (comprising inter alia compensation for interest rate risk). The signalling channel would mainly lead to a compression of the expectations component, whereas the portfolio re-balancing channel would mainly make the term premium shrink. While yield changes are observable, individual changes in the two components are not: hence, we deploy a dynamic term structure model in order to decompose changes of long-term Bund yields into changes in the expectations and the term premium component.

We find that the large decline in government bond yields since the summer of 2014 can be attributed almost exclusively to decreasing term premia. On the day of the PSPP announcement, it was likewise a decrease in the term premium rather than the expectations component, which moved long-term yields. Our results thus speak in favor of the portfolio re-balancing channel being at work. We also show that there were episodes in the past (notably during the financial and euro area sovereign debt crisis), when the expectations component rather than the term premium was the more dominant driver of yields. Hence, the identified strong dominance of term premium changes during the PSPP period is not an artefact in the sense that the model would *always* tend to attribute bond yield changes mainly to premia. A series of robustness checks confirms the main results.

1 Introduction

On 22 January 2015, the European Central Bank (ECB) announced a large-scale public-sector purchase programme (PSPP). The PSPP comprised purchases of bonds issued by euro area central governments, agencies and European institutions. Together with purchases of private-sector assets (asset-backed securities and covered bonds), which had been ongoing since September 2014, the PSPP constituted the ECB's so-called Expanded Asset Purchase Programme (APP). Complementing a series of policy rate cuts (eventually into negative territory) and other non-standard monetary policy measures, the APP was intended to help bring euro area inflation back to the ECB's desired level of close to, but below, 2%.[1] On 5 March 2015, the ECB announced the concrete purchase modalities. Purchases started four days later and initially amounted to Eur 60 bn per month. Public-sector securities accounted for more than 75%, thus the PSPP made up for the largest part of the overall APP envelope.

Beginning in summer 2014, markets increasingly began to anticipate that the ECB would embark on large-scale asset purchases, and German government bond yields (a prominent benchmarks for 'risk-free assets' in the euro area) showed a persistent decline. On 22 January 2015, the day of the official announcement of the PSPP, the ten-year German Bund yield decreased by a further 15 basis points – marking the twelfth largest daily decline since the start of Economic and Monetary Union in 1999.

In this paper, we decompose long-term German government bond yields on the day of the announcement and during the anticipation phase of the PSPP into expectations and term premia. The analysis is based on an arbitrage-free term structure model estimated on monthly German data using the method by Joslin, Singleton, and Zhu (2011) (JSZ). The estimated model is then applied to analysing daily movements in German bond yields.

Such decomposition is helpful for understanding the channels, via which asset purchases affect government bond yields. Existing literature distinguishes in particular between a signaling channel, which would primarily affect the expectations component (i.e. average expected future short-term rates) of long-term yields, and a portfolio re-balancing channel, which would mainly affect the term premium component.[2]

Most studies for the United States and the United Kingdom find that yield decreases

[1] See, e.g., European Central Bank (2015).

[2] A further distinction in the literature is on the distinction between stock and flow effects. The literature has arguably settled on the understanding that it is the stock of assets eventually absorbed by the central bank, which drives the bulk of the yield impact rather than the purchase transaction itself. For the euro area, flow effects are likewise found to be small, yet sometimes significant, see, e.g., the overview table in Arrata and Nguyen (2017) and the references given therein, as well as De Santis and Holm-Hadulla (2017) and Schlepper, Ryordan, Hofer, and Schrimpf (2017). The subsequent discussion in this paper on the channels of PSPP will focus on the stock effect.

were mainly propagated via the portfolio re-balancing channel[3], whereas Bauer and Rudebusch (2014) stress the presence of an economically and statistically significant signaling channel, which may explain up to almost one half of the yield decline induced by large-scale asset purchases by the Federal Reserve.[4] Regarding the ECB, several studies confirm that the PSPP announcement and its anticipation had an economically meaningful impact on government bond yields and other asset prices[5], but these studies do not focus on the distinction between the impact on expectations and the impact on the term premium.

We find that the large decline in government bond yields between the summer of 2014 and the start of purchases in early March 2015 ('anticipation period') can be attributed mostly to a decrease in the term premium.[6] Around 22 January 2015, when the ECB officially announced the PSPP ('announcement day'), it was likewise a decrease in the term premium rather than the expectations component, which led the decline in long-term yields. Our results thus speak – and even more distinctly compared to the findings for the US and UK – in favor of the portfolio re-balancing channel.[7]

We argue that the strong dominance of term premium changes during the PSPP anticipation period is not an artefact in the sense that the model would *always* tend to attribute bond yield changes mainly to premia. In fact, for the time between January 1999 and March 2015, the average decline in bond yields is attributed almost equally to decreases in the expectations and the term premium component. Also when looking at individual days of extreme bond yield declines as, e.g., during the financial crisis or during the euro area sovereign debt market tensions, the relative contribution of premia vs. expectations differs from event to event.

Finally, we conduct a couple of robustness analyses: we change the number of factors driving the yield curve, alter the estimation sample, use the regression-based method by

[3]See, e.g, Gagnon, Raskin, Remache, and Sack (2011) and Joyce, Lasaosa, Stevens, and Tong (2011).

[4]They stress that one may underestimate the relevance of the expectations component in decomposing yields, if one does not properly correct for an estimation bias that induces a too low persistence in risk factor dynamics. We address this concern explicitly in the robustness section.

[5]See, e.g., Altavilla, Carboni, and Motto (2015), Andrade, Breckenfelder, De Fiore, Karadi, and Tristani (2016), Arrata and Nguyen (2017), Blattner and Joyce (2016) and De Santis (2016).

[6]We did not extend the sample to the time when purchases were executed, as it turns out to be difficult to identify specific and large news about the size and the pace of the PSPP going forward. In particular, there is no clear-cut division into separate episodes of the PSPP, which would be comparable to the case of the Federal Reserve, where the literature tends to distinguish between three phases of Large Scale Asset Purchases and the Maturity Extension Programme.

[7]They are also in line with the finding of Pericoli and Veronesi (2017) that changes in term premia explain most of the movements in long dated yields between January 2013 and September 2016. They investigate three sub-periods, the last of which reaching from January 2013 to September 2016, i.e. containing our sample. However, their focus is on a general measure of monetary policy path surprises which are constructed from looking at all ECB Governing Council meetings in the respective period, i.e. not with an exclusive view on APP-related events.

Adrian, Crump, and Moench (2013) (ACM) as an alternative estimation approach and conduct a bias correction in order to avoid a possible under-estimation of persistence. All robustness checks corroborate the prominent role of the term premium in explaining the yield declines during the PSPP period. Our finding that using the ACM and JSZ approach generates strikingly similar results in terms of model fit and implied term premia is of independent methodological interest.

The next section introduces the model structure, estimation approach and data, section 3 presents and discusses the main results, and section 4 contains the robustness analysis.

2 Model, data and estimation

In order to conduct the yield decomposition we use an arbitrage-free affine four-factor term structure model for nominal zero-coupon yields. The law of motion of factors X_t (of dimension 4×1) is a VAR(1) under both the 'physical' ($\mathbb{P}$) and the 'risk-neutral' ($\mathbb{Q}$) measure,

$$X_t = \mathcal{K}_0^j + \mathcal{K}_1^j X_{t-1} + \Sigma \epsilon_t^j, \quad \epsilon_t \sim N(0, I), \quad j = \mathbb{P}, \mathbb{Q} \tag{1}$$

and the short-term (one-month) interest rate is an affine function of factors,

$$i_t = \delta_0 + \delta_1' X_t. \tag{2}$$

Under the no-arbitrage condition, yields y_t^n of zero-coupon bonds at time t maturing at time $t+n$ are given by risk-neutral (under the measure $\mathbb{Q}$) expectations of average future short rates (plus a Jensen inequality term). Those yields can be decomposed into an 'expectations component' EC_t^n, i.e. the hypothetical yield that would arise under the expectations hypothesis, $EC_t^n = \frac{1}{n} E_t^{\mathbb{P}} \sum_{k=0}^{n-1} i_{t+k}$, and a 'term premium', TP_t^n, so that

$$y_t^n = EC_t^n + TP_t^n. \tag{3}$$

The affine structure (1)-(2) implies that yields themselves, the expectations components and term premia are all affine functions of factors, i.e.

$$y_t^n = A_n + B_n' X_t, \tag{4}$$

$$EC_t^n = A_n^{EC} + B_n^{EC\prime} X_t, \tag{5}$$

$$TP_t^n = A_n^{TP} + B_n^{TP\prime} X_t, \tag{6}$$

where the intercepts A and factor loading vectors B are functions of the parameters appearing in (1) and (2).[8] For yields themselves it is only the $\mathbb{Q}$ parameters of (1) that enter A and B, for the expectations component only the the $\mathbb{P}$ parameters matter, while the term premium is a function of both sets of parameters.

[8] These can be computed by means of iterating forward difference equations in n, starting from initial conditions for A_1 and B_1. See, e.g., the annex in Joslin et al. (2011).

We deploy the estimation procedure suggested by Joslin et al. (2011) which use a specific representation and parameterization of the model above, under which the factors X_t correspond to principal components of observed bond yields. The estimation of model parameters is based on end-of-month zero coupon yields of German government bonds for maturities of 1, 9, 12, 24, ..., 108 and 120 months, over the period January 1999 to June 2012. That is, we use 162 months, where in each month we observe 12 points on the term structure. The data are provided by Deutsche Bundesbank.[9] The start of the estimation sample coincides with the introduction of the Euro, i.e. the single monetary policy for the currency area. The end of the estimation sample is about two-and-a-half years before the introduction of the PSPP. The reason for ending in mid-2012 is to avoid parameter estimates being affected too much by a zero or negative interest-rate regime: while in June 2012 key policy rates were still strictly positive, the ECB decided in July to decrease its deposit facility rate[10] to zero and subsequently to negative levels, which was accompanied by short-term Bund ('Schatz') yields turning negative.

The four-factor model elicits a very good fit to the term structure. The average (across months) in-sample absolute pricing error (actual minus model-implied yield) amounts to around one basis point across maturities. The persistence of factors is high, with the maximum absolute eigenvalue of $\mathcal{K}_1^{\mathbb{P}}$ governing the physical factor dynamics amounting to 0.992. Under a similar model specification with only three factors, fitting errors for the estimation sample are only slightly higher, ranging between one and three basis points. However, when going beyond the estimation sample to fit yield changes during the anticipation of the PSPP (the approach being further explained below), the fitting error for the three-factor model is distinctly higher than for the four-factor specification (about 9 vs 1 bps for the ten-year maturity). Hence, we decide to adopt the four-factor specification as our baseline model and cross-check with the results of the three-factor model as part of the robustness analysis.

Given the parameter estimates and factors X_t (constructed as principal components), we can compute the intercept A_n, A_n^{EC} , A_n^{TP} and the factor loading vectors B_n, B_n^{EC}, B_n^{TP} in (4) - (6) for an arbitrary maturity n and obtain the model-implied yield, its expectations component and the term premium. Note that these objects can be computed not only for the end-of-month dates involved in the estimation sample, but also for any other day,

[9] See `https://www.bundesbank.de/Navigation/EN/Statistics/Time_series_databases/Money_and_capital_markets/money_and_capital_markets_list_node.html?listId=www_skms_it03a`. Maturities used in estimation but not directly provided at this link have been computed by using the estimated Nelson-Siegel-Svensson parameters, likewise available from the Bundesbank website. For Sept-2008 and Aug-2011, this approach led to clear outliers for the one-month rate, which we corrected by interpolating between the two neighbouring months.

[10] The deposit facility rate is the rate, at which banks can park their liquidity overnight with the central bank.

where yields are available. For any day, the four principal components, X_t are constructed as $X_t = WY_t$, where $Y_t = \left(y_t^{1m}, y_t^{9m}, y_t^{12m}, y_t^{24m}, \ldots, y_t^{120m}, \right)$ contains the observed yields and W is a 4×12 matrix, obtained from estimating the principal components from the monthly data in the estimation sample. Those daily factors are then combined with equations (4) - (6) to obtain daily estimates of fitted yields, expectations components and term premia.[11] Proceeding in this fashion we obtain decomposition results for all business days between 1999 and 6 March 2015, the day on which the ECB announced the final parameters of the PSPP.

3 Results and discussion

According to the famous quote from former FOMC chairman Ben Bernanke, "The problem with QE is that it works in practice, but it doesn't work in theory".[12] The 'theory' aspect of the statement refers to stylized models of the term structure (and the macroeconomy) where indeed the supply of bonds is irrelevant for the pricing of such securities. Given the accumulating evidence that large-scale asset purchases by central banks *did* have an impact on the yield curve (the 'practice' aspect), the literature has proposed a host of approaches and model amendments in order to explain how such an impact can arise. One broad classification distinguishes between a 'signalling' channel and a 'portfolio re-balancing' channel.

As regards the signalling channel, bond purchases would underline the central bank's commitment to keeping their key interest rates at low levels for an extended period of time. This in turn stabilises market expectations of short rates and depresses the expectations component for long rates at least for the short- to medium-term horizon.

The portfolio channel is examined in the literature in several variants, in particular (i) as a local-supply or scarcity channel and (ii) as a duration extraction channel.[13]

Under the local-supply or scarcity channel, central bank purchases of bonds in a certain maturity bracket extract supply available for investors particulary interested in those maturities. This raises the price (compresses the yield) of those bonds, while not affecting bonds with maturities distinctly different from those of the bonds purchased.

Under the duration extraction channel, central bank purchases decrease the overall duration (i.e. interest rate sensitivity) risk to be borne by the market, thus compressing the 'price of risk' for all bonds, hence compressing excess returns and term premia, and in turn compressing overall yields. A distinct aspect of the duration extraction channel is that central bank purchases in one maturity bucket compress bond yields of all maturities,

[11] The mean absolute fitting errors for daily data are of similar magnitude (around 1 bp) as those obtained for the end-of-month data entering the estimation.

[12] Thus remarked in an interview at Brookings Institution, on 16 January 2014.

[13] See, e.g., D'Amico and King (2013) and Greenwood and Vayanos (2014).

not only those at or near the maturities of the bonds acquired.

Summing up, the two polar cases that can arise from our decomposition exercise would have the following interpretation: if the decrease in bond yields can be solely attributed to a decrease in the expectations component, it would imply that mainly the signalling channel was at work; if, by contrast, bond yield declines emanated from declining term premia only, this would suggest that bond purchases have not contributed to decreasing rate expectations (no signalling channel in this sense), but the portfolio channel would have been predominantly at work.[14]

It is also important to note that the signalling and the portfolio channel would have an impact on bond yields already at the time when expectations about purchases are building up (typically following central bank communication), and not only when actual purchases would have started. For the case of the euro area, there was no single date, at which the ECB would have surprised the market with an announcement of its PSPP. Rather, against the background of a series of evolving ECB communication (speeches, interviews, press conferences) on this topic, expectations of a public-sector purchase programme were gradually building up since summer 2014.

Figure 1, left panel, compares the term structure of 3 September 2014 to that of 6 March 2015.[15] The first date is the day before the ECB Governing Council meeting, at which the first two legs of the APP, i.e. the purchases of covered bonds and asset-backed securities, had been decided. Some observers took that as a trigger to speculate about a further broadening of asset purchases to also include government bonds.[16] The last date is the day after the ECB Governing Council meeting, at which the purchase modalities of the PSPP had been announced. Between the two dates, the yield curve has shifted down with long-term maturities decreasing more strongly than the short end of the curve ('bull-flattening').

Focusing on the ten-year maturity (Figure 1, right panel), the model-based decomposition shows that the bulk of its decline came from a decline in the term premium

[14] This classification notwithstanding, there is no perfect one-to-one mapping between expectations-component vs premia on the one hand and signalling vs portfolio channel on the other hand: to the extent that bond purchases would also decrease the uncertainty about future policy paths, the signalling channel may also compress the (absolute) size of the term premium to some extent. Still, if one observes that a yield decrease is fully matched by a change in the term premium, it is unlikely that the term premium change is co-induced by a signalling channel as otherwise the latter would leave a footprint on rate expectations as well.

[15] Altavilla et al. (2015) identify key events starting with the ECB Governing Council meeting on 4 September 2014 and reaching until the Governing Council meeting on 5 March 2015.

[16] For instance, at the press conference, following the Governing Council one journalist asked "[...] did you discuss QE today?", on which ECB President Draghi replied that "[...] A broad asset purchase programme was discussed, and some Governors made clear that they would like to do more.", see European Central Bank (2014).

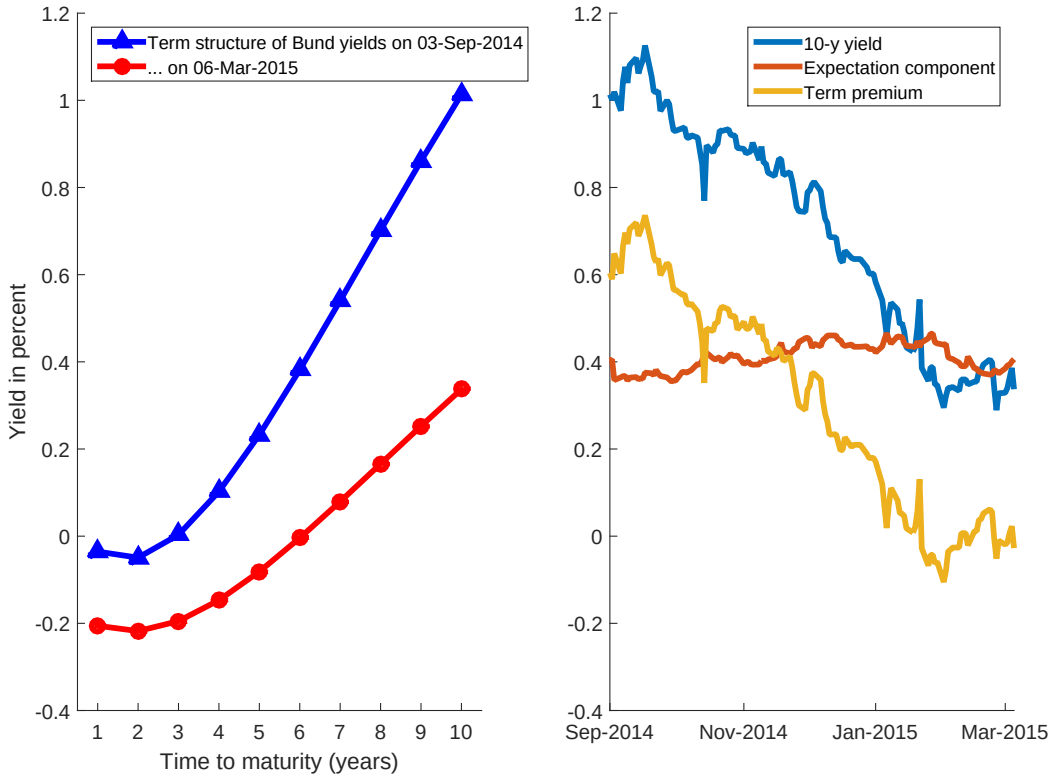

Figure 1: **Shift in the yield curve in anticipation of the ECB's public-sector purchase programme (PSPP)**. Left panel: German zero-coupon yield curve on 3 Sep 2014 (one day before the ECB Governing Council announcing private-sector bond purchases) and 6 Mar 2015 (one day after the ECB Governing Council announcing modalities of PSPP). Right panel: Ten-year zero-coupon German bond yield between 3 Sep 2014 and 6 Mar 2015, its model-implied expectations component and term premium component.

component, whereas the expectations component has been fairly stable. This is a first indication that the PSPP was not so much affecting policy rate expectations, but rather term premia via a portfolio re-balancing channel. In order to refine the analysis, one could in principle single out specific events, at which communication of ECB officials has led to changes in market expectations about future purchases. For instance, Altavilla et al. (2015) select 17 such events (speeches, interviews, press conferences after the Governing Council) during the time window shown in Figure 1. However, they use intraday data in their analysis, allowing them to inspect yield reactions during small time windows, which is important when the effect of the respective communication was relatively small or short-lived and possibly distorted by subsequent economic news that likewise had the potential to move bond markets. Applying our analysis conducted at daily frequency[17] to such events would lead to biased results. Accordingly, we focus only on the two days of

[17]To our knowledge, decomposition analysis of the type conducted in this paper has never been applied to intraday data. One reason is probably that a construction of the required zero-coupon curve at each time tick is not feasible or subject to considerable measurement error.

the ECB Governing Council meetings on 22 January and 5 March 2015, when the PSPP was announced as such (January) and the specific purchase modalities were communicated (March). As our Bundesbank yield curve data relate to the time of around noon of a given day rather than close of business, we will compare the day of the Council to the following day. This is because at the Thursday of an ECB Governing Council, the press release with the monetary policy decision comes out at 13:45 and the press conference starts at 14:30: that is, the relevant information is not know at noon yet and hence not reflected in the corresponding bond yield recorded for that day. Hence, for the 22 January 2015 Governing Council decision, we will look at the change in yield from 22 January (noon) to 23 January (noon). Similarly, for the 5 March 2015 event, we consider the yield change between 5 March (noon) and 6 March (noon).

The day-on-day decrease of the ten-year yield after the January-2015 ECB decision on PSPP amounted to about 16 bps, which corresponds to the 0.3% quantile of daily yield changes and represents the 12th largest daily decrease observed since 1999, see left red-framed bar in Figure 2. While the inception of sovereign asset purchases as such had been expected, the communication following the January meeting carried genuine news, as both the intended scope and length of the programme exceeded market expectations.[18] The model-based decomposition attributes the yield decline almost fully to a decline in the term premium. In fact, there is a tiny (1 bp) *up*-tick in the expectations component, which should, however, not be over-interpreted given the general estimation uncertainty surrounding any term premium estimate and given the fact that the fitting error of the yield change for that date is of a similar order of magnitude.

Following the 5-March-2015 Governing Council meeting, the ten-year yield declined again, but only by about 5 bps, corresponding to about the 13%-quantile of daily yield changes since 1999, see second red-framed bar in Figure 2. Yet again, in terms of its components the model ascribes this decline primarily to a decline in the term premium.

Is the prominent role of the term premium in accounting for those yields declines over PSPP-related epsiodes a model artefact? That is, does the term structure model have a *general* tendency to favour the term premium as the key driving force as opposed to the expectations component? A comparison with earlier yield declines across the sample suggests otherwise. For the average daily yield decline, the term premium and expectations component contributed almost equally (last bar in Figure 2). In a similar vein, we compute the standard deviations of day-to-day changes of ten-year term premia and expectations components over the estimation sample. These turn out to be of a very similar order of magnitude of about 6 basis points, i.e. there is no general tendency of the model over our sample to account for yield volatility mainly via the term premium.[19]

[18] See, e.g., various market reports following the January press conference, or Financial Times (2015).

[19] Computing the same measures for the US premia based on the approach by Kim and Wright (2005) (updated results from `https://www.federalreserve.gov/pubs/feds/2005/200533/200533abs.html`), the

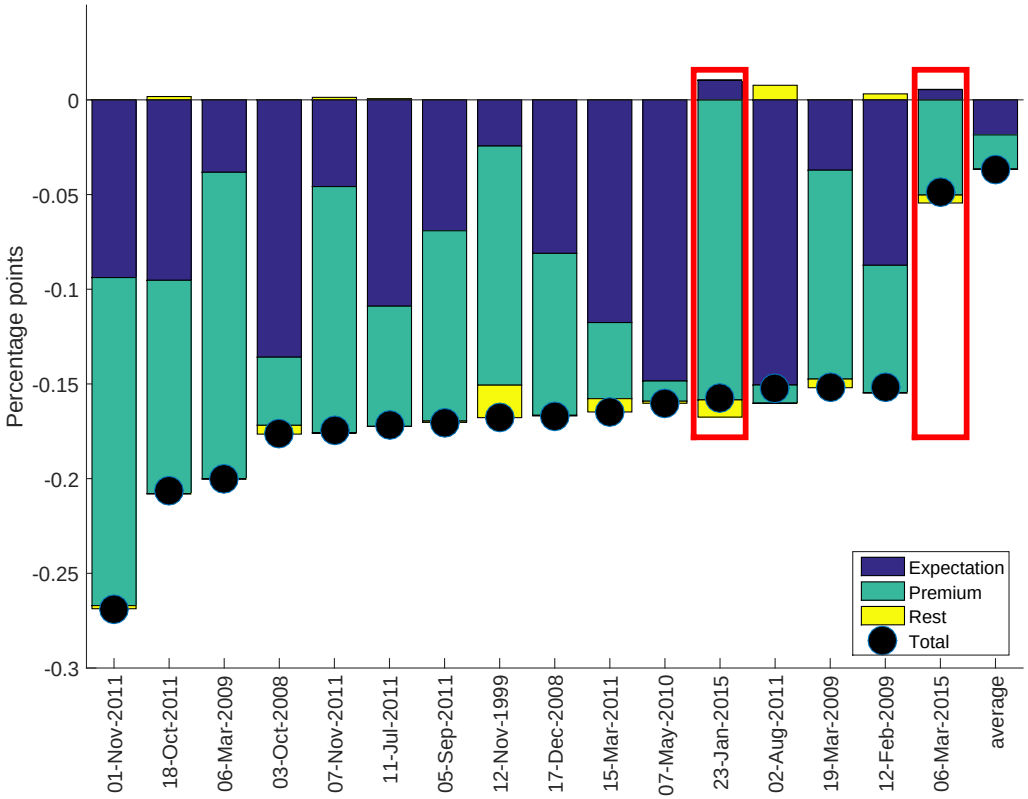

Figure 2: **Decomposed daily changes in 10y bond yields**. The first 15 bars from the left depict the 15 strongest daily yield declines for German 10y zero-coupon bonds from 1999 to March 2015, decomposed into change in expectations, term premium and residual component. It includes the decomposed change of the 10y yield for the 23 Jan 2015 i.e. after the ECB had announced PSPP (left bar with red frame). The second bar with red frame corresponds to 6 Mar 2015, i.e. after the ECB communicated its purchase modalities. The rightmost bar is the decomposed average daily decline in bond yields from 1999 to March 2015.

Also looking across the largest 15 yield decreases during the sample, the 23-Jan-2015 sticks out with its eminent contribution of the term premium. The other occasions of large yield declines are mostly stemming from the time of the global financial crisis (observations from 2008 and 2009) or the euro area sovereign debt market tensions (observations from 2010 and 2011). They show different relative contributions of expectations vs. term premium components. For instance, the largest decrease (most left bar in Figure 2) occurred on 1 November 2011, when markets reacted to Greece proposing a referendum on a new European Union support package. The model assigns about two-thirds of the yield decline to falling term premia, reflecting possibly flight to safety movement, and one third to declining rate expectations. By contrast, the fourth-largest bar from 3 October 2008 has the majority of the yield decline attributed to expectations. This makes sense as it followed an ECB press conference, at which key interest rates were kept on hold, but

pairs of standard deviations (term premium, expectations component) amount to 5 and 2 bps, respectively. That is, for their US results, premia tend to fluctuate relatively more strongly compared to expectations.

ensuing communication was interpreted by market participants as alluding to a series of rate decreases in the near future.[20]

Overall, we conclude that the magnitude of the PSPP-related yield decline was exceptional from a historical perspective, but also the fact that almost all of this decrease was attributable to the term premium rather than the expectations component.

4 Robustness of results

We modify our analysis across several dimensions in order to study the robustness of our main findings. The results are summarized in Table 1.

	3-Sep-14 to 6-Mar-15				22-Jan-15 to 23-Jan-15			
	Δy	ΔEC	ΔTP	$\Delta Resid$	Δy	ΔEC	ΔTP	$\Delta Resid$
Baseline	-68	0	-63	-5	-16	1	-16	-1
– 3 factors	-68	-6	-49	-12	-16	-1	-12	-3
– est. Jan-99 to Mar-15	-68	6	-70	-4	-16	2	-17	-1
– ACM approach	-68	1	-63	-5	-16	1	-16	-1
– Bias correction	-68	-1	-62	-5	-16	1	-16	-1

Table 1: **Decomposed change of 10y yield over two time windows - robustness analysis.** Each line summarizes the decomposition of the change in the 10y yield (Δy) into the expectations component (ΔEC), the term premium component (ΔTP) and the residual ($\Delta Resid = \Delta y - \Delta EC - \Delta TP$) over the period 3 September 2014 to 6 March 2015 (first four columns) and for the PSPP announcement day, i.e. 22 to 23 January 2015 (last four columns). The first results line ('Baseline') corresponds to the baseline specification, i.e. the four-factor affine model as described in section 2, estimated by the method of Joslin et al. (2011) using monthly data from January 1999 to June 2012. The other rows deviate from the baseline specification as follows: the second row ('3 factors') is based on the JSZ approach with the number of factors reduced to three; the third row ('est. Jan-99 to Mar-15') is based on a prolonged estimation sample; the fourth row ('ACM') is based on the four-factor model estimated by the Adrian et al. (2013) approach; the fifth row ('Bias correction') corrects for small-sample bias in the autoregressive matrix under the $\mathbb{P}$ measure.

First, we consider a model specification with only three (instead of four) factors. Like the four-factor baseline specification, the three-factor model attributes the bulk of the total yield decline from 3 September 2014 to 6 March 2015 (68 bps ovall) to the term premium. However, there are some minor quantitative deviations from the baseline results. Specifically, the alternative model attributes six instead of zero basis points to the expectations component, and the term premium contribution is reduced to a decline of 49 bps vs 63 bps in the baseline. This specification also provides a worse fit (12 vs 5 bps

[20] Indeed, the main refinancing rate, the key ECB policy rate, was kept at 4.25% after the 2 October meeting, but was then lowered to 3.75% one week later, followed by further decreases bringing it down by overall 325 bps in the next seven months, to reach 1.00% in May 2009.

residual) of the total decline during the PSPP-anticipation period – in line with its overall inferior fit over the estimation sample (see section 2). A qualitatively similar pattern holds for the decomposition of the yield decline on the PSPP announcement day.

Second, we extend the estimation period to include also the months from mid-2012 until March 2015, i.e. a period during which ECB policy rates were near zero and eventually turned negative, dragging capital market rates into negative territory as well. With parameters based on this longer sample, the decline of the term premium during the PSPP anticipation period is even a bit more pronounced (70 vs 63 bps), while the expectations component increases slightly, and the overall fit is comparable. For the day of the PSPP announcement, results are almost indistinguishable from the baseline.

Third, we keep the number of factors and the estimation sample as in the baseline set-up, but deploy the estimation approach proposed by Adrian et al. (2013) instead of using JSZ. While Adrian et al. (2013) highlight several differences between the two approaches, the models turn out to deliver quantitatively very similar results in our case, i.e. for decomposing ten-year Bund yields around the time of the PSPP. Moreover, also over the estimation sample as a whole, the two models give very similar ten-year term premia, see Figure 3.

Fourth, as discussed in particular by Bauer and Rudebusch (2014), the prominence of term premia may result from an underestimated persistence implied by the model's autoregressive matrix $\mathcal{K}_1^{\mathbb{P}}$ for the factors' $\mathbb{P}$ dynamics in (1): a too low estimated persistence implies quicker mean reversion and renders the expectations component less volatile. In our case, the OLS-based maximum eigenvalue of $\mathcal{K}_1^{\mathbb{P}}$ is already 0.992, but we nevertheless apply bias correction approaches. Specifically, we re-estimate the VAR dynamics of the principal component factors under the $\mathbb{P}$ measure using the asymptotic bias correction approach of Pope (1990), a direct bootstrap and the indirect inference approach expounded in Bauer, Rudebusch, and Wu (2012).[21] Under all approaches, the maximum absolute eigenvalue of $\mathcal{K}_1^{\mathbb{P}}$ increases to a level above one, implying implausible explosive behavior of yields and expectations. Therefore, we also applied a shrinkage approach as discussed in Bauer et al. (2012), where we compress the estimated bias in small steps such that the maximum absolute eigenvalue of $\mathcal{K}_1^{\mathbb{P}}$ just matches a stationarity threshold. Here, we set this threshold to 0.999. Overall, the persistence adjustment leads to a more volatile expectations component over the estimation period as a whole, but the decomposition of yield changes for our specific events is virtually unaffected compared to the baseline model without bias correction (see last row of Table 1).[22]

Finally, a word is in order why our analysis has been conducted using Bund yields rather than overnight index swap (OIS) rates. Following Joyce et al. (2011) for the UK and

[21] We use the code kindly provided on Cynthia Wu's website for replicating Bauer et al. (2012).

[22] Results are also very similar if instead we restrict the maximum absolute eigenvalue of $\mathcal{K}_1^{\mathbb{P}}$ to be smaller than or equal or its $\mathbb{Q}$-measure counterpart as suggested by Bauer et al. (2012).

the discussion in Bauer and Rudebusch (2014) for the US, the term premium component may be (conceptually) split into a general term premium $TP^n_{risk,\,t}$ and an instrument-specific component $TP^n_{bond,\,t}$, which captures bond-specific liquidity premia or demand-supply imbalances. That is, we can refine the decomposition in (3) further as : $y^n_t = EC^n_t + TP^n_t = EC^n_t + TP^n_{risk,\,t} + TP^n_{bond,\,t}$. The expectations component and the first part of the term premium would arguably also show up in OIS rates, $y^n_{OIS,\,t} = EC^n_t + TP^n_{risk,\,t}$ while the second part is Bund-specific, so that $y^n_t = y^n_{OIS,\,t} + TP^n_{bond,\,t}$. If, as a polar case, the portfolio re-balancing channel only works via generating scarcity of the instruments being purchased, then the bond-specific part $TP^n_{bond,\,t}$ of the term premium would decline, while the OIS-embedded part $TP^n_{risk,\,t}$ would not react at all. But if the purchase programme also works via the duration extraction channel, it will also impact on $TP^n_{risk,\,t}$.

When inspecting the change in the Bund-OIS spread, i.e. $y^n_t - y^n_{OIS,\,t}$, it turns out that the change in this spread accounts for a considerable part of the decline in Bund yields, pointing to the relevance of local-supply effects being at work as part of the portfolio re-balancing channel. This holds both for the announcement day and for the anticipation period. Hence, focusing only on OIS rates and ignoring bond-based information would have led to ignoring a considerable part of the term premium decline induced by the PSPP. At the same time, we find that the Bund-OIS spread decline does not *fully* account for the overall decline in Bund yields. Thus, duration extraction and – based on that spread information alone – possibly also the expectations channel played a role. However, as we know in turn from our results based on the estimated term structure model, the expectations channel is not quantitatively important.

Overall, the model-based analysis and the subsequent robustness checks suggest that the PSPP-related decline in Bund yields is mainly driven by the portfolio re-balancing channel rather than by the signalling channel. The additional information coming from the Bund-OIS spread allows to qualify the portfolio re-balancing channel further: apart from affecting overall duration risk premia, the PSPP has probably also worked via local-supply or scarcity effects. A joint analysis of the OIS and Bund yield curve in one encompassing framework may help analyse these two dimensions of the portfolio re-balancing channel further, but is beyond the scope of this short paper.

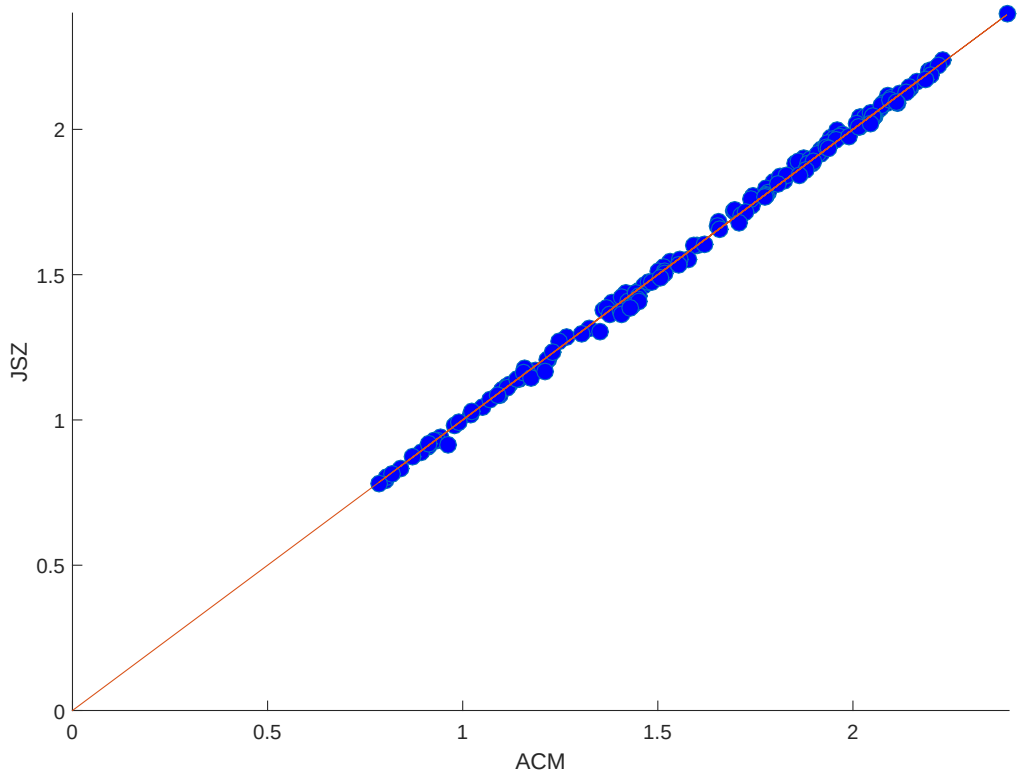

Figure 3: **Estimated term premia of 10y German bond yields, Joslin et al. (2011) vs Adrian et al. (2013) approach.** Dots in the scatter plot denote estimates of the 10y term premium embedded in 10y German government zero-coupon bond yields for the months from Jan 1999 to Jun 2012. Each dot (x, y) corresponds to a certain month, where x is the term premium estimate stemming from using the Joslin et al. (2011) approach and y is the estimate implied by using the Adrian et al. (2013) approach. The red line is the 45 degree line.

5 Conclusion and outlook

Our analysis suggests that the expectation and announcement of the ECB's Public Sector Purchase Programme affected long-term German yields mainly via a compression of the term premium as opposed to a decrease in the expectations component. This evidence speaks in favour of a portfolio re-balancing channel being the dominant part in the PSPP's transmission as opposed to a signalling channel. The decomposition exercise based on a 'yields-only' arbitrage-free model can only be a first step to understanding the working of non-standard monetary policy measures. However, the results may be useful for informing the specification of more structural approaches, or of models that can more explicitly differentiate between the different manifestations of the portfolio re-balancing channel (extracting duration risk vs working via local-supply effects). Future research may refine the analysis by expanding the sample, by controlling for PSPP-related vs other news, by including intraday data, by separately focusing on real and inflation risk premia, or by jointly modeling the term structure of OIS and Bund yields.

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