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The interest rate effects of government bond purchases away from the lower bound

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ABSTRACT

I analyze the recent experience of unconventional monetary policy in Sweden to study the interest rate transmission mechanisms of government bond purchases when interest rates are away from the lower bound. Using dynamic term structure models and event study regressions I find that government bond purchases have important portfolio balance and signaling effects. The signaling channel operates mainly by lowering short-rate expectations in the intermediate segment of the yield curve, while the portfolio balance channel is effective in lowering longer maturity term premia. In addition, I find that target interest rate policy and government bond purchases operate in different segments of the yield curve. This suggests that a combination of the two policies can be used to lower interest rates across the whole maturity spectrum, making monetary policy more expansionary.

1. Introduction

During the financial crisis of 2008 and the following years, a number of central banks reduced their target interest rates - the traditional tool of monetary policy - essentially to their lower bounds. In the face of deteriorating economic conditions and deflationary pressures, and with little scope for further cuts in target interest rates, central banks initiated unprecedented expansions of their balance sheets by purchasing large amounts of government debt and other types of assets across different maturities. While it is widely accepted that such policies have helped to reduce long-term interest rates (Gagnon et al., 2011; Christensen and Rudebusch, 2012), the understanding of their interest rate transmission channels is at best partial and has become the topic of a growing literature.

The literature has focused mainly on two channels of transmission: the signaling and the portfolio balance channels. The first channel works through changing market expectations of future policy rates. For instance, by announcing asset purchases, the central bank may send a signal to market participants that it intends to keep policy rates low for longer than otherwise. The central bank may also influence market expectations by communicating its future monetary policy intentions and by providing forward guidance about its future policy rate path. The other is the portfolio balance channel, which arises from the reduction in the available supply of the assets purchased. In this channel, under the assumption that bonds of different maturities are not perfect substitutes and that maturity-specific bond demands by certain investors exist, central banks may be able to affect bond yields by changing the risk premia that investors require for holding the securities purchased.

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Recent research, however, has shown that nominal bond yields have been constrained by the interest rate lower bound in different economies. For instance, Swanson and Williams (2014) discuss that intermediate-maturity Treasury yields seem to have been especially constrained from late 2011, around the time the FOMC started providing explicit calender-based forward guidance. Bauer and Rudebusch (2016) document that the wedge between the ten-year Treasury yield and the corresponding shadow yield, a measure of the tightness of the lower bound constraint, increased substantially over the period from 2009 to 2012, reaching its maximum in mid-2012 and then gradually decreased over 2013 and 2014, when macroeconomic conditions improved in the US. They discuss that this phenomenon is mainly due to the constraints the zero lower bound imposes on the expected path of policy rates and its conditional distributions, which affects the behavior of yields, depending on how long the lower bound is expected to be binding.[1] This implies that the signaling channel of government bond purchases may be weaker in a lower bound environment.

In this paper, I analyze the recent experience of unconventional monetary policy in Sweden to study the interest rate transmission mechanisms of government bond purchases when the policy rate is away from the lower bound. Unlike other central banks, Sveriges Riksbank has been able to lower its target interest rate, the repo rate, deep into negative territory while government bond purchases have been announced. This makes it possible to studythe effects of government bond purchases across the full yield maturity spectrum, without lower bound constraints. In addition, the Riksbank has not announced a lower bound for its policy rate, imposing no formal restrictions on expected policy rate paths.

In order to identify the channels through which the bond purchases may have operated I follow the literature and use dynamic term structure models combined with an event study approach. More specifically, I estimate discrete-time Gaussian dynamic affine term structure models (DATSMs) and decompose yield changes into changes to expected short-rate and term premium components for different maturities.[2] The expected short-rate component is then associated with monetary policy expectations, or the signaling effect, while portfolio balance effects are associated with the term premium component. One important aspect to consider, however, is that the Riksbank has announced its decisions about target interest rate and bond purchase policies at the same time, which means that it is necessary to separate the effects of the two policies on yields and components in order to study the interest rate channels of government bond purchases. In this paper, I use an event study regression approach. More specifically, I project changes in yields, the expected short-rate component and term premia onto expected and unexpected changes in the repo rate, a repo rate path factor and a foreign yield variable for the period in which only conventional monetary policy was being implemented, and use coefficient estimates to predict the effects of conventional monetary policy announcements on days in which the two policies were announced. I then use the predicted regression residuals as a measure of the effects of bond purchase announcements. The idea of this approach is to isolate the effects from each policy on yields and components.

I document that Swedish interest rates did respond in the immediate aftermath of the announcements. Long-term government bond yields dropped by a cumulative total of around 46 basis points following the five Riksbank monetary policy announcements that involved bond purchases in 2015. Relative to the ten-year bond yield of 0.65 percent on the eve of the first announcement, 46 basis points represent a substantial and significant drop. Importantly, yields declined more strongly on announcements that involved changes in the repo rate and purchases of government bonds, with long-term yields declining more than short-term yields on net. This suggests that the combination of the two policies was effective in lowering interest rates.

Results also suggest that government bond purchases have important portfolio balance and signaling effects. The signaling channel operates by lowering the short-rate expectations component across maturities but mainly in the intermediate segment of the yield curve, while the portfolio balance channel is more effective in lowering longer maturity term premia. In addition, I find that target interest rate policy and government bond purchases operate in different segments of the yield curve, being effective in lowering yields across the full maturity spectrum when implemented together. The policy announcement of July 2, 2015 is a good example of how the three channels seem to work and interact. On that day, the decisions to cut the repo rate by 10 basis points and to purchase government bonds for a further SEK 45 billion were largely unexpected by market participants. The surprise regarding the interest rate cut affected short-rate expectations strongly, driving the fall in short-term yields. At the same time, bond purchases contributed, to a large extent, to lower the short-rate expectations component and term premia in the two- to five-year and in the five- to ten-year segments of the yield curve, respectively, suggesting that both the signaling and the portfolio balance channels seemed to have contributed to the observed fall in mid- and long-term bond yields.

The findings of this paper have important policy implications. They suggest that, when the policy rate is not constrained by the lower bound, it is possible to design bond purchase programs with the aim of influencing bond yieds across maturities, but especially in the mid and long segments of the yield curve. Furthermore, when implemented together, target interest rate policy and government bond purchases may be used by central banks to lower yields across the full maturity spectrum, making monetary policy more expansionary than otherwise. While interest rate policy may lower short-term

[1] Using shadow-rate term structure models Wu and Xia (2015), Bauer and Rudebusch (2016), Christensen (2015) and Lemke and Vladu (2014) have demonstrated that yields for different maturities have been constrained by the lower bound in several economies, mainly due to the constraints the lower bound imposes on short-rate expectations.

[2] Gagnon et al. (2011), Christensen and Rudebusch (2012) and Bauer and Rudebusch (2014) are among the previous studies that use term structure models to decompose yields and analyze the interest rate effects of bond purchase programs in the US and in the UK.

yields mainly through policy rate expectations, government bond purchases are expected to operate by lowering mainly mid-horizon policy rate expectations and longer maturity term premia.

The remainder of this paper is organized as follows. The next section describes the Swedish experience of unconventional monetary policy and shows a preliminary analysis on the interest rate effects of government bond purchases. Section three introduces the affine term structure models that are used to decompose government bond yields into the short-rate expectations and term premium components together with event study framework. Section four describes the main results of the paper and the fifth section concludes.

2. The Swedish experience of unconventional monetary policy

In this section, I describe in more detail the Swedish program of government bond purchases launched in February 2015 and perform a preliminary analysis of its impact on interest rates.

2.1. The Riksbank's government bond purchase program

According to the Sveriges Riksbank Act, the Riksbank aims for price stability with conventional monetary policy being implemented by setting the repo rate, and by steering the overnight rate towards this rate through short-term market operations. The instruments that the Riksbank uses are daily fine-tuning transactions and weekly issues of Riksbank certificates.[3] The bounds for the overnight rate are set by an interest rate corridor equal to the repo rate plus/minus 0.75 percentage points. The exchange rate is floating and the Riksbank sets an inflation target rate of 2 percent per year. This policy framework has been implemented since 1993.

This policy reached its limit in July 2009 when, in response to developments related to the financial crisis, the Riksbank reduced its target rate to 0.25 percent and lowered its repo-rate path. Further monetary policy easing continued to be desirable and, in connection with the interest rate decision, the Riksbank decided to launch a bank lending program with a fixed minimum auction interest rate of 0.4 percent and a maturity of twelve months. This was intended to contribute to lower interest rates on loans to businesses and households. By November 2009, SEK 296.5 billion had been auctioned, equal to approximately 9 percent of Sweden's GDP. The rapid recovery of the Swedish economy led the Riksbank to end its bank lending program by 2011 with the last variable-rate loans, also included in the program, maturing in January of that year. A large part of the increase in the Riksbank's balance sheet was absorbed. By the same time, the rapid recovery of the Swedish economy, followed by the increase of inflation above the target, led the Riksbank to raise interest rates.[4] However, the slower than expected recovery of foreign economies, together with the consequent drop in consumer prices, led the Riksbank to start lowering its policy rate again in December 2011.

Against this background and with considerable downward pressure on consumer prices, the Riksbank announced complementary monetary policy measures based on the purchase of government bonds in February 2015, which are the focus of this paper. The Executive Board of the Riksbank announced that the Riksbank would start buying nominal government bonds on the secondary market to the amount of SEK 10 billion. The purchases took place by means of auctions in which the Riksbank's monetary policy counterparties and the Swedish National Debt Office's primary dealers were able to participate. Later on, further monetary policy easing continued to be desirable, in particular due to concerns about the strengthening of the Swedish krona (SEK), and the Riksbank announced further extensions of its bond purchase program. At the same time, the repo rate was gradually lowered, reaching the levels of −0.35 percent in July 2015 and −0.50 percent in February 2016. Table 1 shows a description of the key monetary policy announcements that happened during 2015 and that are the main objects of study of this paper.

One important aspect of the Swedish program is that it was not aimed at providing extra liquidity to restore the functioning of certain markets. The main goal was to lower interest rates in various markets as a means of avoiding a quick appreciation of the Swedish krona and encouraging banks to lend, thereby stimulating the economy and making inflation return to its 2 percent target. Purchases of Swedish government bonds were concentrated in the two- to eleven-year maturity segment, reflecting the availability of the outstanding debt (see Fig. 1 - Panel A). In addition, the pace of the purchases evolved fairly smoothly over the course of the program with purchases being somewhat heavier in early 2015 and slowing down during the summer and the end of the year (see Fig. 1 - Panel B). Purchases were also spread across maturities when we look from a time perspective, which reflects the idea that the Riksbank aimed at lowering interest rates across the whole maturity spectrum ranging from two to eleven years.

2.2. The responses of market interest rates: preliminary analysis

A preliminary assessment of how interest rates reacted to the Swedish program can be performed by looking at how interest rates behaved in event windows around the monetary policy announcements. I use one-day windows as the baseline

[3] Fine-tuning transactions imply that, at the end of the day, banks can deposit liquidity with the Riksbank overnight at the repo rate minus 0.10 percentage points. Alternatively, banks can invest in the Riksbank certificates, which are issued at the repo rate with a maturity of one week.

[4] The rapid increase in Swedish household debt and housing prices that followed from the low interest rate environment were also considered by the Riksbank when deciding on raising the repo rate. This policy is commonly known as "leaning against the wind" (see Per Jansson, 2014).

Table 1
Monetary policy announcements by the Riksbank.

Date	Announcement description
Feb 12, 2015	Riksbank cuts repo rate to −0.10 percent, buys government bonds for SEK 10 billion and is prepared to do more at short notice
Mar 18, 2015	Riksbank cuts repo rate to −0.25 percent and buys government bonds for SEK 30 billion
Apr 29, 2015	Riksbank buys government bonds for SEK 40–50 billion and lowers the repo-rate path significantly
Jul 2, 2015	Repo rate cut to −0.35 percent and purchases of government bonds extended by SEK 45 billion
Sep 3, 2015	Repo rate unchanged at −0.35 percent
Oct 28, 2015	The Riksbank purchases government bonds for a further SEK 65 billion and keep the repo rate at −0.35 percent for a longer time

Notes: This table describes the six key monetary policy announcements made by the Riksbank in 2015.

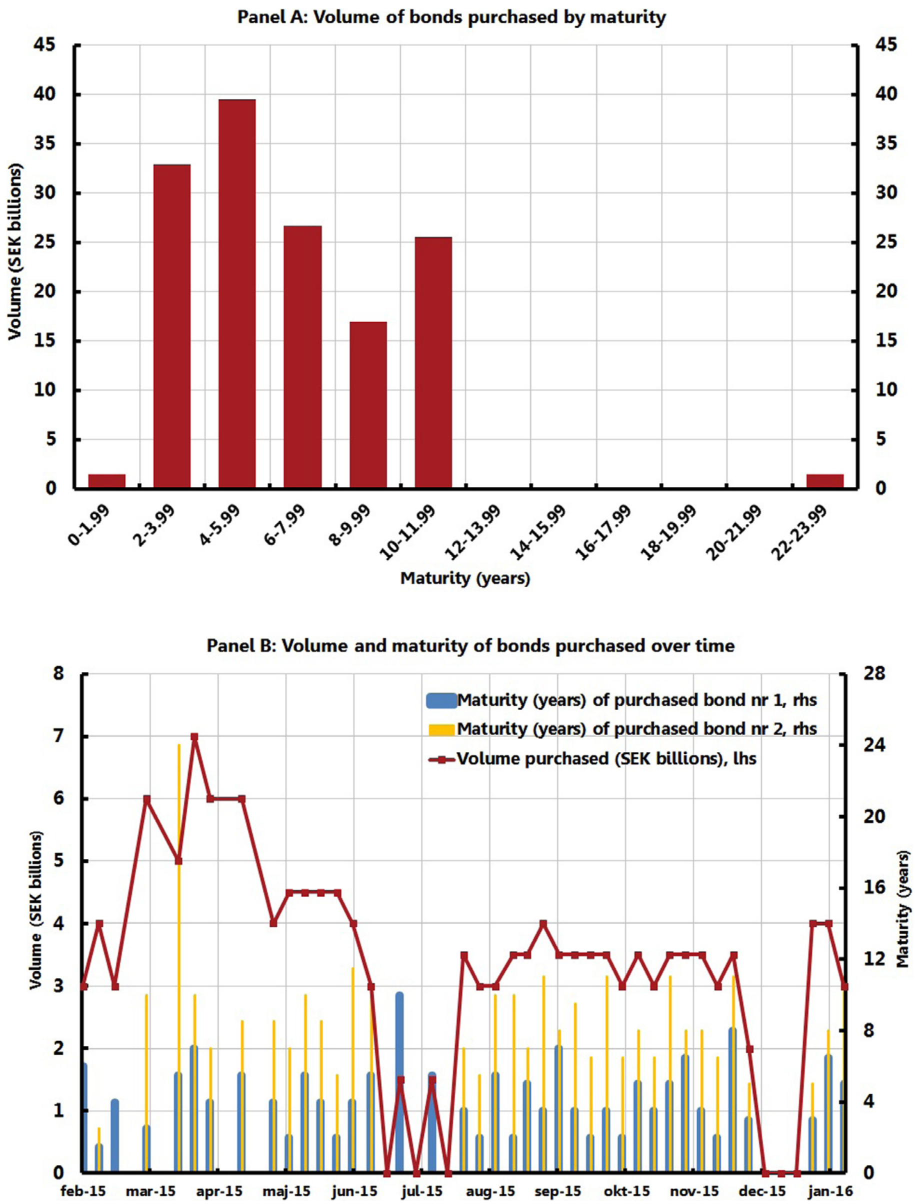

Fig. 1. Volume and maturity of government bond purchases. *Notes:* Panel A shows the distribution of bond purchases by maturity. Panel B shows the volume (in SEK billions) and maturity of the bonds purchased over time.

for the study, which is in line with the literature (see Gagnon et al., 2011; Christensen and Rudebusch, 2012; Bauer and Rudebusch, 2014). The bond yields analyzed are zero-coupon yields constructed using a smooth discount function based on the Svensson (1994) parameterization and provided by the Riksbank staff.[5] In addition, I look at STIBOR (Stockholm Interbank Offered Rate) interest rates at different maturities, which is a reference rate that shows the average interest rate at which a number of active banks on the Swedish money market are willing to lend to one another, without collateral.

Table 2 shows one-day responses of Swedish government bond yields and STIBOR interest rates around the six Riksbank monetary policy announcements described in Table 1. As noted, there is a negative interest rate response around most announcements, with interest rates declining more strongly on February 12, March 18 and July 2, when changes in the repo rate and purchases of government bonds were both announced. Moreover, long-term bond yields declined more strongly than short-term bond yields on net, with differences being particularly larger following the announcements of September 3 and October 28, when the Riksbank decided to keep the repo rate unchanged. Interestingly, on these particular dates, market participants were surprised by the decision of not cutting the repo rate (see Fig. 2), which helped to increase short-maturity bond yields as well as STIBOR interest rates. Following government bond yields, yield differentials against Germany also declined after most policy announcements, with long-term yield differentials declining more than their short-term counterparts. Another important reason for the decision to purchase government bonds was to avoid a large and fast appreciation of the Swedish krona. As can be seen, there is a positive net Swedish krona response around announcements with large depreciations happening on February 12, March 18 and July 2, when changes in the repo rate and purchases of government bonds were both announced.

The transmission of negative interest rate policy to other interest rates in the economy has been mostly unaffected. Although banks have been somewhat reluctant to lower their deposit and lending rates to companies and households (see Fig. 3 - Panel A), the transmission to market interest rates has functioned as if the repo rate was positive, with STIBOR and government bond rates following the decline in the repo rate, and reacting normally to interest rate cuts (see Fig. 3 - Panel B). One interesting remark, however, is that the spreads between STIBOR and risk-free rates - the repo rate or the three-month government bond yield - have decreased considerably since February 2015, which can be explained by the higher liquidity in the interbank market resulted from the Riksbank's bond purchase policy.

Another evidence suggesting that market rates have reacted normally to repo rate cuts to negative levels can be obtained by testing for the presence of structural breaks in the relationship between changes in the repo rate and market rates. More specifically, we can estimate event study regressions as in Kuttner (2001) and Gürkaynak et al. (2005) and use structural break tests to verify whether coefficient estimates have remained stable after the repo rate turned negative. The regression specification to be estimated is the following,

$$\Delta R_t^n = \beta_0^n + \beta_1^n \Delta r_t^e + \beta_2^n \Delta r_t^u + \beta_3^n \Delta rpf_t^u + \varepsilon_t^n \tag{1}$$

where ΔR_t^n is the change in an n-maturity interest rate observed in a day of monetary policy announcement, Δr_t^e and Δr_t^u are the expected and unexpected changes in the repo rate and Δrpf_t^u is a repo path factor constructed as the path factor Z_2 of Gürkaynak et al. (2005).[6] Results shown in Table 3 indicate the existence of no structural breaks in government bond and STIBOR interest rate regressions. Neither the fluctuation tests nor the F-tests, which assign the day in which the Riksbank announced a cut in the repo rate to -0.10 percent as the break date, indicate the existence of parameter instability. This suggests that the transmission of interest rate policy to market rates has been mostly unaffected.

Interestingly, market participants have also expected the repo rate to go continuosuly negative, which can be seen from repo rate forecast distributions obtained from surveys. Fig. 4 shows probability distributions of the mean, minimum and maximum repo rate expectations published on October 14, 2015 and on February 17, 2016, when the repo rate was at -0.35 and -0.5 percent, respectively.[7] Notice that, regardless of the forecast horizon, there is substantial probability mass below repo rate levels of -0.5, -0.6 or even -0.8 percent. This is more evident for the minimum distribution, but is also noticeable for the mean and maximum forecast distributions. Interestingly, the distributions of the minimum are always way to the left compared to those of the mean and maximum, which suggests that repo rate expectations have not been particularly constrained.

3. Empirical analysis

In this section, I introduce the class of Gaussian term structure models that I use for decomposing bond yields into a short-rate expectations component and an associated term premium component, and proceed to find a preferred specification. I end the section by introducing the event study regression approach to disentangle the effects of conventional and

[5] The Svensson (1994) yield curve model assumes the following functional form, $y_t^n = \beta_{0,t} + \beta_{1,t}\left(\frac{1-e^{-\lambda_{1,t}n}}{\lambda_{1,t}n}\right) + \beta_{2,t}\left(\frac{1-e^{-\lambda_{1,t}n}}{\lambda_{1,t}n} - e^{-\lambda_{1,t}n}\right) + \beta_{3,t}\left(\frac{1-e^{-\lambda_{2,t}n}}{\lambda_{2,t}\tau} - e^{-\lambda_{2,t}n}\right)$. The data used for estimation are the benchmark government bonds with maturities from two to ten years and T-Bills with maturities of three, six, nine, and twelve months, in addition to the repo rate.

[6] Δr_t^e and Δr_t^u are constructed using the one-month STINA (Stockholm Tomorrow Next Interbank Average) contract rates and a window of fifteen minutes before and two hours and forty-five minutes after each policy announcement. Δrpf_t^u is constructed as the path factor Z_2 of Gürkaynak et al. (2005) using Δr_t^u and FRA (Forward Rate Agreements) contract rates with maturities of one, two, four and eight quarters. The repo path factor can be interpreted as all aspects of monetary policy announcements that move the path of future repo rates without changing the current repo rate. More details on the construction of $\Delta r_t^e, \Delta r_t^u$ and Δrpf_t^u are provided in the Appendix.

[7] These are provided by TNS Sifo Prospera. Survey respondents are money market participants. TNS Sifo Prospera has been used by the Riksbank as the main source of survey expectations for several Swedish economic variables including inflation, GDP growth, repo rate, among others, since 1997.

Table 2
One-day responses of Swedish government bond yields and exchange rates.

Maturities	Feb 12, 2015	Mar 18, 2015	Apr 29, 2015	Jul 2, 2015	Sep 3, 2015	Oct 28, 2015	Net chg
6-month gov bond	−10.5	−15.1	4.0	−8.4	1.0	0.6	−28.4
1-year gov bond	−9.6	−12.8	4.9	−9.3	2.6	0.0	−24.2
2-year gov bond	−12.3	−10.4	5.5	−11.4	2.7	−2.4	−28.3
5-year gov bond	−15.6	−11.8	6.7	−13.0	−2.2	−7.5	−43.4
7-year gov bond	−13.6	−13.2	6.9	−11.1	−3.3	−8.2	−42.5
10-year gov bond	−11.0	−14.7	6.9	−8.8	−3.6	−8.1	−39.3
1-week STIBOR	−4.0	−9.0	0.0	−6.0	1.0	1.0	−16.0
3-month STIBOR	−5.0	−13.0	2.0	−6.0	4.0	2.0	−16.0
6-month STIBOR	−8.0	−11.0	2.0	−6.0	3.0	1.0	−19.0
2-year Sweden-Germany	−12.0	−9.4	3.5	−10.2	3.6	−1.2	−25.7
5-year Sweden-Germany	−15.6	−9.8	2.7	−15.1	−1.2	−4.5	−43.5
10-year Sweden-Germany	−11.1	−14.8	0.9	−15.9	−4.6	−3.2	−48.7
Krona index (kix) (%)	0.77	0.26	−0.61	0.85	−0.75	−0.25	0.27
SEK per EUR (%)	0.96	0.28	−0.40	0.84	−0.83	−0.10	0.75
SEK per USD (%)	0.72	0.21	−1.30	1.33	−0.61	0.02	0.37

Notes: This table shows the one-day responses of Swedish government bond yields, STIBOR rates, government bond yield spreads against Germany, krona index, SEK per EUR and SEK per USD, around the six key monetary policy announcements made by the Riksbank in 2015. Interest rate changes are measured in basis points.

unconventional monetary policy announcements. Finally, in Section 4, I provide the quantitative results and analyze the transmission channels of government bond purchases to interest rates.

3.1. Dynamic term structure models

Assessing the effects of government bond purchases on short-rate expectations and term premia components requires a model that is able to decompose bond yields. In this paper, I follow the literature since Ang and Piazzesi (2003) and use discrete-time Gaussian DATSMs to model zero-coupon bond yields as functions of pricing factors. More specifically, I assume that the $p \times 1$ vector of pricing factors X_t follows a VAR(1) process under the objective probability measure $\mathbb{P}$,

$$X_{t+1} = \mu + \Phi X_t + \Sigma\epsilon_{t+1} \tag{2}$$

where $\epsilon_t \sim iid\,N(0, I_p)$ and Σ is an $p \times p$ lower triangular matrix. The stochastic discount factor (SDF) that prices all assets under the absence of arbitrage is assumed to be conditionally lognormal

$$M_{t+1} = exp\left(-r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\epsilon_{t+1}\right) \tag{3}$$

where $\lambda_t = \lambda_0 + \lambda_1 X_t$ is a $p \times 1$ vector of risk prices. I allow the short rate to vary freely, without imposing any restrictions or asymmetries in the conditional distributions of short-rate expectations. The one-month interest rate is then affine in the pricing factors, $r_t = \delta_0 + \delta_1' X_t$. Under the risk-neutral measure $\mathbb{Q}$ the vector of pricing factors follows the dynamics,

$$X_{t+1} = \mu^{\mathbb{Q}} + \Phi^{\mathbb{Q}} X_t + \Sigma\epsilon_{t+1} \tag{4}$$

where $\mu^{\mathbb{Q}} = \mu - \Sigma\lambda_0$ and $\Phi^{\mathbb{Q}} = \Phi - \Sigma\lambda_1$.

Under no-arbitrage bond prices are then exponential affine functions of the state variables, $P_t^n = exp(A_n + B_n' X_t)$, where A_n is a scalar and B_n is an $p \times 1$ vector that satisfy the recursions

$$\begin{aligned} A_{n+1} &= -\delta_0 + A_n + \mu^{\mathbb{Q}\prime} B_n + \frac{1}{2} B_n' \Sigma\Sigma' B_n \\ B_{n+1} &= \Phi^{\mathbb{Q}\prime} B_n - \delta_1 \end{aligned} \tag{5}$$

which start from $A_1 = -\delta_0$ and $B_1 = -\delta_1$. Model implied yields are computed as $y_t^n = -n^{-1} log\, P_t^n = -n^{-1}(A_n + B_n' X_t)$.

It is interesting to note that the functions A_n and B_n are computed under the risk-neutral measure $\mathbb{Q}$ and not under the objective probability measure $\mathbb{P}$. The difference is determined by the risk premium demanded by investors to invest in an n-year bond and that is embodied in X_t. Following this argument, the term premium is then defined as the return difference between buying and holding an n-year bond until maturity and rolling over the one-month interest rate,

$$TP_t^n = y_t^n - \frac{1}{n}\sum_{i=0}^{n-1} E_t^{\mathbb{P}}(r_{t+i}) \tag{6}$$

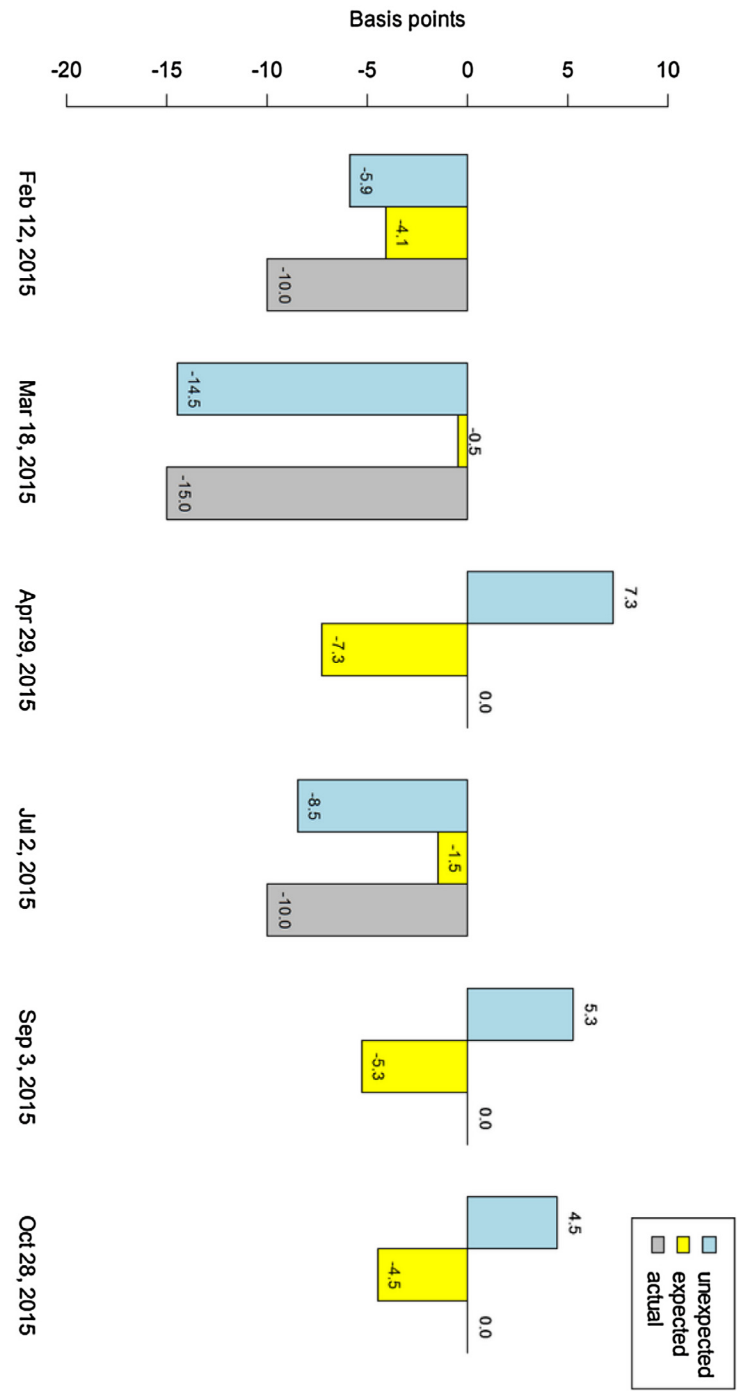

Fig. 2. Expected and unexpected changes in the repo rate. *Notes:* This figure shows the decomposition of announced repo rate changes into expected and unexpected changes. Unexpected changes in the repo rate are constructed using the 1-month STINA (Stockholm Interbank Offered Rate) rates with a window of fifteen minutes before and two hours and forty-five minutes after each monetary policy announcement.

The specification described above is quite general and is suitable for a large number of models in the class of discrete-time Gaussian DATSMs. Here, I focus on two models that have been popular in recent studies. The first model I consider is provided by Joslin et al. (2011) (JSZ henceforth). Its main distinctive features are the inherent separation between the parameters of the $\mathbb{P}$ and $\mathbb{Q}$ distributions and the use of observable yield portfolios as pricing factors, $X = Wy$, with bonds being priced without error. As noted by JSZ, this feature of the model facilitates enormously its estimation with a near-instantaneous convergence to the global optimum of the likelihood function. In addition, I follow Bauer et al. (2012)

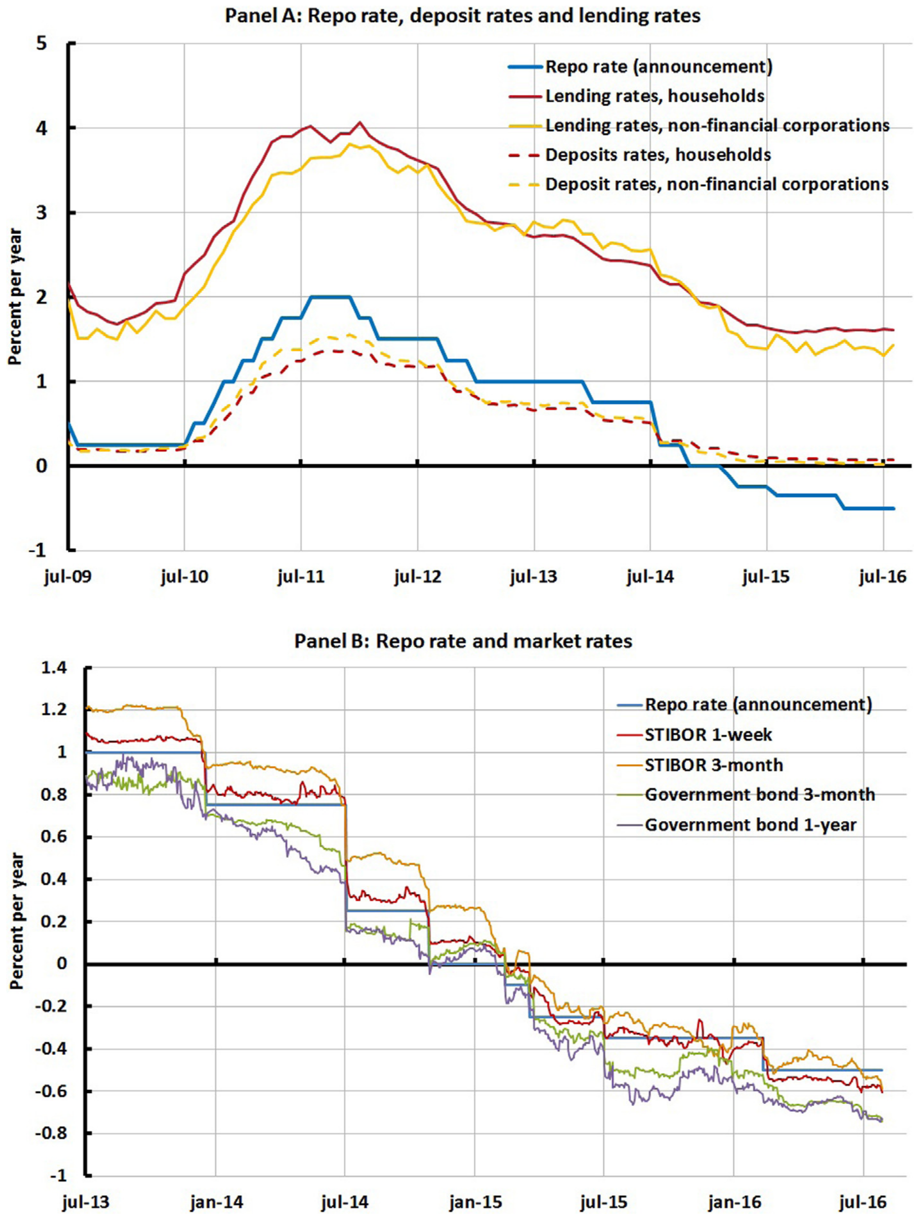

Fig. 3. Repo rate, market rates, lending and deposit rates. *Notes:* Panel A shows the repo rate and the bank lending and deposit interest rates to households (mortgage rates) and non-financial corporations. Panel B shows the repo rate, STIBOR (Stockholm Interbank Offered Rate) and government bond interest rates.

(BRW henceforth) and consider a version of the JSZ model in which parameters of Eq. (2) are corrected for small-sample bias.[8] The idea behind this approach is to correct the downward bias in Eq. (2) that tends to underestimate the interest rate persistence so that short-rate expectations do not converge to its sample mean as quickly as the non-bias-corrected model, delivering estimates of the term premium and the short-rate expectations components that are more consistent with data and theory. Several papers have compared interest rate decompositions obtained from bias-corrected and non-bias-corrected models and conluded that results may differ considerably.[9] This is undesirable since conclusions regarding the evaluation of the interest rate transmission mechanisms of bond purchases may differ depending on the model considered.[10] The approach

[8] In this paper, we use the bootstrap method of small-sample bias correction. Results are essentially the same as correcting the bias through indirect inference, but the estimation is faster.

[9] See Bauer et al. (2012), Bauer and Rudebusch (2014), Bauer et al. (2014) and Wright (2014) for a debate around this topic.

[10] See Bauer and Rudebusch (2014).

Table 3
Structural break tests.

	Gov. bond yield			STIBOR		
	3-month	6-month	1-year	3-month	6-month	1-year
Fluctuation tests						
OLS-CUSUM	1.025	1.346	1.338	0.789	0.791	–
Rec-CUSUM	0.625	0.453	0.693	0.379	0.452	–
OLS-MOSUM	1.166	1.264	1.342	1.262	1.312	–
Rec-MOSUM	1.227	1.868	1.733	0.940	1.026	–
F tests						
supF (Feb 2015)	0.943	0.711	1.207	0.549	0.671	–
aveF (Feb 2015)	0.657	0.377	0.500	0.485	0.593	–
expF (Feb 2015)	0.333	0.194	0.275	0.243	0.297	–
Nyblom-Hansen	0.874	1.248	1.164	1.073	1.077	–

Notes: This table shows structural break test statistics for the regression $\Delta R_t^n = \beta_0^n + \beta_1^n \Delta r_t^e + \beta_2^n \Delta r_t^u + \beta_3^n \Delta rpf_t^u + \varepsilon_t^n$, where ΔR_t^n is the change in an n-maturity interest rate, Δr_t^e and Δr_t^u are expected and unexpected changes in the repo rate and Δrpf_t^u is the unexpected change in the repo path factor. Regressions are estimated with data observed on days of monetary policy announcements (86 observations), over a sample that ranges from February 07, 2003 to July 6, 2016. The following test statistics are reported: Ploberger and KrÃ€mer (1992, "OLS-CUSUM" and "Rec-CUSUM"), Chu et al. (1995, "OLS-MOSUM" and "Rec-MOSUM"), Andrews (1993, "SupF'), Andrews and Ploberger (1994, "aveF" and "ExpF'), Nyblom (1989) and Hansen (1992, "Nyblom-Hansen"). The tests are conducted at the 5% significance level.

I followed was then to combine the estimates generated from the two models in such a way that short-rate forecasting errors are minimized (Baumeister and Kilian, 2014). Although simple, this approach is very effective as it eliminates the need to rely on one single model or on two or more models that may be subject to misspecifications. Moreover, several papers have favored the use of forecast combinations to deal with problems such as structural breaks, model misspecifications as well as unknown forecast loss functions (see Timmermann, 2006 for a survey). In this paper, I combine two versions of each model, one with three pricing factors and one with four pricing factors, i.e. $p = 3$ and $p = 4$, in a total of four models.

The models are estimated using daily zero-coupon bond yields for fourteen maturities - one, three, six and nine-month, and one to ten-year - for the period ranging from December 1, 1998, to July 27, 2016. As can be seen from Fig. 5, this sample is marked by three monetary tightening and easing cycles, with nominal yields showing a declining pattern over the whole sample period, following the international trend (see Wright, 2011). For this sample period, the optimal model combination that minimized the quadratic forecast loss function for horizons equal to two, five and ten years was the one that attributed a weight of 0.19 to $JSZ_{p=3}$, 0.28 to $JSZ_{p=4}$, 0.22 to $BRW_{p=3}$ and 0.31 to $BRW_{p=4}$. I use this model combination to decompose yields.

Fig. 6 shows the decomposition of the 5-year yield using the optimal model combination. As can be seen, term premia and short-rate expectations both follow the decline in yields, with term premia declining more strongly. The estimated term premium on the five-year government bond reached its lowest level of around -1 percent in July 2016. There are at least four possible explanations for why long-term term premia have been compressed in Sweden. The first is the low inflation environment in Sweden, Europe and the United States observed since late 2013, which has led bondholders to be willing to accept less compensation for bearing inflation risk.[11] Another important factor is the low uncertainty about the near-term outlook for policy rates in Sweden and major economies. The low inflation environment increases the likelihood that policy rates around the world will remain low for some time, lowering uncertainty about future policy rates and helping to compress term premia in long-term yields. It is likely that the zero-lower bound in the US also contributed to lowering uncertainty about future US policy rates, as investors were quite sure that the Fed would keep the fed funds rate at zero for some time. Another possible explanation for the observed decline in Swedish government bond term premia is the bond purchases in Europe, Japan and elsewhere. It is likely that bond purchases in foreign economies have possibly caused a "spillover" effect into the demand for Swedish bonds, pushing down their term premia. And lastly, it is important to note that government bonds typically work as a hedge against different types of risk that may hurt returns on other riskier assets, and may be especially demanded by certain institutional investors due to liquidity and regulatory reasons. Investors may then be willing to accept low or even negative compensation for holding long-term government bonds, which helps to explain why term premia have been negative more recently.

3.2. Event study methodology

Following other papers in this literature, I assess the interest rate effects of government bond purchases by using an event study methodolgy with a one-day window. Although a one-day event window may be too short to capture all of the announcements' effects on interest rates, it lowers considerably the likelihood that other events affect interest rates within the window, which would cloud the true effects of bond purchase announcements.

One important aspect to consider, however, is that the Riksbank has announced interest rate policy and government bond purchases at the same time, which means that the observed responses of yields and components on announcement dates

[11] Historically, the most important risk for long-term bondholders has been the risk of unexpected inflation rises, as they deteriorate the returns associated with a nominal bond.

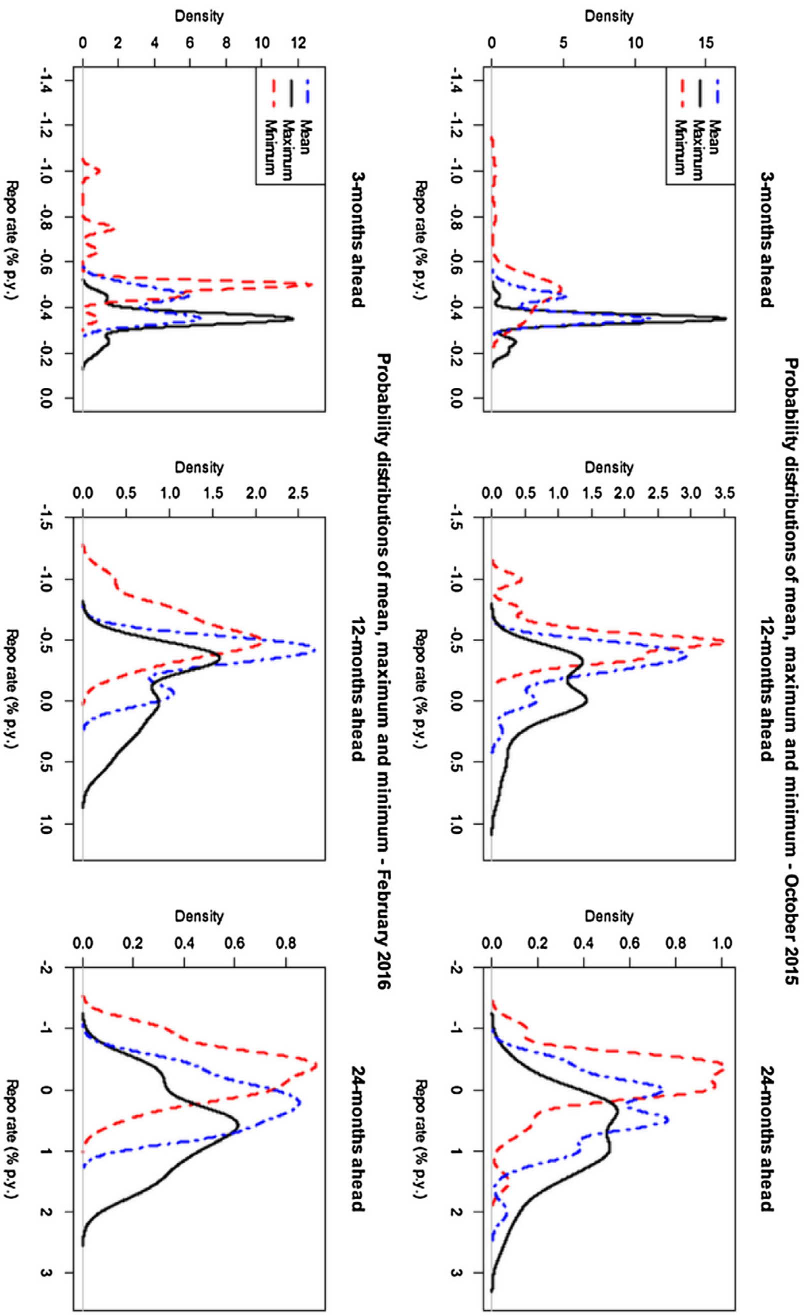

Fig. 4. Repo rate forecast distributions from surveys. *Notes:* This figure shows repo rate forecast distributions obtained from surveys conducted by TNS Sifo Prospera. Survey respondents are money market participants, who report their mean, minimum and maximum forecasts for the repo rate 3-months, 12-months and 24-months ahead. The survey publication dates are October 14, 2015 and February 17, 2016.

cannot be interpreted as responses coming from bond purchase announcements only. This means that separating the effects from each policy is necessary in order to study the interest rate effects of bond purchases only.[12] In this paper, this is done with the help of event study regressions. More specifically, the approach I follow is to project changes in yields, short-rate expectations and term premia onto expected and unexpected changes in the repo rate, a repo rate path factor and a foreign yield variable using data for the period in which only conventional monetary policy was used, and then use coefficient estimates to

[12] As noted from Table 2, yields and exchange rates reacted more strongly to the February, March and July policy announcements, which involved changes in the repo rate as well as purchases of government bonds. This also motivates my analyses.

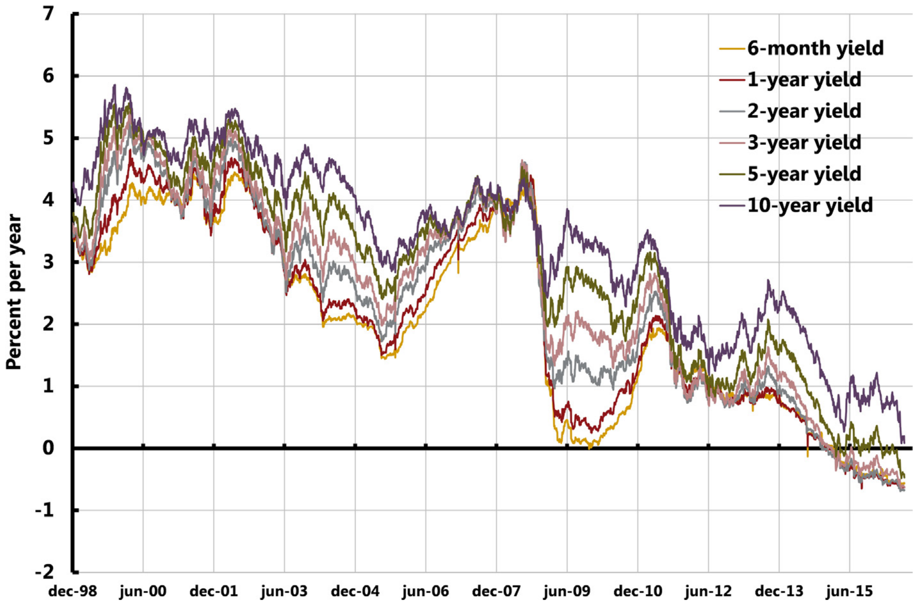

Fig. 5. Swedish government bond yields. *Notes:* This figure shows the daily Swedish government zero-coupon bond yields covering the period from December 1, 1998, to July 27, 2016. The yields shown have maturities in 6-month, 1-year, 2-years, 3-years, 5-years and 10-years.

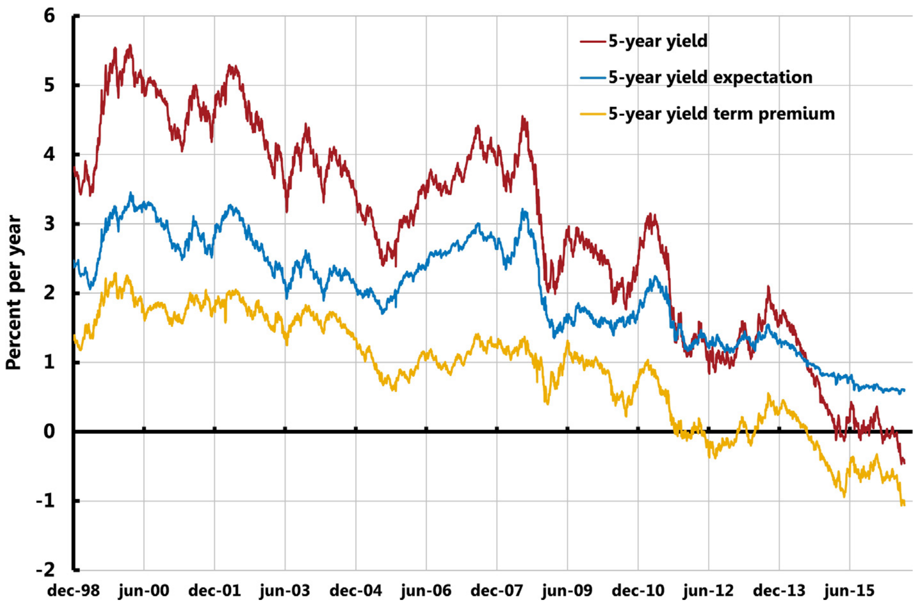

Fig. 6. A decomposition of the five-year Swedish government bond yield. *Notes:* This figure shows the decomposition of the five-year daily Swedish government zero-coupon bond yield into short-rate expectations and term premium components for the period from December 1, 1998, to July 27, 2016. The decomposition is a weighted average of estimates from four models: Joslin et al. (2011) with three and four factors and Bauer et al. (2012) with three and four factors and bootstrap bias correction. The weights attributed to each model are: 0.19 to $JSZ_{p=3}$, 0.28 to $JSZ_{p=4}$, 0.22 to $BRW_{p=3}$ and 0.31 to $BRW_{p=4}$. These were obtained by minimizing a quadratic loss function of short-rate forecasts for horizons equal to 2, 5 and 10 years.

predict the effects of conventional monetary policy announcements in days in which the two policies were announced. The prediction errors are used as a measure that approximates the pure responses of yields and components to bond purchase announcements. The estimated event study regressions are a slightly modified version of Eq. (1),

$$\Delta R_t^n = \beta_0^n + \beta_1^n \Delta r_t^e + \beta_2^n \Delta r_t^u + \beta_3^n \Delta rpf_t^u + \beta_4^n \Delta 5y\,kix\,yield_t + \varepsilon_t^n \tag{7}$$

where ΔR_t^n is now the change in an n-maturity yield, an n-maturity short-rate expectations component or an n-maturity term premium observed in a day of conventional policy announcement, and $\Delta 5y\,kix\,yield_t$ is the change in the weighted average of foreign five-year yields.[13] $\Delta 5y\,kix\,yield_t$ is included in (7) in order to control for movements in international yields, which tend to correlate strongly with Swedish interest rates.

This approach is similar to Bernanke et al. (2004) who study the effects of central bank communication on asset prices. In Section 4, I show that this framework delivers very intuitive results and works as a good way of approximating the interest rate effects of bond purchases, and studying their transmission mechanisms. Furthermore, it allows for studying how target interest rate policy and bond purchases operate across yields, short-rate expectations and term premia of different maturities. The regression is estimated with data observed on days of conventional monetary policy announcements only, over a sample that ranges from February 07, 2003 to December 16, 2014, in a total of 76 observations. This is crucial for the framework to work since parameter estimates should reflect the effects of covariates Δr_t^e, Δr_t^u, Δrpf_t^u and $\Delta 5y\,kix\,yield_t$ on yields and components when the repo rate as well as comunication were the only instruments of monetary policy.

Table 4 shows the estimation results for regression (7). As commonly found in this literature, yields respond strongly to unexpected changes in the repo rate with coefficients on expected changes being small and mostly non-statistically significant. Moreover, reactions to repo rate surprises decline with maturities, with coefficients ranging from 0.661 to 0.162. Results imply that, on average and considering everything else constant, a surprise of 25 basis points tightening in the repo rate leads to a little more than 10 basis points increase in the two-year yield. Yields also react to the repo path factor, indicating that unexpected changes in the repo rate alone are not sufficient to describe the responses of asset prices to monetary policy announcements. Interestingly, the repo path factor has a larger impact on mid-maturity yields, with a 1 percentage point innovation to the factor causing responses of 18 and 23 basis points in one- and three-year yields, respectively. Reactions reach maximum value at the two-year maturity. Lastly, foreign yields move the long-end of the Swedish yield curve strongly with the ten-year yield moving, on average, 59 basis points for each 1 percentage move on the five-year kix yield. Table 4 also reveals how short-rate expectations and term premium components react to changes in the repo rate, the repo path factor and foreign yields. Notice that the reactions of yields to unexpected changes in the repo rate and the repo path factor are mainly a result of responses of short-rate expectations. Reactions of term premia are small and non-statistically significant in several maturities. Moreover, term premia do not react to changes in the repo path factor.

4. The responses of Swedish yields to bond purchase announcements

I analyze now the transmission channels of the Riksbank's bond purchase announcements to Swedish yields using the results from the event study regressions. Of course, there are issues that should be considered. Firstly, I have no reliable measures of what was expected prior to each bond purchase announcement, so I assume that the entire announcement was a complete surprise. In addition, the attempt to isolate the effects of bond purchase announcements using the regression framework may introduce estimation uncertainties. However, I believe that at the very least the results provide an approximation of the true effects of bond purchase announcements that help on the understanding of the transmission mechanisms of such actions.

The responses of yields around the Riksbank's monetary policy announcements are reported by Table 5. The decomposition of the responses into short-rate expectations and term premia are provided in Tables 6 and 7, respectively, with Figs. 7–9 showing the results in bar charts. As mentioned above, the responses to bond purchase announcements are approximated by the predicted residuals of regression (7), $\hat{\varepsilon}_t^n$, on announcement dates.

I start my analyses by looking at the February announcement. This is perhaps the most important announcement as it stated that the Riksbank would start buying government bonds, even though the amount of SEK 10 billion was considered small. Moreover, the repo rate was lowered to -0.10 percent, informing market participants that the Riksbank could set negative interest rates and make conventional monetary policy more expansionary. First, we note fairly big responses of yields resulted from the repo rate cut. On that particular day, the interest rate cut was largely unexpected by market participants (-5.9 basis points as seen in Fig. 2) with observed effects on short maturities being very much in line with that number. The announcement of bond purchases also lowered yields considerably, with the larger effects being observed on the three- to seven-year segment. Here, it is important to note that the effects from the bond purchase announcement blend with those coming from the fact that the Riksbank set a negative repo rate for the first time in history. My interpretation is that trespassing the zero lower bound worked as an additional tool of unconventional monetary policy on February 12, with repo rate expectations becoming particularly unconstrained after that date. The decomposition into short-rate expectations and term premia reveals that short-rate expectations were the main drivers of the observed fall in yields, suggesting that the signaling channel played an important role in the transmission of the February decision. Responses of term premia were small but noticeable in the five- to ten-year segment of the yield curve.

[13] The kix ("krona index") variable was originally created as a geometric index for exchange rates, where the weights are based on total flows of processed goods and commodities for 32 countries. The weights are computed by the Riksbank staff and take into account exports and imports, as well as third-country effects. They are updated each year, and are based on data with a time lag of several years. In this paper, I borrowed the idea behind the original kix and built the five-year kix yield. This index is built as a weighted average of five-year yields of three foreign economies: Euro Area, US and UK; with weights equal to 0.775, 0.13 and 0.095, respectively.

Table 4
Separating conventional and unconventional monetary policy: regression results.

Maturity (n)	Constant	Δr^e_t	Δr^u_t	Δrpf^u_t	$\Delta 5y\,kix\,yield_t$	$\overline{R2}$
6-month yield	−0.972***	0.125***	0.660***	0.097***	−0.131	0.90
	(0.347)	(0.024)	(0.059)	(0.029)	(0.096)	
1-year yield	−1.255***	−0.023	0.520***	0.183***	−0.137	0.75
	(0.458)	(0.027)	(0.066)	(0.027)	(0.120)	
2-year yield	−0.900**	−0.027	0.423***	0.240***	−0.029	0.79
	(0.372)	(0.022)	(0.060)	(0.028)	(0.109)	
3-year yield	−0.504	0.036	0.387***	0.234***	0.109	0.82
	(0.335)	(0.024)	(0.053)	(0.033)	(0.131)	
5-year yield	−0.353	0.073**	0.316***	0.189***	0.317**	0.78
	(0.372)	(0.032)	(0.056)	(0.041)	(0.155)	
7-year yield	−0.567	0.041	0.245***	0.151***	0.437***	0.69
	(0.403)	(0.035)	(0.071)	(0.039)	(0.140)	
10-year yield	−0.893*	−0.016	0.170*	0.116***	0.532***	0.51
	(0.499)	(0.041)	(0.102)	(0.036)	(0.132)	
6-month expectation	−0.609*	0.183***	0.703***	0.106***	−0.214**	0.94
	(0.320)	(0.026)	(0.048)	(0.032)	(0.097)	
1-year expectation	−0.500	0.113***	0.612***	0.182***	−0.274***	0.89
	(0.360)	(0.019)	(0.043)	(0.027)	(0.099)	
2-year expectation	−0.192	0.061**	0.453***	0.232***	−0.259*	0.76
	(0.415)	(0.023)	(0.077)	(0.029)	(0.131)	
3-year expectation	−0.055	0.038*	0.328***	0.213***	−0.179	0.70
	(0.375)	(0.022)	(0.076)	(0.027)	(0.127)	
5-year expectation	−0.064	0.023	0.204***	0.146***	−0.048	0.72
	(0.235)	(0.014)	(0.046)	(0.019)	(0.088)	
7-year expectation	−0.112	0.019*	0.165***	0.112***	−0.003	0.77
	(0.168)	(0.011)	(0.030)	(0.015)	(0.066)	
10-year expectation	−0.132	0.015	0.139***	0.093***	0.031	0.79
	(0.136)	(0.009)	(0.023)	(0.013)	(0.054)	
6-month term premium	−0.363*	−0.058***	−0.043	−0.009	0.084	0.54
	(0.193)	(0.017)	(0.041)	(0.010)	(0.058)	
1-year term premium	−0.754*	−0.136***	−0.091	−0.002	0.137	0.62
	(0.390)	(0.035)	(0.080)	(0.022)	(0.121)	
2-year term premium	−0.708*	−0.088***	−0.030	0.008	0.231**	0.42
	(0.359)	(0.030)	(0.077)	(0.015)	(0.094)	
3-year term premium	−0.450	−0.002	0.059	0.021	0.287***	0.32
	(0.270)	(0.022)	(0.059)	(0.018)	(0.069)	
5-year term premium	−0.289	−0.050*	0.112*	0.043	0.364***	0.57
	(0.301)	(0.026)	(0.058)	(0.030)	(0.101)	
7-year term premium	−0.455	−0.022	0.080	0.039	0.434***	0.41
	(0.365)	(0.030)	(0.074)	(0.030)	(0.104)	
10-year term premium	−0.761	−0.031	0.031	0.023	0.501***	0.24
	(0.477)	(0.038)	(0.104)	(0.028)	(0.116)	

Notes: This table shows estimation results for the regression $\Delta R^n_t = \beta^n_0 + \beta^n_1 \Delta r^e_t + \beta^n_2 \Delta r^u_t + \beta^n_3 \Delta rpf^u_t + \beta^n_4 \Delta 5y\,kix\,yield_t + \varepsilon^n_t$, where ΔR^n_t is the change in an n-maturity yield, yield expectation or term premium, $\Delta 5y\,kix\,yield_t$ is the change in the weighted average of foreign five-year yields, Δr^e_t and Δr^u_t are the expected and unexpected changes in the repo rate and Δrpf^u_t is the unexpected change in the repo path factor. The regressions are estimated with data observed on days of conventional monetary policy announcements (76 observations), over a sample that ranges from February 07, 2003 to December 16, 2014. MacKinnon and White (1985) heteroskedastic consistent standard errors are reported in parenthesis.

We can also exploit the regression framework and verify whether the estimated effects of bond purchases are statistically significant. This can be done by comparing the predicted regression residuals - or bond purchase effects - to the standard deviation of the fitted regression residuals.[14] Results suggest that the observed responses of yields on February 12 were statistically significant on the two- to seven-year segment, with changes in short-rate expectations being particularly significant from the two-year maturity. Term premia changes do not seem to be significant, except at the five-year maturity, which confirms the predominance of the signaling channel in the transmission of the February decision.

In March 18, between two regular monetary policy meetings, the Executive Board of the Riksbank decided to cut the repo rate by a further 15 basis points, to increase purchases of government bonds by SEK 30 billion and also to purchase bonds with maturities longer than five years. At that time, market participants speculated that the rapid strengthening of the Swedish krona observed at the beginning of the month could lead the Riksbank to act before the ordinary monetary policy meet-

[14] Bond purchase effects that are more than 1.64, 1.96 and 2.58 standard deviations large can then be considered as being statistically significant at the ten, five and one percent levels. The estimated standard deviations are the following. Bond yields: 2.79 (six-month), 3.48 (one-year), 3.15 (two-year), 3.03 (three-year), 3.24 (five-year), 3.27 (seven-year) and 3.98 (ten-year); short-rate expectations: 2.61 (six-month), 2.92 (one-year), 3.65 (two-year), 3.40 (three-year), 2.17 (five-year), 1.56 (seven-year) and 1.25 (ten-year); term premium: 1.46 (six-month), 2.92 (one-year), 2.71 (two-year), 2.17 (three-year), 2.53 (five-year), 3.00 (seven-year) and 3.80 (ten-year).

Table 5
Effects of bond purchase announcements on yields.

Event	Effect	6-month	1-year	2-year	3-year	5-year	7-year	10-year
Feb 12	Fitted yield	−8.3	−9.6	−13.2	−15.3	−15.2	−13.5	−11.2
	Repo rate, repo path factor and kix yield	−6.5	−6.5	−6.6	−6.5	−5.9	−5.3	−4.7
	Bond purchase	1.9	−3.1	−6.6**	−8.7***	−9.3***	−8.2**	−6.5
Mar 18	Fitted yield	−12.0	−10.8	−10.1	−10.5	−12.1	−13.4	−14.5
	Repo rate, repo path factor and kix yield	−9.5	−7.5	−6.4	−6.5	−6.9	−7.0	−6.9
	Bond purchase	−2.5	−3.3	−3.7	−4.0	−5.2	−6.4*	−7.5*
Apr 29	Fitted yield	4.1	5.4	6.0	6.1	6.4	6.8	7.3
	Repo rate, repo path factor and kix yield	2.7	3.1	4.0	4.7	5.3	5.4	5.4
	Bond purchase	1.4	2.3	2.0	1.4	1.1	1.4	1.9
Jul 02	Fitted yield	−8.3	−9.1	−11.8	−13.3	−12.9	−11.2	−9.0
	Repo rate, repo path factor and kix yield	−8.0	−8.0	−7.7	−7.2	−6.0	−5.2	−4.4
	Bond purchase	−0.4	−1.1	−4.1	−6.2**	−6.9**	−5.9*	−4.5
Sep 03	Fitted yield	1.5	2.4	1.9	0.6	−1.7	−3.0	−4.1
	Repo rate, repo path factor and kix yield	2.5	2.4	1.9	1.2	−0.2	−1.2	−2.1
	Bond purchase	−1.0	0.0	0.0	−0.6	−1.5	−1.8	−2.1
Oct 28	Fitted yield	0.7	0.0	−2.7	−5.0	−7.3	−8.1	−8.4
	Repo rate, repo path factor and kix yield	0.7	0.0	−0.3	−0.1	0.1	0.0	−0.1
	Bond purchase	0.0	0.0	−2.5	−4.9*	−7.4**	−8.1**	−8.3**
Net chg	Fitted yield	−22.3	−21.7	−29.9	−37.4	−42.9	−42.3	−39.9
	Repo rate, repo path factor and kix yield	−18.0	−16.5	−15.1	−14.5	−13.8	−13.3	−12.9
	Bond purchase	−4.3	−5.2	−14.8	−23.0	−29.1	−29.0	−27.0

Notes: This table shows the effects of bond purchase announcements on fitted yields. "Fitted yield" is the observed change in the fitted yield on a day of monetary policy announcement. "Repo rate, repo path factor and kix yield" is the effect of changes in the repo rate + repo path factor + five-year kix yield, which is approximated by $\widehat{\beta}_0^n + \widehat{\beta}_1^n \Delta r_t^e + \widehat{\beta}_2^n \Delta r_t^u + \widehat{\beta}_3^n \Delta rpf_t^u + \widehat{\beta}_4^n \Delta 5y\, kix\, yield_t$. "Bond purchase" is the effect of a bond purchase announcement, which is approximated by $\widehat{\varepsilon}_t^n$. All interest rate changes are measured in basis points.
* Significance of bond purchase announcement at ten percent level.
** Significance of bond purchase announcement at five percent level.
*** Significance of bond purchase announcement at one percent level.

Table 6
Effects of bond purchase announcements on short-rate expectations.

Event	Effect	6-month	1-year	2-year	3-year	5-year	7-year	10-year
Feb 12	Short-rate expectations	−9.3	−11.1	−12.4	−11.4	−8.4	−6.8	−5.9
	Repo rate, repo path factor and kix yield	−6.5	−6.5	−5.8	−4.8	−3.3	−2.8	−2.4
	Bond purchase	−2.8	−4.6	−6.6*	−6.6*	−5.0**	−4.1**	−3.5***
Mar 18	Short-rate expectations	−10.3	−7.8	−4.8	−3.5	−3.4	−3.5	−3.5
	Repo rate, repo path factor and kix yield	−9.2	−7.2	−4.6	−3.2	−2.5	−2.4	−2.2
	Bond purchase	−1.1	−0.6	−0.2	−0.3	−0.9	−1.2	−1.3
Apr 29	Short-rate expectations	3.2	3.4	3.2	2.8	2.4	2.3	2.1
	Repo rate, repo path factor and kix yield	2.4	2.5	2.5	2.4	2.0	1.8	1.7
	Bond purchase	0.8	0.9	0.7	0.5	0.4	0.4	0.4
Jul 02	Short-rate expectations	−9.3	−10.8	−11.5	−10.3	−7.4	−6.0	−5.1
	Repo rate, repo path factor and kix yield	−8.1	−8.1	−7.0	−5.6	−3.8	−3.1	−2.6
	Bond purchase	−1.2	−2.7	−4.5	−4.7	−3.6*	−2.9*	−2.5*
Sep 03	Short-rate expectations	2.3	3.6	4.0	3.2	1.5	0.8	0.4
	Repo rate, repo path factor and kix yield	3.2	3.5	3.3	2.5	1.3	0.8	0.5
	Bond purchase	−0.9	0.0	0.7	0.7	0.2	0.0	−0.1
Oct 28	Short-rate expectations	1.3	0.9	−0.2	−1.1	−1.7	−1.8	−1.9
	Repo rate, repo path factor and kix yield	0.9	0.4	0.0	−0.2	−0.1	−0.1	−0.1
	Bond purchase	0.4	0.5	−0.2	−0.9	−1.6	−1.7	−1.8
Net chg	Short-rate expectations	−22.1	−21.8	−21.8	−20.3	−16.9	−15.1	−13.9
	Repo rate, repo path factor and kix yield	−17.3	−15.4	−11.7	−8.9	−6.4	−5.7	−5.1
	Bond purchase	−4.7	−6.4	−10.1	−11.4	−10.5	−9.5	−8.8

Notes: This table shows the effects of bond purchase announcements on short-rate expectations. "Short-rate expectations" is the change in the short-rate expectations component of yields on a day of monetary policy announcement. "Repo rate, repo path factor and kix yield" is the effect of changes in the repo rate + repo path factor + five-year kix yield, which is approximated by $\widehat{\beta}_0^n + \widehat{\beta}_1^n \Delta r_t^e + \widehat{\beta}_2^n \Delta r_t^u + \widehat{\beta}_3^n \Delta rpf_t^u + \widehat{\beta}_4^n \Delta 5y\, kix\, yield_t$. "Bond purchase" is the effect of a bond purchase announcement, which is approximated by $\widehat{\varepsilon}_t^n$. All interest rate changes are measured in basis points.
* Significance of bond purchase announcement at ten percent level.
** Significance of bond purchase announcement at five percent level.
*** Significance of bond purchase announcement at one percent levels.

Table 7
Effects of bond purchase announcements on term premia.

Event	Effect	6-month	1-year	2-year	3-year	5-year	7-year	10-year
Feb 12	Term premium	0.9	1.5	−0.8	−3.9	−6.9	−6.7	−5.3
	Repo rate, repo path factor and kix yield	0.1	0.0	−0.8	−1.8	−2.6	−2.6	−2.3
	Bond purchase	0.9	1.5	0.0	−2.1	−4.3*	−4.1	−3.0
Mar 18	Term premium	−1.7	−3.0	−5.4	−7.0	−8.7	−9.8	−11.0
	Repo rate, repo path factor and kix yield	−0.3	−0.3	−1.9	−3.3	−4.5	−4.7	−4.7
	Bond purchase	−1.4	−2.6	−3.5	−3.7*	−4.3*	−5.2*	−6.2
Apr 29	Term premium	1.0	2.0	2.8	3.2	3.9	4.5	5.1
	Repo rate, repo path factor and kix yield	0.3	0.6	1.5	2.3	3.2	3.5	3.6
	Bond purchase	0.6	1.4	1.3	0.9	0.7	1.0	1.5
Jul 02	Term premium	1.0	1.6	−0.3	−3.0	−5.5	−5.2	−3.9
	Repo rate, repo path factor and kix yield	0.1	0.1	−0.7	−1.5	−2.3	−2.1	−1.8
	Bond purchase	0.9	1.6	0.4	−1.4	−3.2	−3.0	−2.1
Sep 03	Term premium	−0.8	−1.2	−2.1	−2.6	−3.2	−3.8	−4.5
	Repo rate, repo path factor and kix yield	−0.7	−1.1	−1.4	−1.3	−1.5	−2.0	−2.6
	Bond purchase	−0.2	0.1	−0.7	−1.2	−1.7	−1.8	−1.9
Oct 28	Term premium	−0.6	−1.0	−2.5	−3.9	−5.6	−6.3	−6.6
	Repo rate, repo path factor and kix yield	−0.1	−0.4	−0.2	0.1	0.2	0.1	0.0
	Bond purchase	−0.4	−0.6	−2.3	−4.0*	−5.8**	−6.4**	−6.5*
Net chg	Term premium	−0.2	0.1	−8.1	−17.2	−26.0	−27.2	−26.0
	Repo rate, repo path factor and kix yield	−0.6	−1.1	−3.4	−5.6	−7.4	−7.7	−7.8
	Bond purchase	0.4	1.3	−4.7	−11.6	−18.6	−19.6	−18.2

Notes: This table shows the effects of bond purchase announcements on term premia. "Term premium" is the change in the term premium component of yields on a day of monetary policy announcement. "Repo rate, repo path factor and kix yield" is the effect of changes in the repo rate + repo path factor + five-year kix yield, which is approximated by $\widehat{\beta}_0^n + \widehat{\beta}_1^n \Delta r_t^e + \widehat{\beta}_2^n \Delta r_t^u + \widehat{\beta}_3^n \Delta rpf_t^u + \widehat{\beta}_4^n \Delta 5y\,kix\,yield_t$. (***) show statistical significance of bond purchase announcement at one percent level. "Bond purchase" is the effect of a bond purchase announcement, which is approximated by $\widehat{\varepsilon}_t^n$. All interest rate changes are measured in basis points.
* Significance of bond purchase announcement at ten percent level.
** Significance of bond purchase announcement at five percent level.

ing of April, but data suggests that the repo rate cut was largely unexpected, with the surprise measure marking −14.5 basis points. Interest rates fell sharply after the announcement, with effects being particularly larger on the short and long-term segments of the yield curve. Fig. 7 indicates that the estimated changes in term premia explain most of the fall in longer yields. On that particular day foreign yields moved strongly ($\Delta 5y\,kix\,yield_t = -7.1$ bps), which helped to lower term premia in the three- to ten-year segment. Still, we observe a faily large impact of bond purchases on term premia with effects being statistically significant between the three- and the seven-year maturities.

In April, we observe a positive response of government bond yields. The repo rate surprise measure marks 7.3 basis points, indicating that the market was expecting an additional interest rate cut. New purchases of SEK 40–50 billion were announced, but market newsletters around that time suggest that the announced increment in purchases was largely expected. As can be seen, fitted yields increased by 5 to 7 basis points with the largests movements being observed on longer maturities. Table 6 and Fig. 8 indicate that a large part of the reactions observed in shorter yields are explained by the unexpected cut in the repo rate that affected the short-rate expectations component. Movements in long yields were largely driven by term premia, which moved mainly with the sharp increase in foreign yields ($\Delta 5y\,kix\,yield_t = 7.5$ bps).

On July 2, the Executive Board of the Riksbank announced a cut in the repo rate by 10 basis points and purchases of government bonds for a further SEK 45 billion until the end of 2015 (SEK 135 billion in total).[15] As can be seen from Fig. 2, the repo rate cut was largely unexpected by market participants, −8.5 basis points according to the surprise measure, which contributed largely to the fall in short-maturity yields (see Table 5 and Fig. 8). Out of the −8.3 and −9.1 basis point changes in the six-month and one-year yields, respectively, −8.0 was due to changes in the repo rate, repo path factor and the foreign yield. Results suggest that bond purchases contributed, to a large extent, to lower bond yields from the two-year maturity, with responses being statistically significant in the three- to seven-year segment. In addition, the effects on short-rate expectations and term premia reveal that the surprise regarding the repo rate cut seems to have been the most important factor behind the observed fall in short-term yields. Another important aspect is the fairly large effects of bond purchases on short-rate expectations, which show statistically significant declines from the five-year maturity. Term premia fell mainly in longer maturities with a −3.2 basis point change in the five-year yield. These results suggest that the signaling channel was relatively more important in the transmission of the July decision. Although not statistically significant, the portfolio balance channel also seemed to help in lowering the long end of the yield curve.

[15] Market newsletters from that time suggest that most market participants did not consider the announcement of SEK 45 billion as their main scenario.

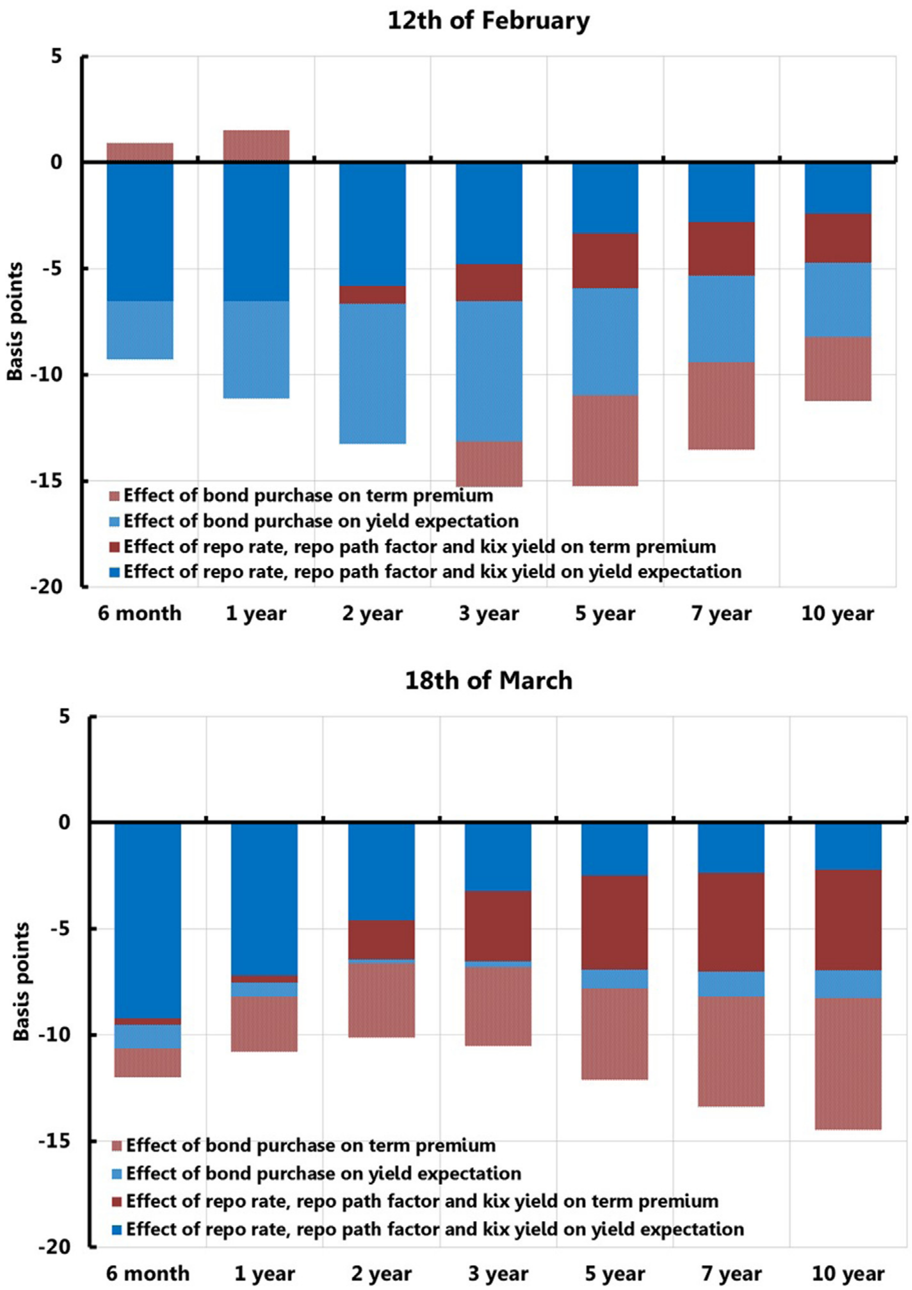

Fig. 7. Monetary policy announcement effects – February and March. *Notes:* This figure shows the effects of monetary policy announcements on short-rate expectations and term premium for the announcements made on February 12, 2015 and March 18, 2015.

The September decision caused a twist in the yield curve with yields of up to three years responding positively and longer yields reacting negatively to the announcement. The repo rate surprise measure of 5.3 basis points indicates that market participants were expecting an interest rate cut that did not materialize. As can be seen, fitted yields for maturities of up to three years increased by up to 2.4 basis points, with a large contribution coming from the interest rate surprise, which mainly caused an increase in short-rate expectations (see Table 6 and Fig. 9). Longer yields fell mainly as a result of term premia. Note from Table 7 that term premia fell across maturities, with the maximum decline being observed in the ten-year maturity. My assessments show that the fall was mainly a result of movements in foreign yields, which declined −3.8 basis points according to the five-year foreign yield index.

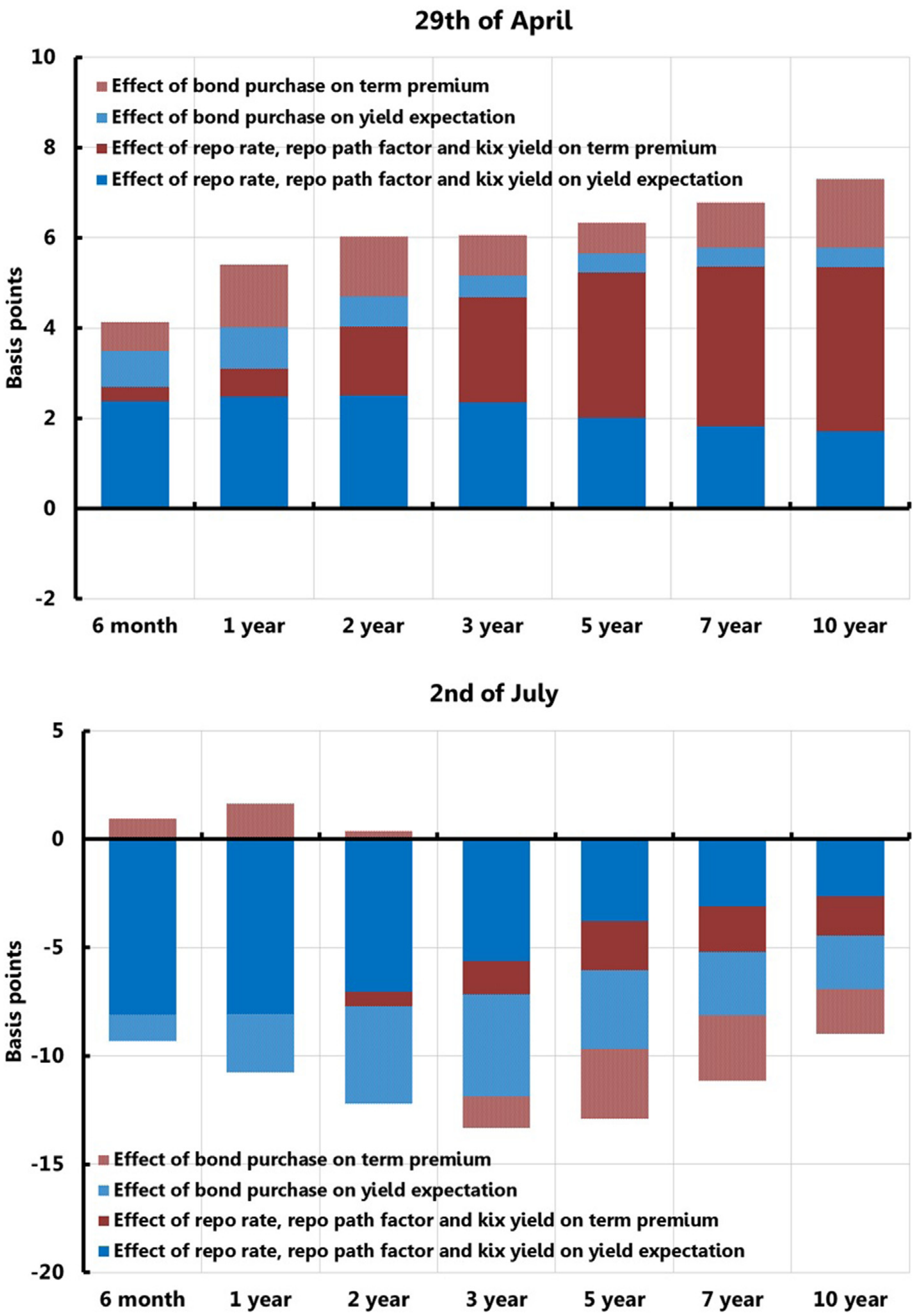

Fig. 8. Monetary policy announcement effects – April and July. *Notes:* This figure shows the effects of monetary policy announcements on short-rate expectations and term premium for the announcements made on April 29, 2015 and July 2, 2015.

The announcement of the additional purchase of SEK 65 billion on October 28 was, again, a big surprise.[16] Note from Table 6 that the ten-year fitted yield declined by −8.4 basis points on that day, which was entirely attributed to the extension of the bond purchase program. Interestingly, results in Table 7 and Fig. 9 suggest that the observed declines in yields were mainly attibuted by the term premium component, with responses being largely significant. These findings suggest that the portfolio balance channel played an important role in the interest rate transmission of the October 28 decision.

[16] Market newsletters at that time suggest that market participants were expecting an extension of the bond purchases of around SEK 35–45 billion.

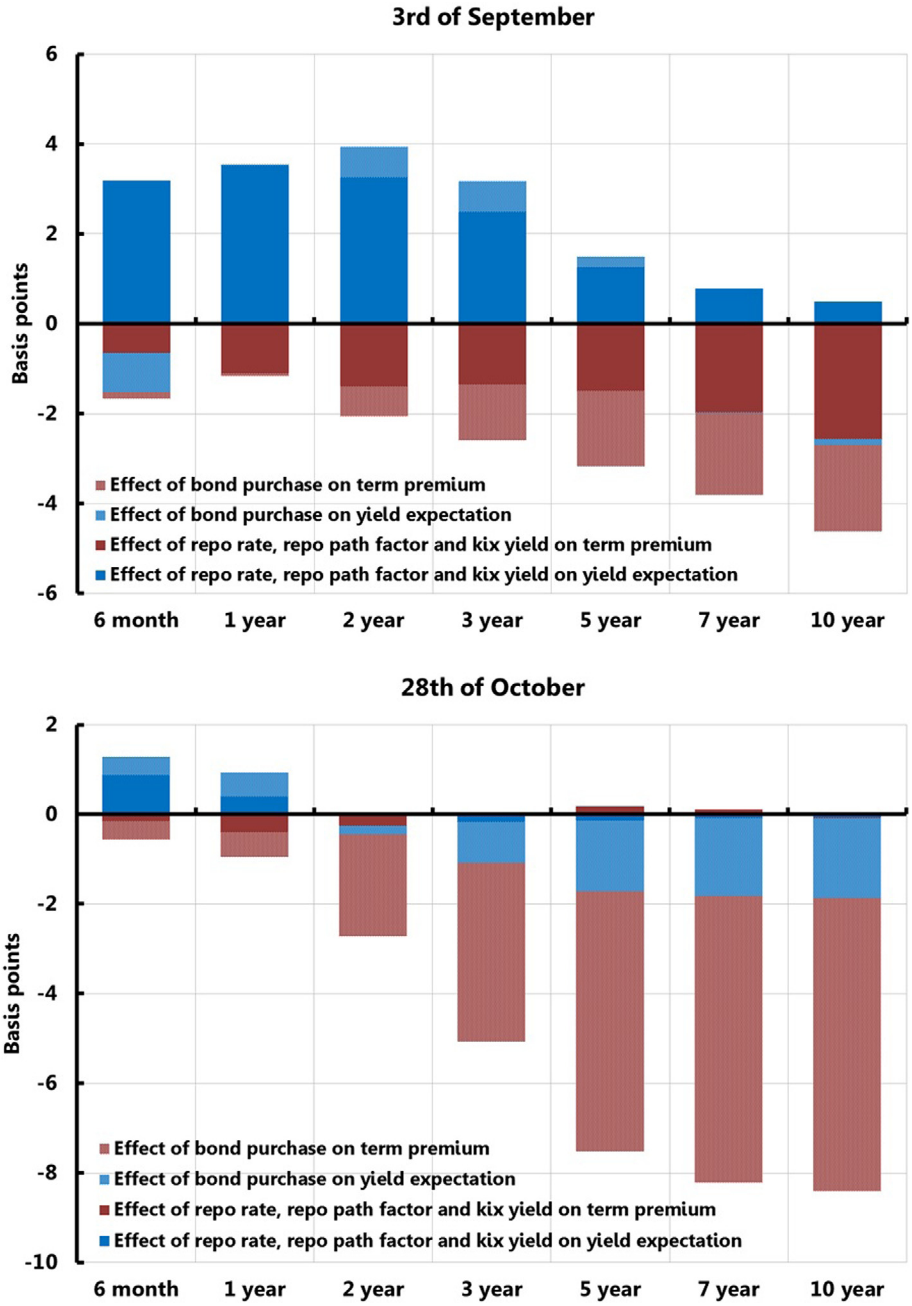

Fig. 9. Monetary policy announcement effects – September and October. *Notes:* This figure shows the effects of monetary policy announcements on short-rate expectations and term premium for the announcements made on September 3, 2015 and October 28, 2015.

It is also interesting to compare the estimated effects of bond purchases in Sweden to the estimates for other countries that are available in the literature. Based on a number of estimates from event-study analysis and term-structure models, Williams (2014) suggest that USD 600 billion of Federal Reserve's asset purchases, which is equivalent to 4.25 percent of the US 2010 GDP, lowered the ten-year Treasury yield by a central estimate of 21.4 basis points.[17] My estimates suggest that

[17] These estimates are based on the works by Bernanke et al. (2004), Gagnon et al. (2011), Hamilton and Wu (2012), Swanson (2011), Neely (2013), Christensen and Rudebusch (2012), Bauer and Rudebusch (2014) and Li and Wei (2013).

Table 8
One-day responses of other Swedish interest rates.

Maturities	Feb 12, 2015	Mar 18, 2015	Apr 29, 2015	Jul 2, 2015	Sep 3, 2015	Oct 28, 2015	Net chg
2-year mortg benchm	−9.3	−11.0	4.5	−9.5	2.0	−2.5	−25.8
5-year mortg benchm	−9.2	−11.5	8.0	−8.0	−2.0	−4.0	−26.7
2-year mortg bond	−8.8	−10.5	2.9	−10.6	3.1	−1.3	−25.2
5-year mortg bond	−9.7	−11.4	7.5	−7.5	−0.9	−4.8	−26.8
10-year mortg bond	−10.7	−10.1	4.5	−5.4	3.8	−4.1	−22.0
1-month STINA	−5.5	−14.0	6.4	−6.3	7.1	4.8	−7.5
6-month STINA	−5.6	−12.7	6.4	−5.3	6.0	−1.4	−12.6
6-month FRA	−7.5	−11.5	4.0	−9.0	2.1	0.5	−21.4
1-year FRA	−8.0	−9.5	3.5	−9.0	1.4	−0.5	−22.1
2-year FRA	−8.5	−7.1	4.5	−8.1	1.0	−2.5	−20.7
6-month impl-path	−7.2	−11.5	5.5	−7.7	3.5	1.6	−15.8
1-year impl-path	−8.0	−11.4	4.0	−8.0	3.7	0.3	−19.4
2-year impl-path	−7.7	−10.3	4.5	−6.9	3.2	−3.2	−20.3
3-year impl-path	−8.2	−9.7	6.1	−4.7	1.8	−4.9	−19.6

Notes: This table shows one-day responses of Swedish mortgage benchmark rates, mortgage bond yields, STINA rates, FRA rates and implied repo rate path rates around the six key monetary policy announcements made by the Riksbank in 2015. All interest rate changes are measured in basis points.

Riksbank purchases that are equivalent to 4.25 percent of Sweden's 2015 GDP, and that amount SEK 176 billion, lowered the ten-year Swedish government bond yield by a central estimate of 24.4 basis points, which is fairly close to the US experience.[18]

To summarize the main findings, the key conclusion is that changes in both the short-rate expectations and the term premia components seem to have contributed to the observed reactions of government bond yields to the six key monetary policy announcements made by the Riksbank in 2015. These results suggest that bond purchases have important portfolio balance and signaling effects that have lowered term premia and expected future short-term interest rates, respectively. In addition, I find that interest rate policy and government bond purchases operate in different segments of the yield curve, being effective in lowering yields across the full maturity spectrum.

4.1. The responses of other interest rates

One additional aspect of the portfolio balance channel is the ability of bond purchases to also influence other asset prices in the economy. This occurs when individuals who sell their share of government bonds decide to buy other assets that are better substitutes for bonds than money, lowering interest rates more broadly in the economy. Table 8 shows the responses of interest rates on several other instruments: (i) mortgage benchmarks, (ii) mortgage bonds, (iii) STINA, (iv) FRA and (v) implied policy rate paths.[19] Note that, following government bond yields, the interest rates shown in Table 8 reacted negatively to most monetary policy announcements. Reactions were stronger in the February 12, March 18 and July 2 decisions, which involved changes in the repo rate and purchases of government bonds. Note also that the bond purchase announcement of October 28, which was considerably larger than the previous ones (see Table 1), lowered long-term mortgage rates substantially. For instance, the ten-year mortgage bond yield declined by 40 basis points. Short-term rates, on the other hand, increased on October 28, given that financial market participants were surprised by the decision of not cutting the repo rate (see Fig. 2). These results show the spillover effects of bond purchases to other interest rates in the economy.

It is also interesting to look at how model-free expectations of future policy rates changed around announcement dates. Fig. 10 shows the future-implied policy rate paths around the six monetary policy announcements shown in Table 1. As can be seen, policy rate expectations appear to have shifted in response to the monetary policy announcements. At the short end, considering all the announcements, the path has shifted down by around 25 basis points, while at longer horizons of one to three years, the total decrease was around 20 basis points. As expected, the shifts observed at the short end are larger in the February, March and July policy decisions, which is a result of the surprises regarding changes in the repo rate (see Fig. 2). The observed shifts in the expected policy rate paths on these dates were, however, mostly parallel, suggesting that market participants also revised longer expectations downwards. This is also observed around the October decision, where we see a twist in the forward curve with long run expectations decreasing relatively more than in the short run. These results confirm the findings described above and suggest that short-rate expectations reacted to the announcements of interest rate and government bond purchase policies.

[18] The effect of −27 basis points reported by Table 5 corresponds to a total announced purchase of SEK 195 billion, or 4.7 percent of Sweden's 2015 GDP.

[19] Implied policy rate paths are constructed as implied forward-rate curves by the Riksbank staff using RIBA (Riksbank futures), FRA and interest-rate swap rates, and are commonly used by the Riksbank as an estimate of market expectations of future policy rates in Sweden. Mortgage bonds are debt instruments issued by mortgage institutions to finance their home mortgage lending and have become important in Sweden in the last few years.

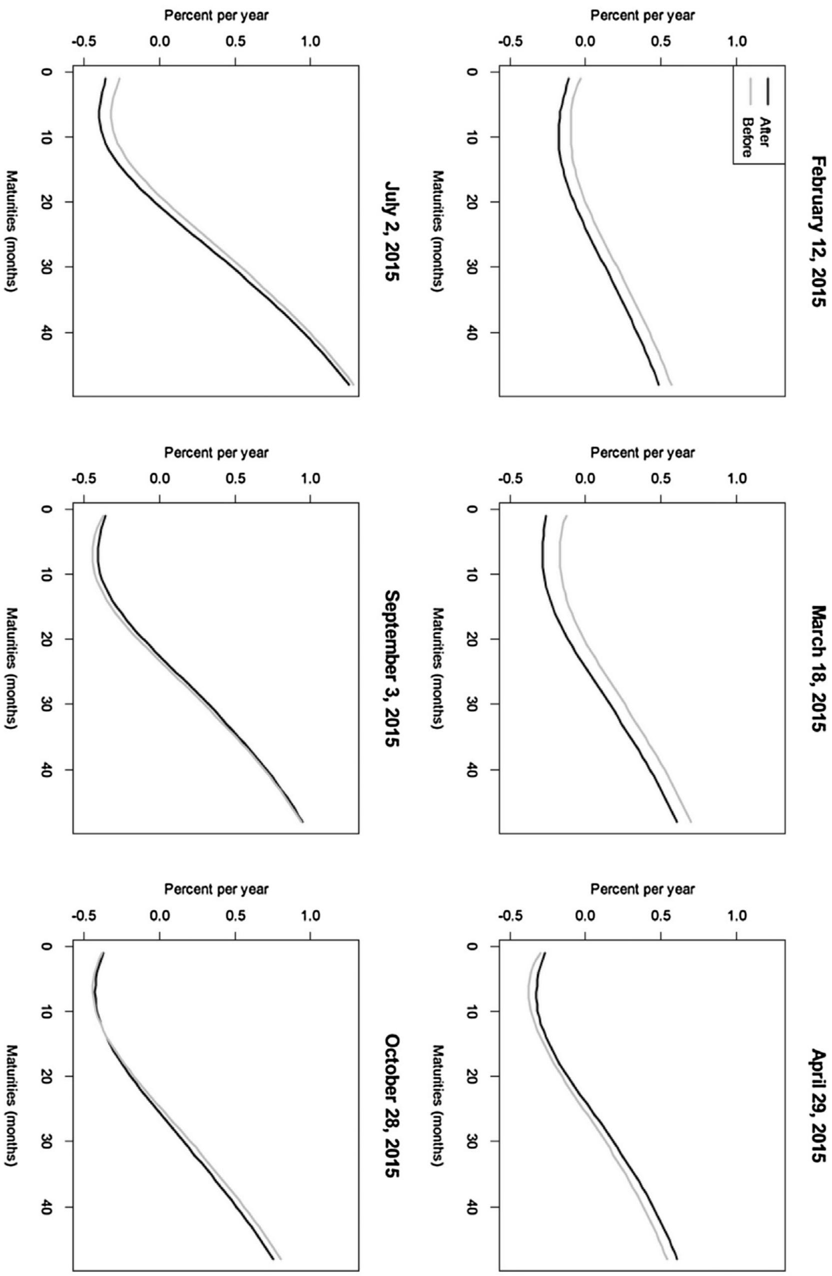

Fig. 10. Shifts in expected policy rate paths around monetary policy announcements. *Notes:* This figure shows expected paths for the repo rate before and after the six key monetary policy announcements made by the Riksbank in 2015. The expected paths are implied forward-rate curves constructed by the Riksbank staff using RIBA (Riksbank futures), FRA (Forward Rate Agreements) and interest-rate swaps.

5. Conclusions

In this paper, I analyze the recent experience of unconventional monetary policy in Sweden to study the interest rate transmission mechanisms of government bond purchases when policy rates are away from the lower bound. Unlike other central banks, Sveriges Riksbank has been able to lower its target interest rate, the repo rate, deep into negative territory while government bond purchases have been announced, allowing one to studythe effects of government bond purchases across the full yield maturity spectrum, without the presence of a lower bound constraint. I use dynamic term structure models together with event study regressions to measure the effects of bond purchase announcements on short-rate expectations and term premia. I find that government bond purchases have important portfolio balance and signaling effects. The signaling channel operates mainly by lowering short-rate expectations in the intermediate segment of the yield curve, while the portfolio balance channel is more effective in lowering longer maturity term premia. In addition, I find that target interest rate policy and government bond purchases operate in different segments of the yield curve, being effective in lowering yields across the full yield maturity spectrum when implemented together.

These findings have important policy implications. They suggest that, when the policy rate is not constrained by the lower bound, it is possible to design bond purchase programs with the aim of influencing bond yields across maturities, but especially in the mid and long segments of the yield curve. Furthermore, when implemented together with the more conventional target interest rate policy, central banks may be able to lower yields across the full maturity spectrum, making monetary policy more expansionary than otherwise. Finally, although banks have been somewhat reluctant to lower their deposit and lending rates to companies and households, the transmission of the more conventional interest rate policy to market interest rates has functioned as if the repo rate was positive in Sweden. The absence of a lower bound constraint for interest rates and policy rate expectations seems to be an important factor behind this result.

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Appendix A

As in Kuttner (2001) the surprise component of the change in the repo rate, Δr_t^u, is given by

$$\Delta r_t^u = (stina_t - stina_{t-\Delta t})\frac{D1}{D1 - d1}$$

where $d1$ denotes the day of the announcement of a policy decision, $D1$ is the number of days in the month and $(stina_t - stina_{t-\Delta t})$ is the change in the 1-month STINA rate around a window of fifteen minutes before and two hours and forty-five minutes after the policy announcement.

The repo path factor, Δrpf_t^u, is estimated as the following. Given the matrix

$$M_t = \left[\Delta r_t^u \; \Delta FRA1q_t \; \Delta FRA2q_t \; \Delta FRA4q_t \; \Delta FRA8q_t\right]$$

where $\Delta FRAXq_t$ is the change in the Forward Rate Agreement contract rate with X-quarter maturity. It is assumed that each element of M_t has a factor structure,

$$M_{lt} = \lambda_l' F_t + e_{lt}$$

where F_t is an $s \times 1$ dimensional vector of factors, λ_l is a $s \times 1$ vector of factor loadings and e_{lt} denotes an idiosyncratic component. In matrix notation,

$$M = F\Lambda + e$$

M is a $T \times 5$ matrix, F is a $T \times s$ matrix of latent factors, Λ is an $s \times 5$ matrix of factor loadings and e is a $T \times 5$ matrix of idiosyncratic components.

As F_t is not observed, it needs to be replaced by estimates $\widehat{F}_t$, which are obtained via standard PCA. As in Gürkaynak et al. (2005), I set the dimension s of $\widehat{F}_t$ as equal to two.

To allow for a more structural interpretation of these unobserved factors, I follow Gürkaynak et al. (2005) and rotate the factors so that the first factor corresponds to surprise changes in the current repo rate and the second factor corresponds to moves in interest rate expectations over the coming two years that are not driven by changes in the repo rate. In other words, I define a matrix Z as

$$Z = FU$$

where

$$U = \begin{bmatrix} \alpha_1 & \phi_1 \\ \alpha_2 & \phi_2 \end{bmatrix}$$

and where U is identified by four restrictions. First, the columns of U are normalized to have unit length (which normalizes Z_1 and Z_2 to have unit variance). Second, the new factors Z_1 and Z_2 should remain orthogonal to each other:

$$E(Z_1 Z_2) = \alpha_1\phi_1 + \alpha_2\phi_2 = 0$$

Lastly, the restriction that Z_2 does not influence the current policy surprise, Δr_t^u, is imposed as follows. Let γ_1 and γ_2 denote the (known) loadings of Δr_t^u on F_1 and F_2, respectively. Since,

$$F_1 = \frac{1}{\alpha_1\phi_2 - \alpha_2\phi_1}(\phi_2 Z_1 - \alpha_2 Z_2)$$

$$F_2 = \frac{1}{\alpha_1\phi_2 - \alpha_2\phi_1}(\alpha_2 Z_1 - \phi_1 Z_1)$$

It follows that:

$$\gamma_2\alpha_1 - \gamma_1\alpha_2 = 0$$

Finally, Z_1 and Z_2 are rescaled so that Z_1 moves the current policy rate surprise Δr_t^u one-to-one.

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