Quantitative Easing and Long-Term Yields in Small Open Economies*

Prepared by Antonio Diez de los Rios, Christopher Evans and Maral Shamloo

ABSTRACT

We analyze government bond yield movements of the United Kingdom, Sweden and Switzerland, comparing the effectiveness of their asset purchase announcements with that of the Federal Reserve and the European Central Bank on these smaller open economies. We decompose government bond yields into (i) an expectations component, (ii) a global term premium and (iii) a country specific term premium to analyze two-day changes in 10-year yields around announcement dates. We find that, in contrast to the Federal Reserve and the European Central Bank's asset purchases, the programs implemented in these smaller economies have not been able to affect the global term premium. Furthermore, they have had limited, but significant, effect in lowering long-term yields.

JEL Classification Numbers: E43, E52, E58, G12

Keywords: Unconventional monetary policy, event study, signaling, portfolio balance, asset purchases.

Authors' E-Mail Address: diez@bankofcanada.ca, christopher.evans@upf.edu and mshamloo@imf.org

* We are very grateful to Greg Bauer and Jonathan Witmer for extensive conversations on the effect of unconventional monetary policies in small open economies. We would also like to thank Rafael Barros de Rezende, Jens Christensen, Nikola Mirkov, Thomas Nitschka, Matt Roberts-Sklar and the Offices of Executive Directors at the IMF for the UK and Switzerland as well as seminar participants at the Bank of Canada Conference on "Unconventional Monetary Policies: A Small Open Economy Perspective," the IMF's Policy Forum, the IMF's Quantum seminar and internal IMF reviewers for their useful comments and suggestions. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Bank of Canada nor the International Monetary Fund.

1. INTRODUCTION

Having reached the effective lower bound on nominal policy rates in the aftermath of the 2007–08 financial crisis, several central banks have adopted other monetary policy tools to further ease their policy stance. In particular, many central banks—the Federal Reserve, the European Central Bank (ECB), the Bank of Japan, but also central banks in smaller economies such as the Bank of England (BoE), the Riksbank and the Swiss National Bank (SNB)—have undertaken large-scale asset purchase (LSAP) programs or quantitative easing (QE) with the aim of lowering long-term yields and thus encouraging consumption and investment and, ultimately, spurring economic activity and consumer price inflation.[1]

While the initial assessment regarding the effectiveness of these unconventional monetary policies has been largely positive, studies have focused mainly on the impact of the Federal Reserve's LSAP program (see, e.g., Gagnon et al., 2011, Christensen and Rudebusch, 2012, and Bauer and Rudebusch, 2014, among others), and more recently the ECB's experience (see e.g., Altavilla, Carboni and Motto, 2015, Andrade et al., 2016 and De Santis 2016) The question therefore remains as to whether the lessons learned from the U.S. and Euro area experiences are applicable for the central banks of small open economies. In this paper, we attempt to answer this question by analyzing the channels through which these programs affect the stance of monetary policy, thereby evaluating the effectiveness of QE programs in small open economies such as the United Kingdom, Sweden and Switzerland and contrasting this against the ability of announcements by central banks of larger economies, the Federal Reserve and the ECB, to affect the bond yields of these smaller economies.

Central bank asset purchases lower long-term yields via at least two main channels.[2] First, asset purchases might contain news about future short-term rates. To the extent that the announcement of an asset purchase program might lead market participants to revise their expected path of future short-term rates, long-term rates will also fall. Changes in long rates due to a revision in expectations are referred to as the *signaling channel* of central bank purchases.

Second, asset purchases can affect long-term yields by reducing the amount of longer-term government securities in private sector portfolios (see Bernanke, 2011, Kohn, 2009, Williams, 2011, and Yellen, 2011). Specifically, as central banks reduce the supply of longer-term government securities, investors need to rebalance their portfolios towards assets of similar characteristics (i.e., maturity, credit, etc.). This tends to bid up not only the price of the

[1] In the remainder of the paper we will use the terms LSAP and QE interchangeably.

[2] QE can potentially affect asset prices through other channels as well, for example, by affecting liquidity and credit risk (see, e.g., Krishnamurthy and Vissing-Jorgensen, 2011, and Christensen and Gillian, 2016). In addition, other factors such as decline in macroeconomic volatility, inflation uncertainty and fiscal balance also determine long-term yields (see, e.g., Orr, Edey and Kennedy,1995). However, as shown in Bauer, Rudebusch, and Wu (2014), estimated term premia have a positive relationship with inflation uncertainty.

purchased security (i.e., lower its yield) but also the price of close substitutes.[3] This is referred to as the *portfolio balance channel* of central bank asset purchases.

In a world with global capital markets, the set of substitutable securities potentially includes foreign bonds. Consequently, some of the portfolio rebalancing occurs at the international portfolio level, i.e., towards the now relatively underpriced foreign debt of similar credit quality. For example, Bauer and Neely (2014) and Neely (2015) find evidence that the effects of the Federal Reserve's asset purchase program spilled over to international bond yields.

This international spillover depends on two factors: (i) the size of asset purchases relative to the size of the pool of substitutable assets, and (ii) the degree of substitutability of domestic and foreign bonds. Put differently, international investors in the bonds issued by small open economies are highly price sensitive because of the existence of a large set of similar (i.e., highly substitutable) assets. In contrast, if U.S. Treasury bonds are special in certain ways and cannot be substituted easily (i.e., because of the dominant reserve currency[4] status of the dollar), the price-taking element is to a large extent eliminated.

The focus of this paper is to understand the differences in the way QE affects long-term yields in small open economies (as opposed to a large country like the United States) and the extent to which these differences might limit the effectiveness of asset purchases in small open economies. Specifically, we study the responses of long-term yields on government securities to the BoE's and the Riksbank's asset purchase announcements, and the SNB's reserve expansion program. In addition, we also contrast the effectiveness of these programs with announcements by the Federal Reserve and the ECB, as these provide natural benchmarks against we can measure the effectiveness of the asset purchase programs implemented by small open economies.

Specifically, using an event-study, we quantify the importance of the signaling and portfolio balance channels by decomposing observed two-day changes in 10-year yields around central bank announcements of asset purchases into their expectations and term premium components, respectively. Importantly, and consistent with Ilmanen (1995), Perignon, Smith and Villa (2007), Hellerstein (2011), Dahlquist and Hasseltoft (2013) and Bauer and Diez de los Rios (2012), among others, we find that our estimates of term premia are highly correlated across countries. For this reason, we further separate changes in term premia into a global and a country-specific component using a one-factor model.

[3] The dependence of longer-term yields on the private sector holdings of longer-term assets was the subject of a substantial literature in the 1950s and 1960s. See, for example, Culbertson, (1957), Modigliani and Sutch (1966) and Wallace (1967). More recently, Vayanos and Vila (2009) and Greenwood and Vayanos (2014) have proposed modern "preferred-habitat" models where shocks to the supply of a particular bond can impact the full-term structure of interest rates.

[4] The British pound and Swiss franc are also reserve currencies but have not been the global dominant reserve currency during our sample period, unlike the United States Dollar.

Three main messages arise from our analysis. First, we find that, in general, the changes in long-term rates around asset purchase announcements by the BoE, the Riksbank and the SNB are substantially smaller than the changes observed after the first round of asset purchases implemented by the Federal Reserve. Specifically, our results suggest that these programs do not affect the global term premium component of the yields. While QE programs in small open economies have involved the purchase of a large proportion of their domestic government bond markets (23 percent of the stock of outstanding nominal government debt in the United Kingdom as of September 2016 and just over 30 percent in Sweden as of February 2016), they are relatively small once we take into account the size of the pool of substitutable assets.[5] Consequently, their impact on long-term interest rates has been limited.

Second, asset purchase announcements by the Federal Reserve and ECB pushed U.K., Sweden and Switzerland push bond yields down through the global term premium channel. For example, we find evidence that asset purchase announcements by the Federal Reserve and ECB, on average, were more effective at lowering Swedish bond yields than similar announcements by the Riksbank. Moreover, the SNB's announcement to purchase bonds denominated in Swiss Francs on the 12 March 2009 was less effective at lowering Swiss bond yields than the 18 March 2009 announcement of the Federal Reserve to start their Treasury purchase program, likely due to much larger size and different aim of the Federal Reserve asset purchase program.

Third, we find evidence for the diminishing effectiveness for the U.S. and U.K. QE programs as initial announcements have a larger impact on bond yields than those near the end of our sample (as discussed in Chodorow-Reich, 2014 and IMF,2013). This empirical result is in line with Haldane et al. (2016) who hypothesize that quantitative easing is likely to have a larger effect during times of market stress and turmoil. Therefore, as the economy and financial markets begin to recover it is unsurprising to find quantitative easing announcements becoming less effective.

However, our analysis should not be interpreted as evidence that asset purchases are not expansionary in small open economies. Rather, asset purchases do not seem to be expansionary through the lowering of long-term yields, as is the case in larger economies. For example, expected returns on international investments depend both on the expected asset return in local currency and on the expected change in the exchange rate. Consequently, exchange rates could be affected as well. Glick and Leduc (2012, 2015) and Neely (2015), for example, find that the U.S. dollar depreciated around the Federal Reserve's asset purchase announcements. In this way, by putting downward pressure on the exchange rate, asset purchases can also be stimulative by encouraging an increase in net exports (i.e., an exchange rate channel). While beyond the scope of this paper due to its focus on long-term yields, we present some preliminary

[5] For example, by the end of 2015, the sizes of the stock of outstanding nominal government debt in the U.K. and Sweden were approximately 20 per cent and 1 per cent, respectively, of the size of U.S. Treasury bond market. The figure for the UK can be found in HM Treasury's Debt Management Report 2017-2018 Chart A.8 (HM Treasury, 2017). The figure for Sweden is from annex B of the Minutes of the Monetary Policy Meeting in the Sveriges Riksbank, 10 February 2016

evidence regarding the effect of QE announcements on exchange rates that suggests for the United Kingdom, Sweden and Switzerland the exchange rate channel may exist but it is limited.

The remainder of this paper is organized as follows: Section 2 discusses the channels of transmission of asset purchases to long-term interest rates. Section 3 presents our empirical methodology to decompose long-term interest rates into an expectation and a term premium component. Section 4 analyzes the changes in the 10-year yield and its components in a two-day window around the announcement of asset purchases by the BoE, the Riksbank and the SNB's reserve expansion program. Section 5 compares changes in the sovereign bond yields of small open economies around the Federal Reserve, European Central Bank and their own asset purchase announcements. Section 6 concludes. The appendix analyzes changes in U.S. Treasury yields from Federal Reserve announcements and movements in German 10-year bond yields from ECB asset purchase announcements, as well as a preliminary analysis of exchange rate movements around our announcement dates.

2. SIGNALING AND PORTFOLIO BALANCE CHANNELS IN AN INTERNATIONAL SETUP

As noted in the literature, central bank asset purchases can potentially lower bond yields through mainly two channels: (i) a signalling channel and (ii) a portfolio balance channel (see, e.g., Gagnon et al., 2011, Christensen and Rudebusch, 2012, Bauer and Rudebusch, 2014, Joyce et al., 2011, Bauer and Neely, 2014, among many others). In order to distinguish between these two channels, it is useful to define the expectations component and the term premium of the yield of a long-term zero-coupon bond, a 10-year bond in our example, as:

$$y_{j,t}^{(10)} = \frac{1}{10}\sum_{j=0}^{9} E_t r_{j,t+j} + tp_{j,t}^{(10)}, \qquad (1)$$

where $y_{j,t}^{(10)}$ is the yield at time t on a n-year zero-coupon bond of country j.[6] The first term is the average of the expected one-year interest rate over the next 10 years. In our model, we use the one-year interest rate in country j as a proxy for that country's policy rate (i.e., $r_{j,t} = y_{j,t}^{(1)}$).[7] The second term is a time-varying term-structure risk premium that represents the extra compensation that investors require for interest rate risk associated with holding a 10-year bond.

A. Signaling Channel

The signaling channel recognizes that asset purchases contain news about the expected path of future short-term rates. To the extent that the announcement of an asset purchase program leads market participants to revise their expectations of future short-term rates, it can affect long-term

[6] A zero-coupon bond is a claim that sells at a price today and yields a payment of $1 at maturity. Investors thus earn a yield on the bond by buying at a price less than $1 today and holding the bond to maturity. The yield on the zero-coupon bond can be calculated from prices of regular coupon-bearing bonds observed in the market.

[7] A country's one-year rate can be viewed as being closely related to the current (short-term) policy rate that is targeted by that country's central bank, as well as to the expectations of near-term policy moves.

rates. This mechanism is captured by the first component of long-term interest rates in equation (1). Specifically, the signaling channel captures the effect on interest rates of any new information that economic agents might learn from the central bank announcement regarding the future path of short-term rates either directly (i.e., in the form of explicit forward guidance) or indirectly (i.e., information regarding the central bank's views on current or future economic conditions, changes in the central bank's reaction function, and/or changes in the policy objectives).[8]

More important for analyzing the international effects of QE, the announcement of an asset purchase program by a large central bank such as the Federal Reserve can trigger market participants to revise their expectations regarding future policy rates in other countries. This could be the case because (i) central banks often respond similarly to common global economic and financial shocks, or (ii) some central banks might be concerned with excessive volatility in foreign exchange markets and therefore adjust their monetary policy stance in response to the major changes in foreign monetary policy. As pointed out by Bauer and Neely (2014), who study spillover effects from the Federal Reserve's asset purchase announcements to international yields, such monetary policy correlations give rise to an international signaling channel.

B. Portfolio Balance Channel

The portfolio balance channel captures the impact on bond prices that occurs when private sector investors adjust their portfolio positions in response to a reduction in the supply of a specific security, for instance, longer-term government bonds (see, e.g., Tobin 1961 and 1963). Such effects are captured by the second component of long-term interest rates in equation (1).

As central bank asset purchases reduce the supply of longer-term government securities, investors rebalance their portfolios towards assets of similar characteristics (e.g., maturity, credit and quality). This not only tends to bid up the price of the purchased bond (i.e., lower its yield) but also bids up the price of a wider set of assets. This result cannot be delivered in the standard representative agent models, because in such models there is no distinction between government and private asset holdings. Consequently, there is no role in such models for the supply of long-term bonds in determining bond prices (see, among others, Gagnon et al., 2011, and Krishnamurthy and Vissing-Jorgensen, 2011).

On the other hand, in a model with incomplete markets and imperfect substitutability between different assets, a QE program can affect asset prices by changing the relative supply of different assets. For example, Vayanos and Vila (2009) and Greenwood and Vayanos (2014) offer such a model, where a group of investors prefer a certain maturity of bonds ("preferred habitat"), while risk-averse arbitrageurs integrate the market by trading across maturities. In this model, a reduction in the supply of a particular security creates a shortage that increases its price.

[8] An example of direct information was the Federal Reserve's December 2008 Federal Open Market Committee (FOMC) press release, which stated that "economic conditions [were] likely to warrant exceptionally low levels of the federal funds rate for some time."

Consequently, arbitrageurs sell the "scarce" security, given that it is now relatively overpriced, and rebalance their portfolio towards other substitutable bonds that are now relatively underpriced. As the markets converge to a new equilibrium, arbitrageurs spread the scarcity created by the central bank in a particular bond across different maturities and to other bonds with similar characteristics.

In a world with global capital markets, the set of substitutable securities includes foreign bonds; as a consequence, some of the portfolio rebalancing occurs at the international portfolio level (i.e., towards the now relatively underpriced foreign debt of similar characteristics). Indeed, Bauer and Neely (2014) find evidence of such international spillover effects following the Federal Reserve's asset purchase program.

This international rebalancing implies that the size of an asset purchase program relative to the size of the pool of substitutable securities should also matter in a world with integrated capital markets. Put differently, an issuer in a small open economy may be, by and large, a price taker in global capital markets given that a large set of highly substitutable bonds is available. In principle, this could limit the effectiveness of asset purchase programs in lowering interest rates in small open economies in contrast to the case of the United States, (where U.S. Treasuries benefit from specialness given the reserve-currency status of the dollar) or the eurozone (where euro-denominated bonds may enjoy better liquidity or higher acceptance as collateral than bonds issued in other jurisdictions). We study the validity of this hypothesis below.

C. Event-Study Methodology

Consistent with the literature on the evaluation of central bank asset purchases, we quantify the importance of the signaling and portfolio balance channels by measuring the respective contribution of the expectations and term premium components to the observed two-day changes in 10-year yields around central bank announcements of asset purchases.[9] As in Bauer and Rudebusch (2014), we primarily focus on announcements rather than asset purchases themselves, given that forward-looking investors will react immediately to news of future purchases. Thus, credible asset purchase announcements should lower the term premium component of long-term yields immediately.

We still note that an event-study approach is, of course, an imperfect methodology and entails many assumptions. First, it assumes that the announcement is entirely unanticipated and that its full effect on yields takes place on the day of the announcement. This is likely to underestimate the asset-price response for later asset purchase announcements, given that market participants might have formed expectations of increasing bond purchases prior to the official

[9] Our database suffers from the same problem as in Christensen and Krogstrup (2016a) in the sense that we do not know exactly when, during the day, the yield data we use were collected. In this regard, a longer window is needed to guarantee that the announcement is reflected in all the yields across all the countries in our sample. However, our results are robust to one-day changes in yields.

announcements.[10] Second, it also assumes that there are no market failures that would prevent the full price effect from taking hold at the time of announcement before any purchases have actually taken place. Third, in using a two-day window in our event study, we are implicitly assuming that this is short enough to abstract from any other event that could affect long-term yields.

As noted by Bauer and Rudebusch (2014) and Joyce et al. (2011), among others, estimated changes in the expectations component are likely to be only a lower bound for the contribution of the signaling channel to changes in the long-term yields because of second-round effects. First, a successful monetary policy action aimed at easing financial conditions and stimulating future growth will raise short-rate expectations for the more distant future, counteracting the decrease in the expectations component due to signaling effects. Second, signaling near-zero policy rates for an extended period of time tends to lower interest rate risk and the term premium, even without any portfolio balance effect.

3. EMPIRICAL METHODOLOGY

As discussed earlier, our empirical methodology allows us to consider the effect of QE announcements on various components of the long-term yields. To do so, we follow a two-step strategy. First, we use a term-structure model to decompose the yields into their expectation and term-premia components (see equation 1). Then, we further decompose the term premium in each country into a global and a country-specific component, by extracting the first principal component of an international cross-section of estimated term premia.

A. Data

Our data set consists of end-of-month observations over the period January 1995 to November 2016 of the term structures of zero-coupon bond yields for the United States, the United Kingdom, Germany, Canada, Sweden and Switzerland, obtained from the BIS Databank (to which the participating central banks report) We consider all annual maturities from 1 to 10 years.

To capture the cross-sectional variation of bond yields, we focus on the first three principal components of each of the yield curves in each country. These three factors explain 99.9 per cent of the variation of yields in each country and have the traditional interpretation of level, slope and curvature (Litterman and Scheinkman, 1991).

[10] Alternatively, we could try to estimate the surprise content of asset purchase programs directly. See, for example, Wright (2012) and Glick and Leduc (2012), who analyze the Federal Reserve's LSAP program, and Rogers, Scotti and Wright (2014) for a cross-country comparison of such shocks.

B. Estimating Term Premia

The average path of the short-term interest rate can be forecasted by estimating a collection of individual or vector autoregression (VAR) models on the level, slope and curvature factors for each of the individual countries' yield curves:

$$\boldsymbol{f}_{j,t} - \boldsymbol{\mu}_j = \boldsymbol{\Phi}_j\left(\boldsymbol{f}_{j,t-1} - \boldsymbol{\mu}_j\right) + \boldsymbol{\varepsilon}_{j,t}, \tag{2}$$

where $\boldsymbol{f}_{j,t} = \boldsymbol{P}_j'\boldsymbol{y}_{j,t}$ and $\boldsymbol{y}_{j,t}$ is a vector that stacks all the yields in a given country, $\boldsymbol{P}_j'$ is a full-rank matrix such that $\boldsymbol{f}_{j,t}$ coincides with the first three principal components of the cross-section of yields in country j, $\boldsymbol{\mu}_j$ is the unconditional mean of $\boldsymbol{f}_{j,t}$ and $\boldsymbol{\varepsilon}_{j,t} \sim iid\ N\left(\boldsymbol{0}, \boldsymbol{\Sigma}_j\right)$.

The expectations component of the n-year yield would then be obtained as follows: First, the loadings of the short-term rates are estimated by regressing the one-year yield $r_{j,t} = y_{j,t}^{(1)}$ on a constant and the three principal components, $\boldsymbol{f}_{j,t}$:

$$r_{j,t} = \delta_{0,j} + \boldsymbol{\delta}_j'\boldsymbol{f}_{j,t}. \tag{3}$$

Second, the h-step-ahead forecast of $\boldsymbol{f}_{j,t}$ given the time t information set implied by the VAR model in equation (2) is:

$$E_t\boldsymbol{f}_{j,t+h} = \left(\boldsymbol{I} - \boldsymbol{\Phi}_j^h\right)\boldsymbol{\mu}_j + \boldsymbol{\Phi}_j^h\boldsymbol{f}_{j,t}. \tag{4}$$

Thus, combining equations (3) and (4), we have that the expectations component of the n-year yield is given by the following expression:

$$\frac{1}{n}\sum_{i=0}^{n-1} E_t r_{j,t+i} = \delta_{0,j} + \boldsymbol{\delta}_j'\boldsymbol{\mu}_j + \left(\boldsymbol{I} - \boldsymbol{\Phi}_j\right)^{-1}\left(\boldsymbol{I} - \boldsymbol{\Phi}_j^h\right)\left(\boldsymbol{f}_{j,t} - \boldsymbol{\mu}_j\right). \tag{5}$$

Therefore, given estimates of $\delta_{0,j}$, $\boldsymbol{\delta}_j'$, $\boldsymbol{\mu}_j$ and $\boldsymbol{\Phi}_j$ (which, in principle, could be obtained using ordinary least squares regressions), one can define the term premium of the 10-year country j zero-coupon bond as the residual of the observed 10-year bond yield from the forecast average path of the short-term rate:

$$tp_{j,t}^{(n)} = y_t^{(n)} - \delta_{0,j} - \boldsymbol{\delta}_j'\boldsymbol{\mu}_j - \left(\boldsymbol{I} - \boldsymbol{\Phi}_j\right)^{-1}\left(\boldsymbol{I} - \boldsymbol{\Phi}_j^h\right)\left(\boldsymbol{f}_{j,t} - \boldsymbol{\mu}_j\right). \tag{6}$$

C. A Near Cointegrated Panel Vector Autoregression

Estimating the term premium component as the residual of the observed 10-year bond yield from the VAR-implied expectations component involves mainly two problems. First, the high persistence of interest rates makes them very hard to predict in the medium and long run. This leads to large statistical and specification uncertainty around these estimates and, consequently, around the estimated term premia (see, e.g., Cochrane and Piazzesi, 2008). Second, VAR estimates tend to suffer from the well-known problem that ordinary least squares (OLS) estimates of autoregressive parameters tend to underestimate the persistence of the system in finite samples. Consequently, expected long-run future short rates tend to be almost constant, which implies that most of the variability in the long end of the yield curve tends to be attributed

to movements in risk premia rather than monetary policy expectations (see, among others, Bauer, Rudebusch and Wu, 2012).

We deal with these two problems in the following way: First, we obtain more precise estimates of the dynamics of the factors by estimating the VAR model in panel format. Specifically, we pool the observations for the countries in our sample while allowing for country-specific constant terms. In other words, we impose cross-country homogeneity on the slope coefficients of the VAR models:

$$\boldsymbol{\Phi}_j = \boldsymbol{\Phi} \qquad \forall j, \tag{7}$$

Figure 1 shows the estimated principal components in each country and across tenors. As the figure shows, the dynamics of the components, particularly the level factor, are similar in different countries, providing support for the assumption above. In fact, we are not able to reject the hypothesis of cross-country homogeneity at conventional levels.

In addition, we also note that the factor loadings are very close in different countries (see Figure 2). As a result, we compute level, slope and curvature factors in each country by using the average of the relevant factor loading across countries: $\boldsymbol{f}_{j,t} = \boldsymbol{P}'\boldsymbol{y}_{j,t}$ where $\boldsymbol{P} = \frac{1}{J}\sum_{j=1}^{J}\boldsymbol{P}_j$.

Second, we impose that the level of interest rates in country j follows a highly persistent autonomous first-order autoregressive (AR) process (i.e., neither slope nor curvature factors have predictable power over changes in the level of interest rates).[11] This assumption can be justified on the basis that the level factor of the yield curve is usually identified with the central bank's implicit inflation target as perceived by private agents (see, e.g., the macro-finance term structure model of Rudebusch and Wu, 2008), which is usually modeled as a highly persistent autonomous AR(1) process itself (see, e.g., Kozicki and Tinsley, 2001). We expect that, by tightly constraining the dynamics of the factors across countries, we are able to further reduce the sampling uncertainty that is likely influencing the forecasts of interest rates. In fact, Duffee (2011) shows that a model similar to ours, where the level follows a random walk process (i.e., a model where the autocorrelation coefficient for the level factor is one), does well in out-of-sample forecasting of U.S. Treasury yields.[12]

While restricting the largest root of the VAR to be equal to one, as in Duffee (2011), should help both reduce estimation uncertainty and avoid the downward bias in the estimated persistence of the system, we find that such an assumption usually leads to decompositions of the yield curve where the estimated term premia play almost no role in explaining the variability

[11] In the absence of these restrictions, we find the change in the expectations and term premium components around several announcement dates to move in opposing directions (while theory suggests that both the signaling and the portfolio balance effects should pull bond yields in the same direction).

[12] We also note that modeling the level factor as an AR process is consistent with the preferred specifications of the term structure models estimated in Christensen and Rudebusch (2011) for the case of the U.S. and U.K. yield curves.

in the long end of the yield curve. For this reason, we depart slightly from this approach and model the level factors of interest rates as a near-unit root process instead.[13]

Specifically, we tackle the persistence bias in our system by considering a weighted average of the estimates of the panel VAR model where the level follows a stationary AR process, and those of a panel VAR where the level factors follow a random walk. Such a model combination approach has been shown by Hansen (2010) and Jardet, Monfort and Pegoraro (2011, 2013) to perform well for time series with high persistence.[14]

To summarize, our restricted near-cointegrated panel VAR model can be expressed as:

$$\begin{pmatrix} l_{j,t} - \mu_{l,j} \\ s_{j,t} - \mu_{s,j} \\ c_{j,t} - \mu_{c,j} \end{pmatrix} = \begin{pmatrix} \tilde{\phi}_{11} & 0 & 0 \\ 0 & \phi_{22} & \phi_{23} \\ 0 & \phi_{32} & \phi_{33} \end{pmatrix} \begin{pmatrix} l_{j,t-1} - \mu_{l,j} \\ s_{j,t-1} - \mu_{s,j} \\ c_{j,t-1} - \mu_{c,j} \end{pmatrix} + \begin{pmatrix} \varepsilon_{j,l,t} \\ \varepsilon_{j,s,t} \\ \varepsilon_{j,c,t} \end{pmatrix}, \quad (8)$$

$$\boldsymbol{f}_{j,t} - \boldsymbol{\mu}_j = \boldsymbol{\Phi}\left(\boldsymbol{f}_{j,t-1} - \boldsymbol{\mu}_j\right) + \boldsymbol{\varepsilon}_{j,t}, \quad (9)$$

for $j = 1,\ldots,J$ where $\tilde{\phi}_{11} = \omega \times 1 + (1-\omega)\phi_{11}$, where ω is the weight of the unit root model and ϕ_{11} is the unrestricted autoregressive parameter for the level factor. Note that when the weight ω is arbitrarily close to one, the first row of the autocorrelation matrix implies that the level factors behave as near random walks. Finally, we do not assume any structure for the cross-correlation of the error terms across countries.[15]

D. Estimation

For simplicity, we focus on a model for the factors in deviation from their sample means. Specifically, we calibrate $\tilde{\phi}_{11}$ such that the impulse response at the five-year horizon for the response of the level factor to a level shock is 0.60, which is in line with the estimated persistence of the system in Bauer, Rudebusch and Wu, 2012, 2014).[16] This implies $\tilde{\phi}_{11} = 0.996$.

[13] This leads to a model where there is a common near random walk variable (i.e., the level factor) driving the yield curve in each country, and hence the use of the "near-cointegration" terminology.

[14] Alternatively, we could have followed Bauer, Rudebusch and Wu (2012) by correcting the bias using bootstrap methods. However, we find the bias-corrected estimates lead to a system with explosive roots that requires the use of the stationary adjustment of Kilian (1998). Importantly, such an adjustment requires a judgement call on how close to one the largest eigenvalue of the system needs to be. For this reason, we felt that averaging between the unit root and the stationary model was, in our case, a cleaner way to document our judgement calls.

[15] Please note that we do not model the existence of a zero lower bound for interest rates given that some of the countries we study (Germany, Sweden, and Switzerland) have negative rates during the sample period under study.

[16] This is equivalent to putting an 81.6 per cent weight in the unit root model, given that the unconstrained estimate (using the minimum distance approach detailed below) of ϕ_{11} is 0.977. Our results are qualitatively similar to those that use other weight choices that differ from the ones reported in this paper in the following way: weights closer to one give more importance to the signaling channel, and weights closer to zero give more importance to the portfolio balance channel (consistent with the intuition provided by Bauer, Rudebusch and Wu, 2012).

We estimate the remaining parameters of the panel VAR model using a minimum distance (MD) estimator. Note that our panel VAR model can be thought of as a larger VAR in the whole set of slopes and curvatures where exclusion restrictions on the parameters have been imposed. This larger-scale VAR can be expressed as:

$$\begin{pmatrix} \tilde{\boldsymbol{f}}_{1,t} - \tilde{\boldsymbol{\mu}}_1 \\ \tilde{\boldsymbol{f}}_{2,t} - \tilde{\boldsymbol{\mu}}_2 \\ \vdots \\ \tilde{\boldsymbol{f}}_{J,t} - \tilde{\boldsymbol{\mu}}_J \end{pmatrix} = \begin{pmatrix} \boldsymbol{A}_{11} & \boldsymbol{A}_{12} & \cdots & \boldsymbol{A}_{1J} \\ \boldsymbol{A}_{21} & \boldsymbol{A}_{22} & \cdots & \boldsymbol{A}_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{A}_{J1} & \boldsymbol{A}_{J2} & \cdots & \boldsymbol{A}_{JJ} \end{pmatrix} \begin{pmatrix} \tilde{\boldsymbol{f}}_{1,t-1} - \tilde{\boldsymbol{\mu}}_1 \\ \tilde{\boldsymbol{f}}_{2,t-1} - \tilde{\boldsymbol{\mu}}_2 \\ \vdots \\ \tilde{\boldsymbol{f}}_{J,t-1} - \tilde{\boldsymbol{\mu}}_J \end{pmatrix} + \begin{pmatrix} \boldsymbol{u}_{1,t} \\ \boldsymbol{u}_{2,t} \\ \vdots \\ \boldsymbol{u}_{J,t} \end{pmatrix}, \tag{10}$$

$$\left(\tilde{\boldsymbol{f}}_t - \tilde{\boldsymbol{\mu}}\right) = \boldsymbol{A}(\boldsymbol{\beta})\left(\tilde{\boldsymbol{f}}_{t-1} - \tilde{\boldsymbol{\mu}}\right) + \boldsymbol{u}_t, \tag{11}$$

where $\tilde{\boldsymbol{f}}_{j,t} = (s_{j,t}, c_{j,t})'$, $\boldsymbol{\mu}_j = \left(\mu_{s,j}, \mu_{c,j}\right)$ and $\boldsymbol{\beta} = (\phi_{22}, \phi_{32}, \phi_{23}, \phi_{33})'$. Specifically, cross-country homogeneity can be written as the following restrictions on the matrix $\boldsymbol{A}(\boldsymbol{\beta})$:

$$vec[\boldsymbol{A}(\boldsymbol{\beta})] = \boldsymbol{G}\boldsymbol{\beta}, \tag{12}$$

for an appropriately chosen full rank matrix $\boldsymbol{G}$.

The idea of the MD estimator is to obtain an estimate of the unrestricted parameter coefficients of the larger VAR (i.e., $\widehat{\boldsymbol{A}}$) using OLS regressions, and then infer the parameters of the panel VAR by forcing the cross-country homogeneity restrictions in equation (13), evaluated at the unrestricted larger VAR parameters, to be as close as possible to zero in the metric defined by a suitable weighting matrix $\boldsymbol{W}$:

$$\widehat{\boldsymbol{\beta}} = \arg\min T\left[vec\left(\widehat{\boldsymbol{A}}\right) - \boldsymbol{G}\boldsymbol{\beta}\right]' \boldsymbol{W}\left[vec\left(\widehat{\boldsymbol{A}}\right) - \boldsymbol{G}\boldsymbol{\beta}\right], \tag{13}$$

$$\widehat{\boldsymbol{\beta}} = (\boldsymbol{G}'\boldsymbol{W}\boldsymbol{G})^{-1}\boldsymbol{G}'\boldsymbol{W}vec\left(\widehat{\boldsymbol{A}}\right), \tag{14}$$

where T is the sample size.

As in the case of the generalized method of moments estimation, (asymptotic) efficiency— in the sense that the difference between the asymptotic variance of the resulting MD estimator and another MD estimator based on any other quadratic form in the same distance function is negative semidefinite—gains can be achieved by selecting an appropriate weighting matrix. Specifically, we use the optimal weighting matrix, which, in our context, is the inverse of the asymptotic covariance of $vec\left(\widehat{\boldsymbol{A}}\right)$.[17] Further, the optimized value of the MD criterion function also has an asymptotic χ^2 distribution with degrees of freedom equal to the number of overidentifying restrictions, which we use to test the restrictions implied by our model (i.e., cross-country homogeneity).

[17] Alternatively, our panel VAR estimation can be thought of as a seemingly unrelated regression (SUR) system in which the error terms are correlated. Specifically, it can be shown that under a suitably chosen weighting matrix (for instance, the one used in this paper), the MD estimator is identical to the Feasible Generalized Least Squares estimator of the parameters of the SUR system (see Moon and Perron, 2008).

Finally, $\delta_{0,j}$ and $\boldsymbol{\delta}_j'$ are estimated by an OLS regression of the one-year yield on a constant and the country j's factors.[18]

E. Global Term Premia

Figure 3 displays our estimates for the decomposition of 10-year yields into the expectations and term premia for each of the six countries in our study. Figure 4 shows that our term premia estimates for all the countries are highly correlated across countries. Specifically, the average correlation across term premia estimates is 0.72 for the whole sample and increases to 0.86 in the post-2007 sample. This high correlation in the term premium component across countries is consistent with Rey's (2013, 2016) assertion of the existence of a global financial cycle in which the prices of risky assets around the world have an important common component (see, e.g., Miranda-Agrippino and Rey, 2012).

Given this large correlation among the cross-country term premia, we use a one-factor model to decompose changes in the term premia into a global and a country-specific component. Specifically, we estimate the following model by OLS:

$$tp_{j,t}^{(10)} = \beta_j gtp_{j,t}^{(10)} + ctp_{j,t}^{(10)}, \tag{15}$$

where $gtp_{j,t}^{(10)}$ is the first principal component of the cross-section of (10-year) term premia across countries, and $ctp_{j,t}^{(10)}$ is the residual resulting from this regression, which we interpret as the country-specific component of the term premium. We note that the R^2 resulting from this regression are the highest for Canada and Germany (92.0 per cent and 90.5 per cent, respectively) and the lowest for the United States and the United Kingdom (45.8 per cent and 51.9 per cent). The R^2 for Switzerland and Sweden fall in between, with values of 76.5 and 79.1 per cent, respectively.[19]

We interpret these results as indirect evidence that the United States' and the United Kingdom's government bonds might be less substitutable than the bonds of the rest of the countries in our sample, given that a large proportion of the variation in the term premia in these two countries seems to be explained by their country-specific risks rather than global factors. This could partly

[18] Note that unlike other papers in the literature (see, e.g., Christensen and Rudebusch, 2012, Bauer and Rudebusch, 2014, or Bauer and Neely, 2014), we do not impose a no-arbitrage restriction, nor we base our analysis on real-time (i.e. out-of-sample) estimations. Regarding the first methodological difference, our model can be considered as the reduced form of such a no-arbitrage model, and, consequently, such no-arbitrage restrictions can easily be imposed using the estimation method of Diez de los Rios (2015). However, in line with Joslin, Singleton and Zhu's (2011) theoretical result on the irrelevance of no-arbitrage restrictions for forecasting and the empirical results in Duffee (2011), we do not anticipate that imposing such restrictions will change our results. Regarding the second methodological difference, it is important to note that most of our results are qualitatively similar to those in these papers, despite that we use full-sample estimates to decompose interest rates.

[19] Adding a second global factor increases the percentage explained of the term premia in the United States and the United Kingdom by global factors to 72.2 per cent and 85.5 per cent, respectively. However, the results reported below remain qualitatively the same. If anything, a model with two factors tends to give more importance to the global term premium component in explaining movements in cross-country term premia than a model with a single factor.

be explained by the dominant role of the dollar (and to a lesser extent the British pound) in cross-border transactions and as a funding currency, and the position of New York and London in global financial markets (see, e.g., Goldberg and Tille, 2009, Gopinath, 2015, and Rey, 2016). This reserve currency status of the U.S. dollar makes it hard to substitute dollar-denominated assets with assets denominated in other currencies.

4. EVENT STUDY OF CENTRAL BANK ASSET PURCHASE PROGRAMS IMPLEMENTED IN SMALL OPEN ECONOMIES

In this section we use the estimates obtained using monthly data to analyze the response of long-term yields to the asset purchase programs announced by the BoE (section 4.A), the Swedish Riksbank (section 4.B) and the asset purchase and reserve expansion programs announced by the Swiss National Bank (section 4.C). Details on these announcements can be found in Tables 1, 3, and 5, respectively.

We analyze two-day changes in the 10-year yield and its components around central bank asset purchase announcements.[20] Our results and general findings of the paper remains robust to one-day changes in the 10-year yield. These decompositions can be found in Tables 2, 4, and 6. Specifically, they show the changes in the 10-year yield between the day before and the day after the announcement, as well as its decomposition into the expectations component and the global and country-specific components of the term premium. Tables 2, 4 and 6 are split into QE announcement dates by their own central bank, the Federal Reserve and the European Central Bank. In this section we focus on the response of bond yields to their own sovereign asset purchase announcement, whereas section 5 analyzes the movements in bond yields due to announcements by the Federal Reserve and ECB. We also follow Glick and Leduc (2012) in reporting *p*-values computed as the fraction of two-day changes in the sample from January 1, 2000, to November 30, 2016, that were smaller than the change on the announcement day.[21]

[20] For example, the term premium component can be expressed as an affine function of the factors: $tp_{j,t}^{(n)} = y_{j,t}^{(n)} - a_j^{(n)} - \boldsymbol{b}_j^{(n)\prime}\boldsymbol{f}_t$ with $a_j^{(n)}$ and $\boldsymbol{b}_j^{(n)}$ computed according to equation (6). Thus we obtain a daily estimate of $\widehat{tp}_{j,t}^{(n)}$ using daily data on $y_{j,t}^{(n)}$ and $\boldsymbol{f}_t$ (which are readily available) by plugging in our implied estimates of $a_j^{(n)}$ and $\boldsymbol{b}_j^{(n)}$ into the previous expression.

[21] Glick and Leduc (2012) compute two-sided *p*-values by focusing on the fraction of daily changes that were larger in absolute value than the change reported on the event day. We focus instead on one-sided *p*-values.

A. United Kingdom

We start by analyzing the results regarding the response of long-term yields to the BoE's asset purchase announcements. We firstly provide a quick summary of the BoE's QE program and then discuss our findings.

The Bank of England's QE program

The BoE's initial response to the financial crisis included cutting its policy rate from 5 per cent in October 2008 to 0.5 per cent in March 2009 and a wide range of measures directed towards supporting functioning of the financial market by providing liquidity support.[22] To this end, the BoE set up the Asset Purchase Facility (APF) Fund on January 30, 2009—a subsidiary of the Bank of England, but indemnified by the Treasury in order to protect the Bank of England from any potential losses. The APF was authorized to purchase up to £50 billion of private sector assets (i.e., corporate bonds and commercial paper) financed by the issuance of short-term gilts in order to improve liquidity in impaired credit markets.

In fact, on March 5, 2009, the BoE Monetary Policy Committee (MPC) decided, after cutting its policy rate from 1 per cent to 0.50 per cent, that further monetary stimulus was still needed. It thus expanded the APF's remit by (i) allowing purchases to be financed by issuing central bank reserves (instead of through the sale of short-term gilts) and (ii) expanding the range of eligible assets to include gilts. Specifically, the BoE's MPC announced that it would purchase £75 billion of assets over the subsequent three months and it would purchase gilts with a residual maturity of between 5 and 25 years. The size of the asset purchase program was subsequently increased, reaching £375 billion by the end of 2012, approximately 30 per cent of the stock of outstanding nominal government debt in the United Kingdom. In addition, the maturity buying range was also extended to include gilts with a residual maturity greater than three years in August 2009.

As well as additional extensions in the amount of asset purchases that the Bank of England conducted during 2011 and 2012, bringing the total up to £375 in July 2012, the BoE implemented further monetary easing in August 2016 following the United Kingdom's vote to leave the European Union. Specifically, the BoE decided, on the 4th of August 2016, to cut the Bank Rate by 25 bps to 0.25%, to increase corporate bond purchases by £10 billion and government bond purchases by £60 billion to £435 billion, and created the Term Funding Scheme, aimed at helping the interest rate cut pass-through to banks and consumers.

Results

Overall, we consider nine asset purchase announcements for the BoE's QE program. These dates, and their specific details, are described in Table 1. Our event set is similar to those analyzed in Christensen and Rudebusch (2012) and Joyce et al. (2011), with two differences:

[22] Further details of the BoE's QE program can be found in Cross, Fisher and Weeken (2010) and Joyce et al. (2011).

First, we include asset purchase announcements in 2011, 2012 and 2016 that followed the publication of these papers. Second, we exclude the announcement on February 4, 2010, given that the announcement did not indicate an expansion of the program. Our results remain qualitatively the same if we use the original event sets employed in these two papers.

The top panel of Table 2 summarizes the results regarding the response of long-term gilts to the BoE's asset purchase announcements. Interestingly, the first two dates in our event study for the BoE announcements (February 11, 2009, and March 5, 2009) had a significantly larger impact on 10-year yields compared with the subsequent events. The February date marks the publication of the Inflation Report, where the possibility of introducing QE was first raised, whereas the LSAP program was officially launched in March 2009. The yields on 10-year gilts fell 35 bps and 67 bps on these two dates, respectively. These two announcements differ, however, in the channel through which they affected the yields.

Following the BoE February 2009 announcement, almost the entire change in the yield is due to a fall in the expectations component (29 bps). The change in the term premium, on the other hand, is economically small (6 bps) and not significant at the 5 per cent level. Such movement can potentially be explained by the fact that, at the time, the policy rate was still 50 bps above the considered effective lower bound, and no purchases were made, nor any details regarding future purchases announced. As such, the February 2009 BoE Inflation Report was mainly viewed as a signal of the impending rate cut later announced at the March 2009 meeting of the BoE's MPC.

On the other hand, the term premium fell significantly subsequent to the launch of the BoE's QE program in March 2009. The 56 bps drop in term premia, roughly 80 per cent of the total drop in long-term yields, is mainly due to the fall in the country-specific term premium (42 bps). While the fall of the global component of the term premium is small (14 bps) compared with the overall reduction in 10-year gilt yields, it is still both economically important and statistically significant, and while unreported from the sake of space, it is also the main contributor to the fall in the yields of the rest of the countries that day. In fact, given our hypothesis that small open economies cannot affect the global we interpret the change in the global term premium component to partly reflect that the March 5, 2009, BoE announcement could have been interpreted by investors as signaling the impending start of the Federal Reserve's purchase of U.S. Treasury bonds (as indeed was the case two weeks later on March 18, 2009).

The last asset purchase announcement in our sample (August 4, 2016), after the U.K. voted to leave the E.U., does have a downward effect on 10-year gilt yields acting through both the signaling and portfolio balance channels. However, the impact is smaller than the initial announcements in our study and it doesn't affect the global term premium component. While, interpreting these results is difficult due to the multiplicity of measures used by the Bank of England as well as the increased uncertainty for the future of the U.K. surrounding this

announcement, this result seems to validate that small open economies cannot affect the global term premium.

Note that, similar to the case of the Federal Reserve's QE program and consistent with Haldane et al. (2016), subsequent rounds of asset purchases by the BoE tend to have a much lower impact on yields; in fact, yields even increased around certain announcements. We propose three potential explanations for this result. First, these results are consistent with the view that investors may have partially anticipated some of the BoE's asset purchases. Second, it can be the case that the full effect of the announcement is only partially captured by two-day changes. For example, Greenwood, Hanson and Liao (2016) propose a model where, due to institutional and informational frictions, capital across asset classes moves slowly and therefore the full effect of an asset purchase program can take longer than two days to take full effect. Third, it could be possible that the BoE program was too small to counteract the concurrent monetary expansions embarked on by the Fed through their corresponding asset purchase programs.

B. Sweden

We now turn to the response of long-term Swedish yields to the Riksbank's asset purchase announcements.

The Riksbank's QE program

In order to fight low inflation in Sweden in 2013–14, and especially a sharp fall in inflation expectations in late 2014 and early 2015, mainly due to the appreciation of their exchange rate, the Riksbank announced in February 2015 the purchases of government bonds with maturities up to five years for the amount of SEK 10 billion.[23]

Simultaneously, the Riksbank cut its repo rate by 10 bps to -0.10 per cent, taking it into negative rate territory for the first time in the history of Sweden, and emphasized that, if necessary, it would take further measures, even between the ordinary monetary policy decisions. Indeed, in March 2015, between two regular monetary policy meetings, the Executive Board of the Riksbank decided to cut the repo rate by a further 15 bps, to increase purchases of government bonds by SEK 30 billion and to extend the maturity of bonds purchased to beyond five years. Further asset purchases were announced on five other occasions between 2015 and 2016, and the repo rate was eventually lowered to -0.50 per cent. The subsequent purchases were significantly larger than the initial SEK 10 billion (ranging between SEK 45 billion to 200 billion), and reached SEK 245 billion by April 2016, approximately 40 per cent of the stock of outstanding nominal government debt in Sweden.[24]

[23] Prior to the announcement of asset purchases, the Riksbank established a securities portfolio in October 2012, in order to ensure that the required systems, agreements and knowledge were in place if the need to take extraordinary measures arose.
[24] Further details of the Riksbank's QE program can be found in De Rezende (2016).

Results

Table 3 provides specific details on the Riksbank's seven asset purchase announcements.

Our results pertaining to Riksbank's asset purchase announcements seem to indicate that changes in the yields were the largest on dates when both an increase in the size of the asset purchase program was announced and the policy rate was cut. This is the case of the initial Riksbank's QE announcement in February 2015, when Swedish yields fell 15 bps, and with the announcements in March 2015 and July 2015, when yields fell 13 bps and 17 bps, respectively (see Table 4). Not surprisingly, most of the fall in Swedish yields on these three dates is mainly due to the expectations component of interest rates (-13.5, -7, and -13 bps, respectively). The drop of the term premium for the Riksbank's March 2015 announcement is mostly due to a fall in the global component of the term premium (which, although statistically significant, is economically trivial). In the case of the July 2015 announcement, the fall in the term premium is due to the country-specific component. However, the magnitude of the fall (4 bps) is neither economically nor statistically significant.

Given the small number of announcements, it is difficult to differentiate between the effect of the LSAP announcement and that of the rate cut into negative territory.[25] However, three factors suggest that the QE-specific effects were small in the case of the Riksbank's program: First, the fall in yields around the announcement days when there was no policy rate cut was small, or indeed the yields rose on certain occasions. Second, most of the effect on long-term yields comes from the signaling channel (which should stronger for rate cuts). Third, whenever term premia were affected, the reduction was due to a lowering of the global term premia.[26]

Contrary to the experience of the U.S. asset purchase program (and to a lesser extent the U.K. program as well), and unreported for the sake of space, the effects of the Riksbank asset purchase announcements are almost entirely associated with Swedish yields. Only on one occasion (March 2015) did the global term premium component of Swedish bond yields significantly fall following an announcement in Sweden. This observation is consistent with the idea that, as a small open economy, the effect of Sweden's asset purchase programs on other countries' bond yields tends to be negligible. In other words, these results seem to suggest that the central banks of small open economies cannot purchase enough domestic (or foreign) assets to significantly shift the global term premium via domestic quantitative easing.

[25] See De Rezende (2016) for an attempt to disentangle these two effects for assessing the effectiveness of the Riksbank's QE program.

[26] Alternatively, it could be that investors may have partially anticipated some further asset purchases or even further rate cuts on these *pure* QE announcements. For example, it seems that investors had formed expectations of further rate cuts for the April 2015 policy decision, which led to an increase in the Swedish bond yields by 13 bps as market participants repriced their expectations.

C. Switzerland

In this section, we analyze two of the unconventional monetary policy programs implemented by the SNB: the asset purchase program implemented in 2009 and the reserve expansion program implemented in 2011. It is important to bear in mind that, in contrast to the QE programs in the United States, United Kingdom and Sweden, which all included purchases of domestic bonds, the SNB so far has not bought Swiss government bonds. Moreover, as in the case of the Riksbank QE program, the response of the SNB was motivated by an appreciation of their currency since the financial crisis of 2007. Still, we believe these programs provide an interesting and different perspective on which channels are at play when one considers unconventional monetary policies in small open economies.

The Swiss National Bank's Asset Purchase Program

On March 12, 2009, the SNB adopted a number of monetary policy tools aimed at fighting the deflationary pressures building in the Swiss economy as a consequence of the strong appreciation of the Swiss franc due to its status as a safe-haven currency.[27] These unconventional measures included foreign exchange intervention, the extension of the maturity for repo operations, and a (small) bond purchase program targeted at Swiss franc private sector bonds. The measures aimed to improve liquidity conditions as well as lower the upward pressures on the exchange rate.

Although at the time of the announcement no specific information about the intended size or type of bonds was given, it was eventually made public that the SNB purchased covered and corporate bonds. Later, in December 2009, the SNB announced that the bond purchase was complete. Uniquely among the programs we have considered, the SNB subsequently sold the purchased bonds, discretely, between March and August 2010. At the height of the program, bond purchases totaled CHF 3 billion: a small program when compared with the size of the one undertaken by the Federal Reserve.

Expansion of reserves

Against the backdrop of the market turmoil caused by the European debt crisis of 2011, which led to a rapid appreciation of the Swiss franc and increased deflationary concerns for the Swiss economy, the SNB announced on August 3, 2011, that it would lower the top of the operating band for the Swiss franc LIBOR from 75 to 25 bps and would expand reserves held at the SNB.[28] In this case, the SNB expanded its balance sheet through purchases of short-term debt securities, repo operations and short-term foreign exchange swaps (rather than through the purchase of long-term Swiss franc bonds, whose market supply remained constant). The

[27] Further details of the SNB's QE program can be found in Mirkov and Sutter (2011) and Kettemann and Krogstrup (2014).

[28] Further details of the SNB reserve expansion program can be found in Christensen and Krogstrup (2016a), among others.

objective of this policy was to put downward pressure on money market interest rates and thus counter the Swiss franc overvaluation.

As the exchange rate continued to appreciate after this announcement, the SNB announced two additional reserve expansions on August 10 and August 17 and also used foreign exchange swaps to implement the reserve expansion. In sum, reserves were expanded from CHF 30 billion to 200 billion—an increase equivalent to approximately 30 per cent of Swiss GDP in 2011.

In fact, Bernanke and Reinhart (2004) and, more recently, Christensen and Krogstrup (2016a) have pointed out that alternative portfolio balance effects also arise due to the increase in the supply of central bank reserves that accompanies a typical LSAP program. The logic relies on the fact that only banks can hold reserves, whereas central banks can purchase assets from banks and non-banks. As a result, the banks may end up with portfolio durations that are shorter than optimal, inducing them to buy long-term bonds. In this sense, an increase in the supply of central bank reserves can put upward pressure on bond prices in particular, and asset prices in general, even if the supply of long-term bonds remains intact. In contrast to the traditional supply-induced portfolio balance effect described above, Christensen and Krogstrup (2016a,b) refer to this new channel as a reserve-induced portfolio balance channel.

Table 5 shows the details of the four dates that we focus on in this paper (the announcement to purchase Swiss Franc denominated bonds in 2009 and SNB's three reserve expansion announcements in 2011.).[29]

Our results suggest that the SNB asset purchase program announcement in March 2009 had a very limited effect. In this case, Swiss bond yields fell by 6 bps (see Table 6). Specifically, most of the drop in yields was due to the expectations component, which fell around 11 bps, which implies a 5 bps increase in the term premium component (mainly due to the increase in the country-specific component of the term premia). This contrasts with the results in Kettemann and Krogstrup (2014), which suggest that the SNB's bond purchase program had an effect on the yields of the purchased (private sector) bonds.

While the Swiss asset purchase program did not include the purchase of government bonds, we would have expected spillover effects from private sector bonds and thus a reduction in the yields of Swiss government bonds (as they are, in principle, close substitutes). Thus, we should have seen the term premium component of Swiss government bonds falling as well (as happened in the United States when the Fed bought agency bonds). We attribute this slightly puzzling result to the lack of specific information about the intended size and type of bonds,

[29] Non-QE announcements have also been analyzed but are not included in this paper. These include, the announcement of a minimum exchange rate in September 2011, the introduction of a negative interest rate in December 2014 and the abolishment of the minimum exchange rate in January 2015. Only the announcement in January 2015 managed to push the 10-year bond yield significantly downwards, with the majority of this fall coming through the expectation channel.

thus potentially leading to increased uncertainty in the market. Moreover, we find no evidence of international spillover effects, neither signaling nor portfolio balance.

As for the reserve expansion program, the only significant reduction in yields occurs around the third reserve expansion announcement, on August 17, 2011, where yields drop by 20 basis points. The majority—close to 70 per cent—of this reduction in yields is due to lower term premia. This result is consistent with those of Christensen and Krogstrup (2016a), who also study the SNB's reserve expansion program. However, our results differ slightly from theirs in that our model gives more weight to the signaling channel. We believe that the difference in results are not completely surprising, given that Christensen and Krogstrup (2016a) do not deal directly with the persistence problem inherent in interest rates and therefore are likely to give more weight to the portfolio balance channel than us (see, e.g., the discussions in Christensen and Rudebusch, 2012, and Bauer and Rudebusch, 2014).

More importantly, our model seems to attribute 60 per cent of the drop in the term premium component to global factors. Under the assumption that a small open economy is unlikely to affect the global component of the term premium, the contribution of the reserve-induced portfolio balance channel to the fall on bond yields on August 17 was 6 bps (i.e., the fall in the country-specific term premium component). Although this is statistically significant, and thus in favour of the existence of a reserve-induced portfolio balance channel, it is lower than the 20 bps contribution found by Christensen and Krogstrup (2016a). Along these lines, it is important to point out that on August 18, 2011, there was a major sell-off in European bank stocks and an increase in market volatility due to market rumours that the ECB dollar facility was tapped for the first time since early 2011 (see Appendix H in Christensen and Krogstrup (2016a) for a list of important events in August and September 2011). This sell-off in European stocks likely led international investors to purchase government bonds around the world (a flight-to-quality event) thus pushing their yields down during the same window that we are trying to measure the effects of the third reserve expansion announcement. Unlike previous papers in the literature, our decomposition of the term premium into a global and a country-specific component allows us to control for the effects of these global events when analyzing the impact of asset purchases in small open economies

Due to the nature of monetary policy announcements, such that the SNB actively tried to influence their exchange rate and eventually instilled a minimum exchange rate, it is expected that exchange rate movements around these announcements should be significant. Analysis of exchange rates movements around asset purchase announcement dates can be found in appendix C. However, these serve as preliminary results used to explore the potential strength of an exchange rate channel for bond yields of SOE as the existence of such channel has already been found for the U.S. by Glick and Leduc (2012, 2015) and Neely (2015).

5. Spillover Effects from The Central Bank Asset Purchase Programs in Large Economies

In this section, we analyze the response of long-term yields in small open economies to the asset purchase programs announced by the Federal Reserve and the ECB, as these provide natural benchmarks against we can measure the effectiveness of the asset purchase programs implemented by small open economies. The small open economies included in this analysis are the United Kingdom (section 5.C), Sweden (section 5.D) and the Switzerland (section 5.E). Details on Fed and ECB asset purchase announcements can be found in Tables 7 and 8.

Tables A1 and B1, provide results of the Federal Reserve and European Central Bank asset purchase announcements, respectively, and accompanying analysis can be found in the appendix. Tables 2, 4 and 6 contrast the effectiveness of the announcements of asset purchase programs by smaller open economies with that of the Fed and ECB on sovereign bond yields.

A. United States

We start by outlining the Federal Reserve's LSAP programs. Since this asset purchase program has been thoroughly studied (see, e.g., Gagnon et al., 2011, Krishnamurthy and Vissing-Jorgensen, 2011, Hamilton and Wu, 2012, and Glick and Leduc, 2015, among others), we move our results on U.S. bond yields to the appendix. However, through the lens of our model we are able to view the effectiveness of the program in bringing down long-term interest rates in the United Kingdom, Sweden and Switzerland through the global term premium channel. This decomposition of term premia into global and country-specific components allows us to provide additional insight into how the international portfolio balance channel operates.

The Federal Reserve's QE Programs

We start by briefly describing the three rounds of the asset purchases undertaken by the Federal Reserve between November 2008 and October 2014. The first round (QE1) was initiated in November 2008 when the Federal Reserve announced the purchase of up to $100 billion of agency debt and up to $500 billion of mortgage-backed securities. It was subsequently extended in March 2009 with the announcement of the additional purchase of up to $850 billion of agency debt and $300 billion in longer-dated Treasury securities.

In November 2010, the Federal Reserve announced yet another bond buying program (QE2), which involved buying an additional $600 billion worth of longer-dated U.S. Treasury bonds by mid-2011. A third round of purchases was announced in September 2012 (QE3). In this case, the Federal Reserve announced it would spend close to $40 billion per month in mortgage-backed securities.

Following QE2 and reports that economic growth remained slow the Federal Reserve decided to implement the Maturity Extension Program[30], which involved extending the average maturity of the Federal Reserve's bond holdings. In the September 2011 FOMC statement the intent to purchase $400 billion of long-term treasury securities (6 to 30 year maturities) and to finance this by selling an equal amount of short-term treasury bills (with 3 years or less maturity) was announced. In June 2012 this program was extended by a further $267 billion. Due to the nature of this program it should depress long-term bond yields only through the term premia channel.

Specifically, we consider 16 asset purchase announcements related to the three rounds of asset purchases implemented by the Federal Reserve. These dates, and their specific details, are described in Table 7. For our comparison exercise, where we compare how U.K., Swedish and Swiss bond yields move following Federal Reserve QE announcements. We focus on first round of QE implemented by the Federal Reserve, i.e. QE1, as it has the larger impact on global bond yields, as shown in panel B of Table A1 in the appendix (where we present results comparing the three rounds of QE) and Bauer and Neely (2014).

B. Euro Area

As well as analyzing the effects of the Federal Reserve's announcements we also further test our hypothesis by using the announcements made by the European Central Bank. The affect of ECB QE announcements on German bunds can be found in Appendix B.

The European Central Bank's QE Programs

The ECB quantitative easing programme officially started in January 2015 under the expanded asset purchase programme (APP). The selection of dates was motivated by previous studies of the ECB QE programme, mostly notably Altavilla, Carboni and Motto (2015), Andrade et al (2016) and De Santis (2016). However, we also include one announcement related to the Securities Market Programme (SMP), as in Rogers, Scotti and Wright (2014), given that, despite being sterilized and therefore the liquidity provided should not affect the stance of monetary policy set by the ECB, its goal was to support liquidity within the debt markets in order to restore the transmission mechanism of monetary policy. Specifically, we include August 8, 2011 as part of our set of announcements, which was the first trading day after the ECB officially acknowledged the use of the SMP by both Spain and Italy.

In January 2015, the official ECB QE programme was announced under the expanded asset purchases programme (APP), which encompasses the asset-backed securities purchase programme (ABSPP), public sector purchase programme (PSPP) and the third wave of the covered bond purchase programme (entitled CBPP3). The aim of which was to address the risks

[30] This is also known as "Operation Twist" as treasury bond yields are depressed at the longer maturities and pushed up at the shorter end of the yield curve.

of a prolonged period of low inflation by easing monetary and financial conditions through purchasing sovereign bonds and lowering their effective interest rate.

The total combined monthly purchases of €60 billion announced on 22 January 2015 was to be carried out until at least September 2016. This programme started purchasing euro-denominated public sector securities in the secondary market on 9 March 2015. However, the purchase of private assets through ABSPP and CBPP3 has been ongoing since 2014. This programme was expanded to allow for monthly purchases of €80 billion and included a corporate sector purchase programme (CSPP). The CSPP will purchase euro-denominated corporate sector bonds. This altered asset purchase programme started on 8 June 2016.

The ECB QE programme may already have been priced into global bond yields and expected from late 2014, limiting the magnitude of the 2015 announcement further.[31] Moreover, the ECB had already completed "QE like" programmes through their implementation of the securities market programme and announcement of their outright monetary transaction programme. Furthermore, the official ECB QE started in January 2015, occurring after the U.S. program and 8 years after the start of the global financial crisis. This could dampen the effect of the ECB QE on global term premium as there is evidence that the effectiveness of quantitative easing is related to the state of the economy (see, e.g., Altavilla, Carboni and Motto,2015 and Haldane et al., 2016).

C. Results of Fed & ECB QE announcements on UK bond yields

The asset purchase announcements by the Federal Reserve had a strong negative impact on UK bond yields, working through the expectations and global term premium channel (Table 2). This contrasts with the BoE's own QE announcements which, apart from February 2009 and March 2009, did not significantly impact the global term premium and therefore the 10-year bond yields of the rest of the countries in our sample. The announcements by the Federal Reserve during December 2008 dampened UK bond yields through the expectation channel as only an indication that the FOMC were considering purchasing long-term US treasuries was conveyed and a Fed funds rate cut was implemented, making it likely that the BoE would also reduce their Bank Rate. Nonetheless, when the Federal Reserve announced in March 2009 that it would purchase $300 billion in Treasury securities was announcement in March 2009 by the Federal Reserve, the global term premium component of UK bond yields falls by 9.4 bps.

Analyzing UK bond yield movements around ECB QE announcement dates provides a similar, but subdued, story. The global term premium component of UK bond yields fell by 4.7 bps due to the ECB QE programme starting in March 2015 and later by 3.9 bps when the expanded program of €80 billion per month and the corporate sector purchase programme began. This supports the hypothesis that the asset purchase programs implemented by the central banks of

[31] This can be seen in a working paper by De Santis (2016) as mentions of "Draghi, QE or quantitative easing, sovereign, euro area" spike in the news around late 2014/early 2015. It is also provided as a justification to explore earlier ECB announcements, interviews and press releases by Altavilla, Carboni and Motto (2015)

larger economies, such as the US and the Eurozone, have an effect on global bond yields through the global term premium channel, affecting the yields of even sizable small open economies such as the UK.

D. Results of Fed & ECB QE announcements on Swedish bond yields

On average, the effects of the announcement of asset purchases, , made by the Federal Reserve and ECB on Swedish bond yields are both larger in magnitude and more significant than the effects of the announcements made by the Riksbank. Moreover, the announcements by the larger economies can be seen affecting the expectation and term premium channel of Swedish bond yields. The announcements by the Federal Reserve in December 2008, one of which included a Fed funds rate cut, worked mostly through the expectation channel likely foreshadowing further cuts in interest rates for smaller open economics, such as the repo rate of the Riksbank which fell from 3.75 in early December 2008 to 0.25 by August 2009. The largest change in global term premium of Swedish bonds is from the Federal Reserve announcement of March 2009 that included purchasing $300 billion in Treasury securities.

The asset purchase announcements by the ECB and the Riksbank provide a fairer comparison as they occur during the same period, 2015-2016, and therefore should nullify the effect found in Haldane et al (2016) that the effectiveness of QE depends on the condition of the economy. Here we find that the January 2015, March 2015 and June 2016 asset purchase announcements of the ECB all have a significant negative impact on Swedish bond yields of around 10 bps with two out of the three announcements also providing a significant negative effect through the global term premium channel.

E. Results of Fed & ECB QE announcements on Swiss bond yields

Evaluating the impact of Federal Reserve and ECB asset purchase announcements compared to that of Switzerland is an interesting case to study given that Swiss bond yields were already negative during the ECB QE programme announcements, thus limiting the possible movement of the global term premium channel. However, as seen in Table 6, announcements by the Federal Reserve and the ECB are still able to affect Swiss bond yields through the expectations and global term premium channel. Specifically, comparing the Federal Reserve asset purchase announcement of 18 March 2009 with that of Switzerland's asset purchase announcement on 12 March 2009 we find that the U.S. announcement had a stronger effect on Swiss Bond yields (9.3 bps fall compared to a reduction of 5.6 bps) and from the Fed announcement, 8.7 bps of this decrease in Swiss bond yields is through the global term premium channel. This finding is likely due to the larger overall amount of assets purchased by the Federal Reserve compared to the SNB. ECB's QE programme announced in January 2015 has a large impact on Swiss bonds yields through the expectations channel, perhaps as the market expected the SNB to later react to the future influx of euros, which would put upward pressure on the CHF-EUR exchange rate. The dates when the ECB asset purchases started and expanded, March 2015 and June 2016,

respectively, affect Swiss bond yields through the global term premium channel, however the impact is relatively small.

6. FINAL REMARKS

We have examined the effects of asset purchase programs undertaken by the Federal Reserve, the BoE, the Riksbank and the SNB and their ability to reduce long-term government bond yields. To this end, we have decomposed government bond yields in these countries into three components: (i) the expectations component, (ii) a global term premium and (iii) a country-specific term premium component. We have used this decomposition in an event study to analyze two-day changes on 10-year yields around announcement days to shed light on the effectiveness of these asset purchase programs.

Our analysis suggests that, in general, asset purchase announcements by the larger economies in our sample, i.e., the U.S. and Eurozone, significantly lower bond yields of the smaller economics through the global term premium channel. The most dominant effect is seen from the QE1 announcement by the Federal Reserve due to its large size, relatively early implementation and lack of substitutable assets for U.S Treasuries. Specifically, the initial asset purchase announcement on 18 March 2009 by the Federal Reserve had a larger impact on Swiss bond yields than their own asset purchase program announced earlier on 12 March 2009. Following a similar explanation, the QE programme announced by the ECB also affects global bond yields although its effects were subdued as purchases were smaller and occurred at a time of less economic stress. However, on average, QE1 announcements by the Federal Reserve and ECB QE announcements both lower Swedish bond yields by more than the announcements made by the Riksbank. Our explanation for this observation is the relatively small size of the asset purchase programs in small open economies when compared with the size of the pool of substitutable assets, which includes foreign bonds. Consequently, we argue, these programs have had limited effect in reducing long-term interest rates.

One open question is whether the limits to the effectiveness of asset purchases in lowering long-term interest rates in small open economies would force most of the portfolio balance adjustment through the exchange rate channel, or whether the exchange rate adjustment would be limited as well. For example, Glick and Leduc (2012, 2015) and Neely (2015) find that the U.S. dollar tended to depreciate around the Federal Reserve's asset purchase announcements. We leave this issue for further research.

Figures and Tables

Figure 1. Estimated Factors

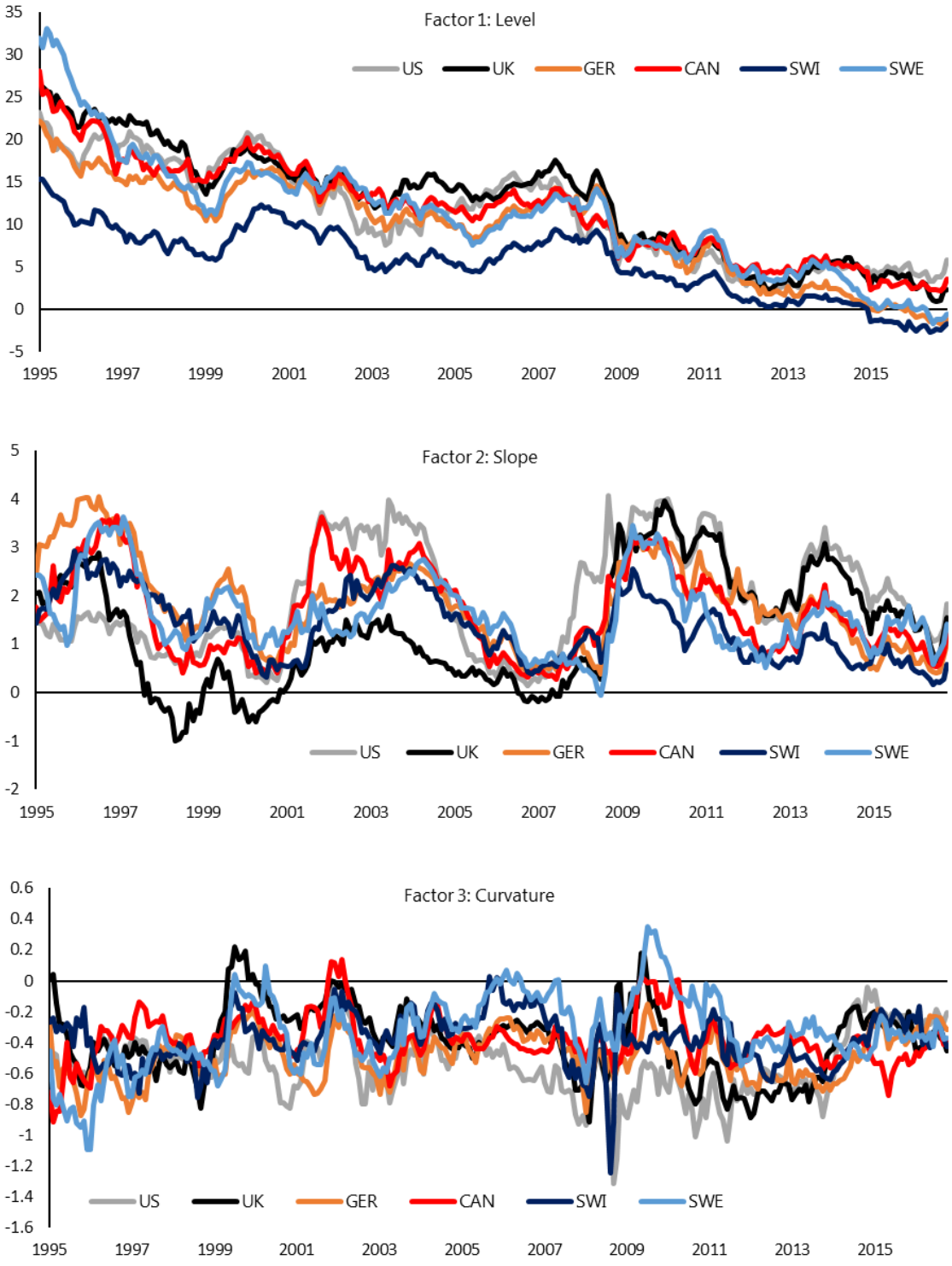
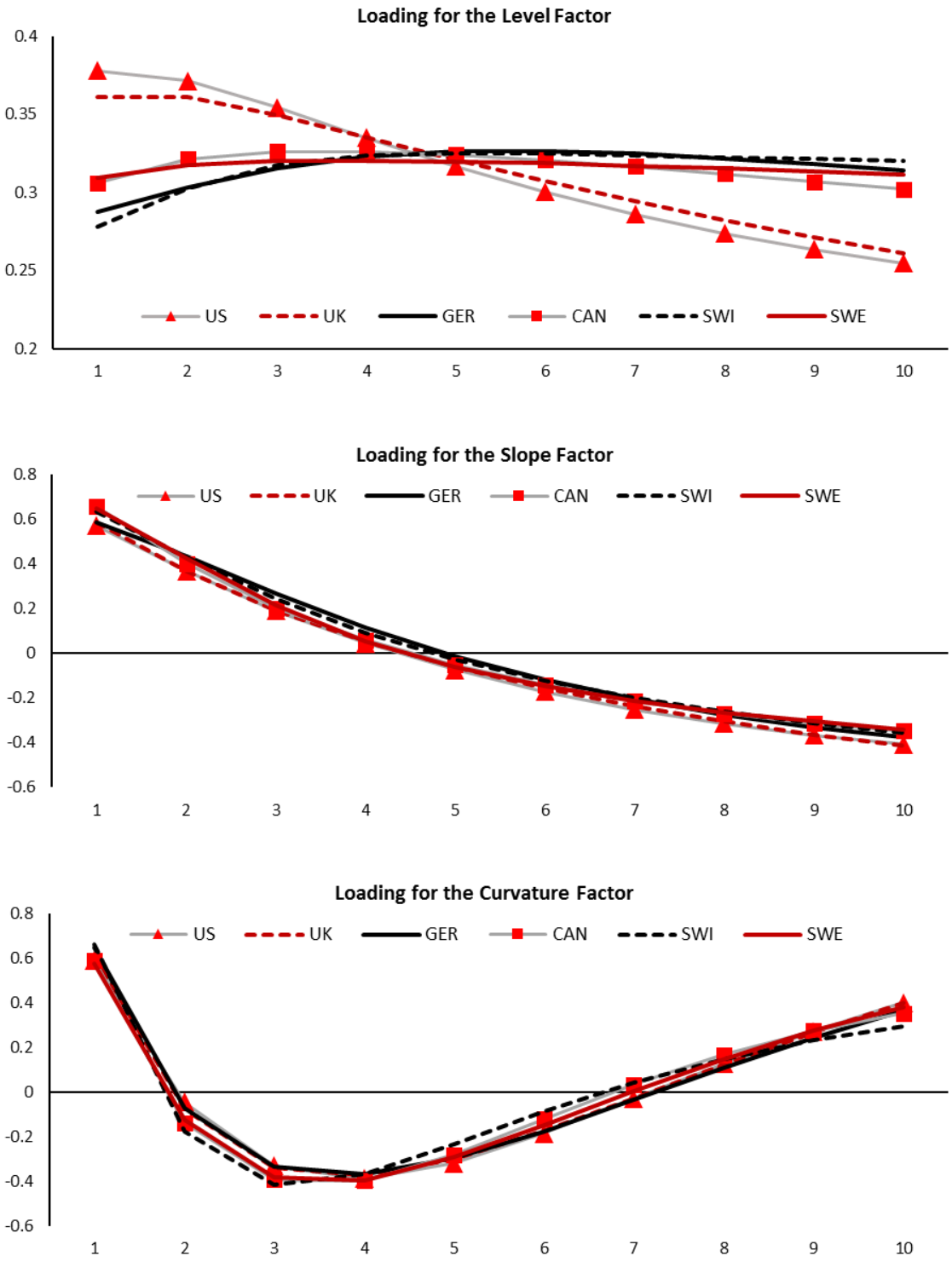
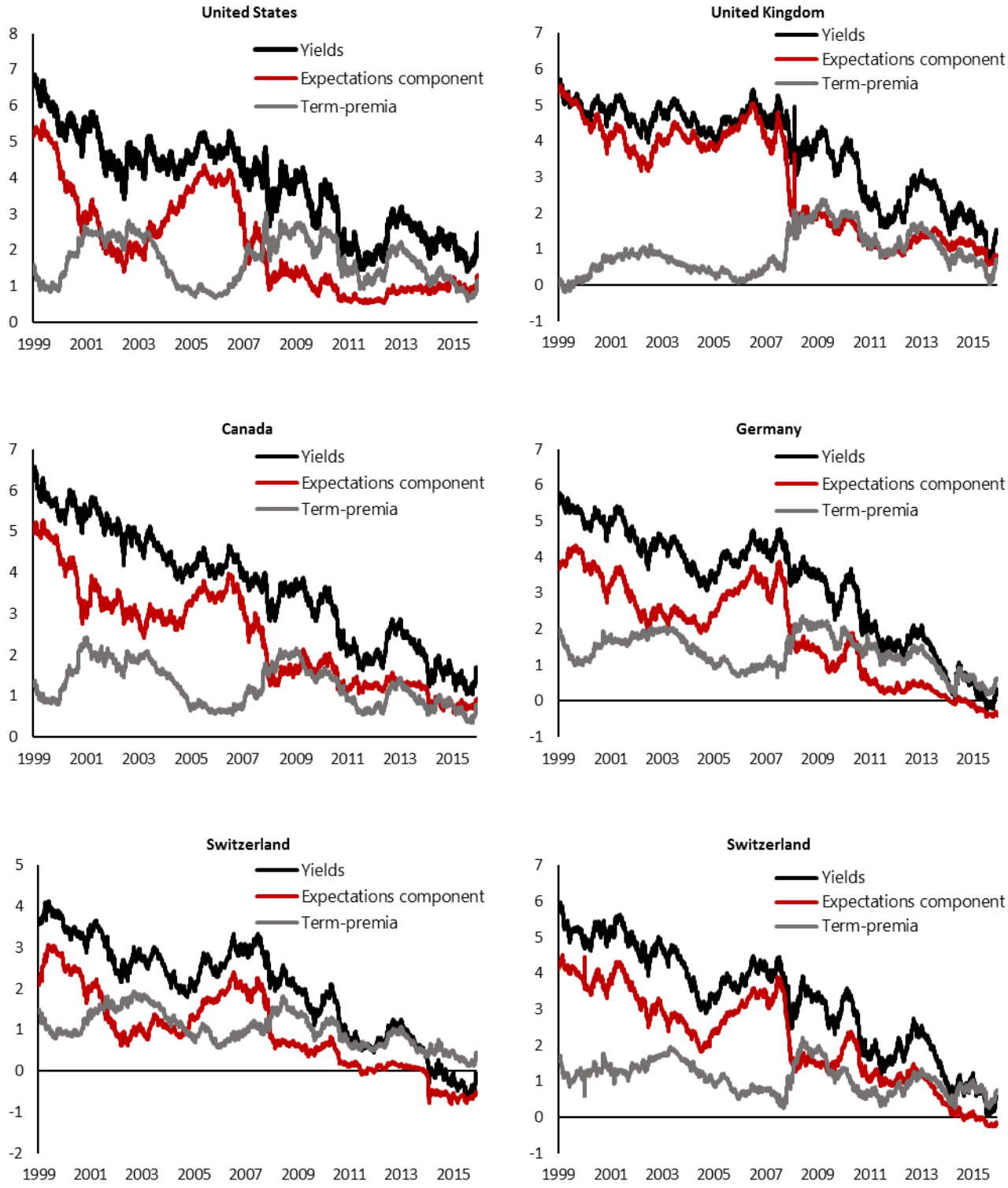


Figure 2. Factor Loadings on Principal Components



This figure represents the factor loadings for the three factors found using Principal Component Analysis on the bond yields at different maturities for 6 countries in our sample as outlined in Equation (2) above.

Figure 3. Yield Decomposition by Country



Following Equation (5) and (6) country specific bond yields are decomposed into expectations and term-premia components using a VAR. The computations and figures were constructed using daily data from 12/31/1999-06/30/2016.

Table 1. Bank of England Asset Purchase Announcements

Date	Program	Event	Description
11-Feb-09	UK-QE	February Inflation Report	Press conference and Inflation Report indicated that asset purchases were likely.
5-Mar-09	UK-QE	MPC Statement	The MPC announced that it would purchase £75 billion of assets over three months financed by central bank reserves. Gilt purchases were to be restricted to bonds with a residual maturity of between 5 and 25 years. Also, the policy rate was cut from 1% to 0.50%.
7-May-09	UK-QE	MPC Statement	The MPC announced that the amount of QE asset purchases would be extended to £125 billion.
6-Aug-09	UK-QE	MPC Statement	The MPC announced that the amount of QE asset purchases would be extended to £175 billion and that the buying range would be extended to gilts with a residual maturity greater than three years.
5-Nov-09	UK-QE	MPC Statement	The MPC announced that the amount of QE asset purchases would be extended to £200 billion.
6-Oct-11	UK-QE	MPC Statement	The MPC announced that the amount of QE asset purchases would be extended to £275 billion.
9-Feb-12	UK-QE	MPC Statement	The MPC announced that the amount of QE asset purchases would be extended to £325 billion.
5-Jul-12	UK-QE	MPC Statement	The MPC announced that the amount of QE asset purchases would be extended to £375 billion.
4-Aug-16	UK-QE	MPC Statement	he MPC announced a 25-basis point reduction in the Bank Rate; a new Term Funding Scheme; purchase of up to £10 billion corporate bonds; expansion of UK government bond purchases to £435 billion.

Table 2. Changes of UK Bond Yields on Fed, ECB and BoE Asset Purchase Announcement Days

Program	Date	10y Yield	Expectations	Term Premium	Global Term Premium	Country-Specific Term Premium
			United Kingdom			
UK-QE	11-Feb-09	-35***	-29.1***	-5.9*	-5.5**	-0.4
		(0.00)	*(0.00)*	*(0.05)*	*(0.02)*	*(0.42)*
	05-Mar-09	-67***	-11.3**	-55.7***	-14.2***	-41.5***
		0.00	*(0.01)*	*(0.00)*	*(0.00)*	*(0.00)*
	07-May-09	10	4.5	5.5	8.2	-2.7
		(0.92)	*(0.89)*	*(0.92)*	*(0.99)*	*(0.12)*
	06-Aug-09	-3	-1.2	-1.8	0.9	-2.7
		(0.31)	*(0.39)*	*(0.30)*	*(0.69)*	*(0.12)*
	05-Nov-09	10	-0.1	10.1	2.8	7.3
		(0.93)	*(0.51)*	*(0.99)*	*(0.89)*	*(0.99)*
	06-Oct-11	12	4.1	7.9	6.1	1.8
		(0.95)	*(0.87)*	*(0.97)*	*(0.98)*	*(0.78)*
	09-Feb-12	-5	-4.4	-0.6	-0.8	0.2
		(0.22)	*(0.14)*	*(0.44)*	*(0.37)*	*(0.55)*
	05-Jul-12	-11**	-7.2**	-3.8	-3.7*	-0.1
		(0.05)	*(0.05)*	*(0.14)*	*(0.05)*	*(0.48)*
	04-Aug-16	-15**	-6.5*	-8.5**	-2	-6.5**
		(0.02)	*(0.07)*	*(0.02)*	*(0.19)*	*(0.01)*
	Average	-11.6**	-5.7*	-5.9*	-0.9	-5**
		(0.04)	*(0.09)*	*(0.06)*	*(0.35)*	*(0.03)*
US-QE1	25-Nov-08	-16**	2.9	-18.9***	-10.3***	-8.6***
		(0.01)	*(0.80)*	*(0.00)*	*(0.00)*	*(0.01)*
	01-Dec-08	-23***	-28***	5	-3*	8
		(0.00)	*(0.00)*	*(0.91)*	*(0.10)*	*(0.99)*
	16-Dec-08	-24***	-17.9***	-6.1*	-8.1***	2
		(0.00)	*(0.00)*	*(0.05)*	*(0.00)*	*(0.80)*
	28-Jan-09	2	-1.5	3.5	3.2	0.3
		(0.66)	*(0.37)*	*(0.84)*	*(0.91)*	*(0.55)*
	18-Mar-09	-4	-4.4	0.4	-9.4***	9.8
		(0.26)	*(0.14)*	*(0.57)*	*(0.00)*	*(1.00)*
	Average	-13**	-9.8**	-3.2	-5.5**	2.3
		(0.03)	*(0.02)*	*(0.18)*	*(0.02)*	*(0.83)*
ECB-QE	08-Aug-11	1	1.4	-0.4	-3*	2.6
		(0.57)	*(0.67)*	*(0.47)*	*(0.10)*	*(0.86)*
	22-Jan-15	-1	-1.9	0.9	-2.9	3.8
		(0.45)	*(0.33)*	*(0.62)*	*(0.11)*	*(0.93)*
	09-Mar-15	-15**	-6.2*	-8.8**	-4.7**	-4.1**
		(0.02)	*(0.08)*	*(0.02)*	*(0.03)*	*(0.05)*
	10-Mar-16	11	7.8	3.2	3	0.1
		(0.94)	*(0.96)*	*(0.82)*	*(0.90)*	*(0.53)*
	08-Jun-16	-3	1.2	-4.2	-3.9**	-0.3
		(0.33)	*(0.65)*	*(0.12)*	*(0.05)*	*(0.45)*
	Average	-1.4	0.5	-1.9	-2.3	0.4
		(0.42)	*(0.58)*	*(0.29)*	*(0.16)*	*(0.58)*

P-values are presented in parentheses and significance levels are at the *10% **5% and ***1% levels. We follow Glick and Leduc (2012) in reporting *p*-values computed as the fraction of two-day changes in the sample from January, 1, 2000 to November 30, 2016 that were smaller than the change on the announcement day. Principal Component Analysis is used to seperate the yield curve into level, slope and curvature, which is then decomposed further into term premia and expectation components using a VAR. Following, we separate the term premia into global and local factors using a one-factor model.

Table 3. Swedish Riksbank Asset Purchase Announcements

Date	Program	Event	Description
12-Feb-15	SWE-QE	Repo rate decision	The Executive Board announced it would cut the repo rate from 0% to −0.10% and that the Riksbank would buy government bonds for the sum of SEK 10 billion.
18-Mar-15	SWE-QE	Repo rate decision	The Executive Board decided to cut the repo rate by 15 bps to -0.25% and to buy government bonds for SEK 30 billion.
29-Apr-15	SWE-QE	Repo rate decision	The Executive Board decided to extend the purchase of nominal government bonds by a further SEK 40–50 billion to a total of SEK 80–90 billion.
2-Jul-15	SWE-QE	Repo rate decision	The Executive Board decided to cut the repo rate by 10 bps to −0.35% and to extend the purchase of government bonds to a total of SEK 125–135 billion with effect from September and until the end of the year.
28-Oct-15	SWE-QE	Repo rate decision	The Executive Board decided to extend the government bond purchasing program to a total of SEK 200 billion.
21-Apr-16	SWE-QE	Repo rate decision	The Executive Board decided to extend the government bond purchasing program to a total of SEK 245 billion.

Table 4. Changes in Swedish Bond Yields on Fed, ECB and Riksbank Asset Purchase Announcement Days

Program	Date	10y Yield	Expectations	Term Premium	Global Term Premium	Country Term Premium
			Sweden			
SWE-QE	12-Feb-15	-15.1**	-13.5***	-1.6	0.7	-2.3
		(0.01)	*(0.01)*	*(0.31)*	*(0.64)*	*(0.14)*
	18-Mar-15	-12.7**	-7.2**	-5.5*	-5**	-0.5
		(0.03)	*(0.04)*	*(0.06)*	*(0.03)*	*(0.40)*
	29-Apr-15	13.2	6.4	6.7	7.7	-1
		(0.97)	*(0.95)*	*(0.96)*	*(0.98)*	*(0.31)*
	02-Jul-15	-16.9***	-13.3***	-3.7	-0.4	-3.3*
		(0.01)	*(0.01)*	*(0.13)*	*(0.46)*	*(0.08)*
	28-Oct-15	-1.8	0.9	-2.7	2.3	-5
		(0.39)	*(0.65)*	*(0.20)*	*(0.83)*	*(0.03)*
	21-Apr-16	13.9	3.3	10.6	6.7	3.9
		(0.98)	*(0.84)*	*(0.99)*	*(0.98)*	*(0.95)*
	Average	-3.2	-3.9	0.6	2	-1.4
		(0.30)	*(0.14)*	*(0.61)*	*(0.80)*	*(0.25)*
US-QE1	25-Nov-08	-16.8***	-5.2*	-11.6***	-11.7***	0.1
		(0.01)	*(0.09)*	*(0.01)*	*(0.00)*	*(0.52)*
	01-Dec-08	-21.1***	-19.9***	-1.2	-3.3*	2.1
		(0.00)	*(0.00)*	*(0.35)*	*(0.10)*	*(0.85)*
	16-Dec-08	-31.5***	-21.6***	-9.9**	-9.2****	-0.7
		(0.00)	*(0.00)*	*(0.01)*	*(0.00)*	*(0.36)*
	28-Jan-09	-0.2	-1.8	1.6	3.6	-2
		(0.51)	*(0.30)*	*(0.71)*	*(0.91)*	*(0.17)*
	18-Mar-09	-9.1*	-0.4	-8.7**	-10.6***	2
		(0.07)	*(0.47)*	*(0.02)*	*(0.00)*	*(0.83)*
	Average	-15.7**	-9.8**	-6**	-6.2**	0.3
		(0.01)	*(0.02)*	*(0.05)*	*(0.02)*	*(0.55)*
ECB-QE	08-Aug-11	-16.7***	-13.3***	-3.3	-3.3*	0
		(0.01)	*(0.01)*	*(0.15)*	*(0.10)*	*(0.50)*
	22-Jan-15	-10.8**	-2.7	-8.2**	-3.2	-4.9**
		(0.05)	*(0.22)*	*(0.02)*	*(0.11)*	*(0.03)*
	09-Mar-15	-10.9**	-4.5	-6.4**	-5.3**	-1.1
		(0.04)	*(0.11)*	*(0.04)*	*(0.03)*	*(0.29)*
	10-Mar-16	8.1	3.1	5	3.4	1.6
		(0.91)	*(0.83)*	*(0.92)*	*(0.90)*	*(0.79)*
	08-Jun-16	-10.6**	-3.2	-7.4**	-4.4**	-3*
		(0.05)	*(0.18)*	*(0.03)*	*(0.05)*	*(0.09)*
	Average	-8.2*	-4.1	-4.1	-2.6	-1.5
		(0.09)	*(0.13)*	*(0.11)*	*(0.16)*	*(0.24)*

P-values are presented in parentheses and significance levels are at the *10% **5% and ***1% levels. We follow Glick and Leduc (2012) in reporting *p*-values computed as the fraction of two-day changes in the sample from January, 1, 2000 to November 30, 2016 that were smaller than the change on the announcement day. Principal Component Analysis is used to seperate the yield curve into level, slope and curvature, which is then decomposed further into term premia and expectation components using a VAR. Following, we separate the term premia into global and local factors using a one-factor model.

Table 5. SNB Asset Purchase and Reserve Expansion Announcements

Date	Program	Event	Description
12-Mar-09	SWI-QE	Monetary Policy Assessment	The SNB announces it will buy Swiss franc bonds issued by private sector borrowers and purchase foreign currency on the foreign exchange markets.
3-Aug-11	SWI-QE	Press release	Target range for three-month CHF LIBOR lowered to 0 to 25 bps. In addition, banks' sight deposits at the SNB will be expanded from CHF 30 billion to CHF 80 billion.
10-Aug-11	SWI-QE	Press release	Banks' sight deposits at the SNB will rapidly be expanded from CHF 80 billion to CHF 120 billion.
17-Aug-11	SWI-QE	Press release	Banks' sight deposits at the SNB will immediately be expanded from CHF 120 billion to CHF 200 billion.

Table 6. Changes in Swiss Bond Yields on Fed, ECB and SNB Asset Purchase Announcement Days

Program	Date	10y Yield	Expectations	Term Premium	Global Term Premium	Country-Specific Term Premium
			Switzerland			
SWI- QE	12-Mar-09	-5.6*	-10.6***	5	-0.5	5.4
		(0.09)	*(0.01)*	*(0.94)*	*(0.42)*	*(0.97)*
	03-Aug-11	-1.8	-3.2	1.4	-0.2	1.6
		(0.34)	*(0.11)*	*(0.71)*	*(0.49)*	*(0.74)*
	10-Aug-11	-5.5*	-3.8*	-1.7	-1.1	-0.6
		(0.10)	*(0.09)*	*(0.27)*	*(0.31)*	*(0.40)*
	17-Aug-11	-20.3***	-5.6**	-14.6***	-9.1***	-5.5**
		(0.00)	*(0.04)*	*(0.00)*	*(0.00)*	*(0.03)*
	Average	-8.3**	-5.8**	-2.5	-2.7	0.2
		(0.04)	*(0.03)*	*(0.19)*	*(0.10)*	*(0.54)*
US-QE1	25-Nov-08	1	8.1	-7.1**	-9.5***	2.4
		(0.64)	*(0.99)*	*(0.02)*	*(0.00)*	*(0.84)*
	01-Dec-08	-6.5*	-7.1**	0.5	-2.7*	3.2
		(0.07)	*(0.02)*	*(0.60)*	*(0.10)*	*(0.90)*
	16-Dec-08	-3.3	-4.9**	1.6	-7.5***	9.1
		(0.22)	*(0.05)*	*(0.74)*	*(0.00)*	*(1.00)*
	28-Jan-09	-10.5**	-5.7**	-4.7*	2.9	-7.7***
		(0.02)	*(0.04)*	*(0.06)*	*(0.91)*	*(0.01)*
	18-Mar-09	-9.3**	-1.5	-7.9**	-8.7***	0.8
		(0.03)	*(0.27)*	*(0.01)*	*(0.00)*	*(0.63)*
	Average	-5.7*	-2.2	-3.5	-5.1**	1.6
		(0.09)	*(0.18)*	*(0.11)*	*(0.02)*	*(0.74)*
ECB - QE	08-Aug-11	-5.8*	-1.1	-4.7*	-2.7*	-2
		(0.09)	*(0.32)*	*(0.06)*	*(0.10)*	*(0.22)*
	22-Jan-15	-10.3**	-18.3***	8	-2.6	10.7
		(0.02)	*(0.00)*	*(0.98)*	*(0.11)*	*(1.00)*
	09-Mar-15	-4.5	-3.2	-1.3	-4.3**	3
		(0.14)	*(0.11)*	*(0.32)*	*(0.03)*	*(0.88)*
	10-Mar-16	9.5	6	3.6	2.8	0.8
		(0.97)	*(0.97)*	*(0.89)*	*(0.90)*	*(0.63)*
	08-Jun-16	-3.8	-1	-2.8	-3.6**	0.8
		(0.18)	*(0.34)*	*(0.17)*	*(0.05)*	*(0.63)*
	Average	-3	-3.5	0.6	-2.1	2.7
		(0.24)	*(0.10)*	*(0.61)*	*(0.16)*	*(0.86)*

P-values are presented in parentheses and significance levels are at the *10% **5% and ***1% levels. We follow Glick and Leduc (2012) in reporting *p*-values computed as the fraction of two-day changes in the sample from January, 1, 2000 to November 30, 2016 that were smaller than the change on the announcement day. Principal Component Analysis is used to seperate the yield curve into level, slope and curvature, which is then decomposed further into term premia and expectation components using a VAR. Following, we separate the term premia into global and local factors using a one-factor model.

Table 7. Federal Reserve's Asset Purchase Announcements

Date	Program	Event	Description
25-Nov-08	QE1	Initial LSAP announcement	The Federal Reserve announces purchases of up to $100 billion in agency debt and up to $500 billion in agency mortgage-backed securities (MBS).
1-Dec-08	QE1	Bernanke's speech	Chairman Bernanke mentions that the Fed could purchase long-term Treasuries.
16-Dec-08	QE1	Federal Open Market Committee (FOMC) statement	Statement indicates that the FOMC is considering expanding purchases of agency securities and initiating purchases of Treasury securities. Also, the fed funds rate target was reduced from 1% to a 0–25 bps target rate.
28-Jan-09	QE1	FOMC statement	The FOMC indicates it is considering expanding purchases of agency debt and initiating purchases of Treasuries.
18-Mar-09	QE1	FOMC statement	Statement announces purchases "up to an additional $750 billion of agency [MBS]," $100 billion in agency debt, and $300 billion in Treasury securities.
10-Aug-10	QE2	FOMC statement	Balance sheet maintained: The Fed will reinvest principal payments from LSAP purchases in Treasuries.
27-Aug-10	QE2	Bernanke's speech	Chairman states that the FOMC "is prepared to provide additional monetary accommodation through unconventional measures."
21-Sep-10	QE2	FOMC statement	Statement projects that inflation "is likely to remain subdued for some time before rising to levels the Committee considers consistent with its mandate."
15-Oct-10	QE2	Bernanke's speech	Chairman Bernanke states that "given the Committee's objectives, there would appear—all else being equal—to be a case for further action."
3-Nov-10	QE2	FOMC statement	Statement announces purchases of $600 billion in Treasury securities.
21-Sep-11	MEP	FOMC statement	Purchase of $400 billion in longer-dated Treasuries by selling shorter-dated ones.
20-Jun-12	MEP	FOMC statement	Extension to the MEP program by adding additionally $267 billion thereby extending it throughout 2012.
22-Aug-12	QE3	FOMC minutes	FOMC members "judged that additional monetary accommodation would likely be warranted fairly soon."
31-Aug-12	QE3	Bernanke's speech	Chairman Bernanke states that the Fed "…will provide additional policy accommodation as needed"—which the market interprets as increasing the odds of further QE.
13-Sep-12	QE3	FOMC statement	The Fed will purchase $40 billion of MBS per month as long as "the outlook for the market does not improve substantially [...] in the context of price stability."
12-Dec-12	QE3	FOMC statement	The Fed announces it will purchase longer-term Treasury securities after the Maturity Extension Program is completed at the end of the year, initially at a pace of $45 billion per month, and will continue purchases of $40 billion of agency MBS per month.

Table 8. European Central Bank Asset Purchase Announcements

Date	Program	Event	Description
8-Aug-11	ECB-QE	Press release	Use of the securities market programme (SMP) by Spain and Italy officially acknowledged by the ECB.
22-Jan-15	ECB-QE	Press release	Announcement of expanded asset purchase programme (APP) including the Public-Sector Purchase Programme (PSPP), combined monthly purchases with the third wave of the covered bond purchase programme (CBPP3) and asset backed securities purchase programme (ABSPP) will be €60 billion.
9-Mar-15	ECB-QE	Press release	Start of expanded asset purchase programme (combined monthly of public and private purchases are €60 billion).
10-Mar-16	ECB-QE	Press release	Corporate sector purchase programme (CSPP) added, combined APP increased to €80 billion.
8-Jun-16	ECB-QE	Press release	Altered APP (to include CSPP) and expansion to €80 billion in asset purchases monthly begins.

REFERENCES

Altavilla, C., Carboni, G., & Motto, R. (2015): "Asset purchase programmes and financial markets: lessons from the euro area," European Central Bank Working Paper Series.

Andrade, P., Breckenfelder, J. H., De Fiore, F., Karadi, P., & Tristani, O. (2016): "The ECB's asset purchase programme: an early assessment," European Central Bank Working Paper Series.

Bauer, G.H. and Diez de los Rios, A. (2012): "An International Dynamic Term Structure Model with Economic Restrictions and Unspanned Risks," Bank of Canada Staff Working Paper No. 2012-5.

Bauer, M.D. and Neely, C.J. (2014): "International Channels of the Fed's Unconventional Monetary Policy," *Journal of International Money and Finance*, 44, 24–46.

Bauer, M.D. and Rudebusch, G. (2014): "The Signaling Channel for Federal Reserve Bond Purchases," *International Journal of Central Banking*, 10, 233–289.

Bauer, M.D., Rudebusch, G.D. and Wu, C. (2012): "Correcting Estimation Bias in Dynamic Term Structure Models," *Journal of Business and Economic Statistics*, 30, 454–467.

_____. (2014): "Term Premia and Inflation Uncertainty: Empirical Evidence from an International Panel Dataset: Comment," *American Economic Review*, 104, 323–337.

Bernanke, B.S. (2011): "Testimony: Semiannual Monetary Policy Report to the Congress before the Committee on Banking, Housing, and Urban Affairs, U.S. Senate," March 1.

Bernanke, B.S. and Reinhart, V. (2004): "Conducting Monetary Policy at Very Low Short-Term Interest Rates," *American Economic Association Papers and Proceedings*, 94, 85–90.

Christensen, J.H.E. and Gillian, J.M. (2016): "Does Quantitative Easing Affect Market Liquidity?" Federal Reserve of San Francisco Working Paper 2013-26.

Christensen, J.H.E. and Krogstrup, S. (2016a): "Transmission of Quantitative Easing: The Role of Central Bank Reserves," Federal Reserve of San Francisco Working Paper 2014-16.

_____. (2016b): "A Portfolio Model of Quantitative Easing," Federal Reserve of San Francisco Working Paper 2016-12.

Christensen, J.H.E. and Rudebusch, G. (2012): "The Response of Interest Rates to US and UK Quantitative Easing," *Economic Journal*, 122, 385–414.

Cochrane, J. and Piazzesi, M. (2008): "Decomposing the Yield Curve," mimeo, University of Chicago.

Chodorow-Reich, G. (2014): *Effects of unconventional monetary policy on financial institutions* (No. w20230). National Bureau of Economic Research.

Cross, M., Fisher, P. and Weeken, O. (2010): "The Bank's Balance Sheet During the Crisis," *Quarterly Bulletin* (Bank of England), 50, 34–42.

Culbertson, J.M. (1957): "The Term Structure of Interest Rates," *Quarterly Journal of Economics*, 71, 485–517.

Dahlquist, M. and Hasseltoft, H. (2013). "International Bond Risk Premia," *Journal of International Economics*, 90, 17–32.

De Rezende, R.B. (2016): "The Interest Rate Effects of Government Bond Purchases Away from the Lower Bound," Sveriges Riksbank Working Paper Series 324.

De Santis, R. A. (2016): "Impact of the asset purchase programme on euro area government bond yields using market news," European Central Bank Working Paper Series.

Diez de los Rios, A. (2015): "A New Linear Estimator for Gaussian Dynamic Term Structure Models," *Journal of Business and Economic Statistics*, 33, 282–295.

Duffee, G.R. (2011): "Information in (and not in) the Term Structure," *Review of Financial Studies*, 24, 2895–2934.

Foley-Fisher, N., Ramcharan, R., & Yu, E. (2016): The impact of unconventional monetary policy on firm financing constraints: Evidence from the maturity extension program. *Journal of Financial Economics*, *122*(2), 409-429.

Gagnon, J.E., Raskin, M., Remache, J. and Sack, B.P. (2011): "The Financial Market Effects of the Federal Reserve's Large-Scale Asset Purchases," *International Journal of Central Banking*, 7, 3–43.

Glick, R. and Leduc, S. (2012): "Central Bank Announcements of Asset Purchases and the Impact on Global Financial and Commodity Markets," *Journal of International Money and Finance*, 31, 2078–2101.

_____. (2015): "Unconventional Monetary Policy and the Dollar: Conventional Signs, Unconventional Magnitudes," Federal Reserve of San Francisco Working Paper 2015-18.

Goldberg, L. and Tille, C. (2009): "Macroeconomic Inter-Dependence and the International Role of the Dollar," *Journal of Monetary Economics*, 56, 7, 990–1003.

Gopinath, G. (2015): "The International Price System," Federal Reserve Bank of Kansas City Economic Policy Symposium.

Greenwood, R., Hanson, S.G. and Liao, G.Y. (2016): "Asset Price Dynamics in Partially Segmented Markets," mimeo, Harvard Business School.

Greenwood, R. and Vayanos, D. (2014): "Bond Supply and Excess Bond Returns," *Review of Financial Studies*, 27, 663–713.

Haldane, A.G., Roberts-Sklar, M., Wieladek, T. and Young, C. (2016): "QE: The Story so Far," Bank of England Staff Working Paper 624.

Hamilton, J.D. and Wu, J.C. (2012): "The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment," *Journal of Money, Credit, and Banking*, 44, 3–46.

Hansen, B.E. (2010): "Averaging Estimators for Autoregressions with a Near Unit Root," *Journal of Econometrics,* 158, 142–155.

Hellerstein, R. (2011): "Global Bond Risk Premiums," Federal Reserve Bank of New York Staff Report No. 499.

HM Treasury. (2017): "Dept Management Report 2017-2018," HM Treasury Reports.

Ilmanen, A. (1995): "Time Varying Expected Returns in International Bond Markets," *Journal of Finance* 50, 481–506.

International Monetary Fund. (2013): "Unconventional Monetary Policies—Recent Experience and Prospects," May Edition.

Jardet, C., Monfort, A. and Pegoraro, F. (2011): "Persistence, Bias, Prediction and Averaging Estimators," mimeo, Banque de France.

_____. (2013): "No-arbitrage Near-Cointegrated VAR (p) Term Structure models, Term Premia and GDP Growth," *Journal of Banking and Finance*, 37, 389–402.

Joslin, S., Singleton, K.J. and Zhu, H. (2011): "A New Perspective on Gaussian DTSMs," *Review of Financial Studies,* 24, 926–970.

Joyce, M.A.S., Lasaosa, A., Stevens, I. and Tong, M. (2011): "The Financial Market Impact of Quantitative Easing in the United Kingdom," *International Journal of Central Banking*, 7, 113–161.

Kettemann, A. and Krogstrup, S. (2014): "Portfolio Balance Effects of the Swiss National Bank's Bond Purchase Program," *Journal of Macroeconomics*, 40, 132–149.

Kilian, L. (1998): "Small-Sample Confidence Intervals for Impulse-Response Functions," *Review of Economics and Statistics*, 80, 218–230.

Kim, D. H., & Wright, J. H. (2005): An arbitrage-free three-factor term structure model and the recent behavior of long-term yields and distant-horizon forward rates

Kohn, D.L. (2009): "Monetary Policy Research and the Financial Crisis: Strengths and Shortcomings," speech at the Conference on Key Developments in Monetary Economics, Washington, DC, October 9.

Kozicki, S., Santor, E. and Suchanek, L. (2015): "Large-Scale Asset Purchases: Impact on Commodity Prices and International Spillover Effects," Bank of Canada Working Paper No. 2015-21.

Kozicki, S. and Tinsley, P.A. (2001): "Shifting Endpoints in the Term Structure of Interest Rates," *Journal of Monetary Economics*, 47, 613–652.

Krishnamurthy, A. and Vissing-Jorgensen, A. (2011): "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy," *Brookings Papers on Economic Activity*, 2, 215–87.

Litterman, R. and Scheinkman, J.A. (1991): "Common Factors Affecting Bond Returns," *Journal of Fixed Income*, June, 54–61.

Miranda-Agrippino, S. and Rey, H. (2012): "Funding Flows and Credit in Carry Trade Economies," RBA Annual Conference Volume, Reserve Bank of Australia.

Mirkov, N. and Sutter, B. (2011): "Portfolio Substitution Effect of Quantitative Easing," mimeo, Swiss National Bank.

Modigliani, F. and Sutch, R.C. (1966): "Innovations in Interest Rate Policy," *American Economic Review*, 56, 178–97.

Moon, H.R. and Perron, B. (2008): "Seemingly Unrelated Regressions," in *The New Palgrave Dictionary of Economics*, 1–9, edited by S.N. Durlauf and L.E. Blume.

Neely, C.J. (2015): "Unconventional Monetary Policy Had Large International Effects," *Journal of Banking and Finance*, 52, 101–111.

Orr, A., Edey, M., & Kennedy, M. (1995): "The determinants of real long-term interest rates," *OECD Economics Department Working Papers*, No. 155, OECD Publishing, Paris.

Perignon, C., Smith, D.R. and Villa, C. (2007): "Why Common Factors in International Bond Returns Are Not so Common," *Journal of International Money and Finance*, 26, 284–304.

Rey, H. (2013): "Dilemma not Trilemma: The Global Financial Cycle and Monetary Policy Independence," Federal Reserve Bank of Kansas City Economic Policy Symposium

_____. (2016): "International Channels of Transmission of Monetary Policy and the Mundellian Trilemma," *IMF Economic Review*, 64, 6–35.

Rogers, J.H., Scotti, C. and Wright, J.H. (2014): "Evaluating Asset-Market Effects of Unconventional Monetary Policy: a Multi-Country Review," *Economic Policy*, 29, 749–799.

Rudebusch, G.D. and Wu, T. (2008): "A Macro-Finance Model of the Term Structure, Monetary Policy and the Economy," *Economic Journal*, 118, 906–926.

Sveriges Riksbank. (2016): "Additional monetary policy measures – reinvestments in Swedish government bonds," Annex B to the minutes, Minutes of the Monetary Policy Meeting held on 10 February.

Tobin, J. (1961): "Money, Capital, and Other Stores of Value," *American Economic Review Papers and Proceedings*, 51, 26–37.

_____. (1963): "An Essay on the Principles of Debt Management," in *Fiscal and Debt Management Policies*, 143–218, edited by the Commission on Money and Credit, Englewood Cliffs, NJ: Prentice Hall.

Vayanos, D. and Vila, J. (2009): "A Preferred-Habitat Model of the Term Structure of Interest Rates," NBER Working Paper No. 15487.

Wallace, N.A. (1967): "The Term Structure of Interest Rates and the Maturity Composition of the Federal Debt," *Journal of Finance*, 22, 301–312.

Williams, J.L. (2011): "Unconventional Monetary Policy: Lessons from the Past Three Years," Presentation to the Swiss National Bank Research Conference, Zurich, September 23.

Wright, J.H. (2012): "What Does Monetary Policy Do at the Zero Lower Bound?" *Economic Journal*, 122, 447–466.

Yellen, J. (2011): "Unconventional Monetary Policy and Central Bank Communications," Speech at the U.S. Monetary Policy Forum, New York, February 25.

APPENDIX

Appendix A outlines the effects of Federal Reserve asset purchase announcements on U.S. Treasuries, whereas Appendix B analyzes the affects of the European Central Bank asset purchase announcements on German bond yields. Appendix C details the movements in the exchange rate around central bank asset purchase announcements.

Appendix A and Appendix B reference asset purchase announcements by the Federal Reserve and European Central Bank detailed in Tables 7 and 8, respectively. Where Tables A1 and B1, display the results of asset purchases by the Fed and ECB. Moreover, panel A of each table presents the results for the yields of the country implementing the asset purchase program and panel B presents the decomposition for the average of the yields for the rest of the countries (i.e., "rest of the world" results).

A. Results of Federal Reserve QE on United States Bond Yields

We begin by considering the five LSAP announcements associated with the first round of the Federal Reserve's QE program, between November 2008 and March 2009, studied in Glick and Leduc (2012), Wright (2012) and Rogers, Scotti and Wright (2014). These dates are similar to those used by Gagnon et al. (2011), Bauer and Neely (2014), and Neely (2015) among others.

Two dates are particularly important in our study: November 25, 2008, which is the date of the Federal Reserve's first QE announcement, and March 18, 2009, which is the first announcement of the purchase of long-term Treasuries by the Federal Reserve. Specifically, the U.S. 10-year yield fell by 31 basis points (bps) when the Federal Reserve announced in November 2008 the purchase of agency debt and agency mortgage backed securities even though the Fed did not announce the purchase of U.S. Treasury bonds (see Table A1). Based on our decomposition of the yields, approximately half of this drop (15 bps) was due to a fall in term-premium in the U.S. 10-year bond yield, split between a drop in the global (9 bps) and country specific term premium components (6 bps). The expectations component also fell as the QE announcement was interpreted as a signal of an imminent rate cut of the federal funds rate (as indeed happened when the fed funds rate was cut from 50 bps to a range of 0 to 25 bps at the December 2008 Federal Open Market Committee, FOMC, meeting). Importantly, the Fed's November 2008 QE announcement also had an impact on the 10-year yields of the rest of the countries, which dropped 11 bps on average. This drop was mainly due to a fall in the global term premium component of 11 bps, which is consistent with the existence of an international portfolio balance channel (see panel B of Table A1).

Later, on March 18, 2009, with the fed funds rate close to zero, the FOMC decided to broaden its purchase program to include longer-term Treasury securities. This led to a fall in U.S. 10 year rates of 51 bps, and most of the fall was due to the country-specific term premium (22 bps). In addition, markets interpreted this announcement as a signal that the Fed would have to stay at its effective zero lower bound for longer than previously anticipated, and the expectations component fell by another 22 bps. As in the case with the November 2008 announcement, there were significant international portfolio balance spillovers to the other countries' interest rates, as the fall in the yields of the rest of the countries was similar in magnitude to the November 2008 announcement (10 bps, mainly due to the fall in the global term premium).

In general, the analysis of the five QE1 announcements reveals strong signaling effects for U.S. bond yields, a result consistent with Bauer and Rudebusch (2014). Specifically, the expectations component tends to capture between 20 and 50 per cent of the two-day change around the announcements. In addition, as confirmed by Bauer and Neely (2014), there are important international signaling effects. For example, almost 50 per cent of the fall long-term yields in the other five countries in our sample is due, on average, to the expectation component in these countries (see panel B of Table A1).

As for the contribution of the portfolio balance channel, we find that the main contributor to the fall in the term premium component, on the other hand, is the country-specific component (between 40 and 80 per cent). Even though it is small (5 bps on average), the fall in the global component of the U.S. term premium is also statistically significant. Indeed, the contribution of the country-specific component for the other countries is negligible, and almost all of the fall in their term premia seems to be explained by the global term premium component. Importantly, the results regarding the international portfolio balance channel are reminiscent of Rey's (2016) hypothesis that there is a global financial cycle largely driven by monetary policy decisions in the United States.

Regarding the second round of the Fed's QE program, we follow Glick and Leduc (2012), Wright (2012) and Rogers, Scotti and Wright (2014) and consider five dates that were announced in 2010. Finally, for the third round of QE, we select four dates in 2012 that include the dates analyzed in Bauer and Neely (2012) and Kozicki et al. (2015).

As expected we find for the Maturity Extension Program that the initial announcement and implementation has a relatively large negative effect on the 10-year bond yield. This effect is purely through the term premium channel and is significant both at the global and country-specific level. This is consistent with the findings in Foley-Fisher, Ramcharan and Yu (2016) who highlight a portfolio balance channel as firms 'reach for yield'.

Regarding the second round of the Fed's QE program, we follow Glick and Leduc (2012), Wright (2012) and Rogers et al. (2014) and consider five dates that were announced in 2010. Finally, for the third round of QE, we select four dates in 2012 that encompass the dates analyzed in Bauer and Neely (2012) and Kozicki et al. (2015).

Importantly, our results suggest that, in contrast to the QE1 announcements, the fall in long-term yields in the United States tends to be smaller and less often statistically significant for the QE2 (three out of five announcements) and particularly QE3 (one out of four announcements). For example, the average fall in 10-year yields for the QE2 and QE3 programs is 8 and 0.2 bps for the case of the United States, and 3 and 0.2 bps for the average of the other five countries, respectively. Similarly, consistent with the evidence in Bauer and Neely (2014), we find no evidence of an international signaling nor a portfolio balance channel effect for the second and third rounds of the Fed's LSAP programs. These results are consistent with Haldane et al.'s (2016) hypothesis that the impact of QE programs seems to be larger the weaker the economy is and the more segmented financial markets are. The financial markets were more dislocated in the aftermath of the 2007-08 crisis than in 2010-12, and therefore the Fed's intervention

helped alleviate the existing distortions. However, it may also provide evidence for the diminishing effectiveness of QE, yet it is not possible to distinguish between this effect and that of an improvement in the health of the economy.

B. Results of ECB QE on German Bond Yields

We analyze the affect of the European Central Bank's quantitative easing programme on German bund yields.
As explained in section 4, the effect of the ECB QE programme on Germany bunds is expected to be limited, as the ECB QE programme was largely expected from late 2014 (De Santis, 2016), QE tends to be more effective when financial markets are fragmented and the economy is under stress (Haldane et al., 2016) and the fact that the ECB purchased a basket of euro denominated sovereign bonds and not solely German bunds.

Nonetheless as seen in Altavilla, Carboni and Motto (2015), Andrade et al (2016) and De Santis (2016) the initial asset purchase announcement on 22 January 2015 by the ECB has a significant and negative affect on German bund yields. This affect is through the term premium channel and split between the global term premium and country-specific term premium. Moreover, in panel B of Table B1 we see that this announcement effected the average country in our sample and primarily through the expectations channel.

We also analyze the starting date of these purchases in March 2015. The movement in the German bund term premium channel was significant through the global term premium. Furthermore, the rest of the world, panel B of Table B1 shows that on average for the other countries in our sample the 10-year bond yield fell 9.5 bps, composed of 4.4 bps through the expectation channel and 5.1 bps from the term premium channel, over 90% of which is from movements in the global term premium. This announcement provides evidence that ECB QE announcements and implementation can affect global bond yields through the global term premium and international signalling channel, echoing finding by Andrade et al (2016).

Moreover, following the expansion of asset purchases to €80 billion and the inclusion of the corporate sector purchase programme, significant changes in the global term premium component of German bund yields and Ex-German bonds are visible, however, this affect is not strong enough to change German bund yields or the average bond yield of countries in our sample that excludes Germany.

Further inspection of the ECB QE announcements on other euro denominated sovereign bonds has been undertaken by Altavilla, Carboni and Motto (2015) using an intra-day event study approach. They find that the 10-year bond yield for Spain and Italy, two relatively higher-yield member countries, moved by roughly twice as much compared to a lower-yield country such as Germany. A larger impact of the ECB's asset purchases can also be seen in Andrade et al (2016)

as they use an average of euro-denominated sovereign bond yields rather than solely German bunds.

The securities market programme, announced in May 2010, forms part of the ECB's unconventional monetary policy toolbox and not their official QE programme, which started in 2015 and has been discussed above. Utilization of the SMP by Spain and Italy was announced in August 2011 and used to restore appropriate functioning of monetary policy transmission mechanism in these countries. Therefore, it is not surprising to see a limited effect on German bund yields from the announcement on August 2011. However, this announcement does negatively affect bund yields through the expectation channel and global term premium channel, as is the case for the average of the rest of the countries in our sample. We find that on average for the other countries in our sample the SMP announcement of August 2011 lowers bond yields by 16 bps, in part due to reassuring investors that the ECB will step in to support countries suffering in the European debt crisis. Nevertheless, this announcement date coincides with the first date investors could purchase U.S. Treasuries after their downgrade to AA+ rating, adding uncertainty to the market and potentially causing a flight to safety (increased purchase of U.S. Treasuries).

C. Exchange Rate Movements

For completeness, we also study exchange rate movements around asset purchase announcement. This analysis does not attempt to determine the size or effect of the exchange rate channel on bond yields but aims to serve as a first pass in understanding if asset purchase announcements in small open economies can have an effect on exchange rates.[32] Therefore, the analysis included below serves to provide an initial understanding of the existence of the exchange rate channel for in small open economies. The figures pertaining to changes in exchange rates around quantitative easing announcement dates can be found in Table C1.

The movements in the GBP-USD exchange rate around Fed, ECB and BoE announcement dates were also small but at times, significant. Specifically, the first BoE announcement in February 2009 had a significant negative effect on the exchange rate, however, the movement from the second announcement is insignificant even though this announcement lowered the ten-year bond yield the most. Significant exchange rate depreciations were seen from the December 2008 and August 2010 Fed announcement; August 2011 ECB announcement; and August 2009 and August 2016 BoE announcement, yet the magnitudes of changes in the two-day difference for GBP-USD exchange rate are not abnormal.

Additionally, Federal Reserve, ECB and Riksbank asset purchase announcements have had a negligible effect on SEK-EUR exchange rate. Moreover, the only significant movement in the SEK-EUR exchange rate on Riksbank asset purchase announcement days arose when the repo rate of the Riksbank also fell.

[32] Glick and Leduc (2012,2015) and Neely (2015) find evidence of the exchange rate channel for the U.S.

These results are echoed when observing movements in the CHF-EUR exchange rate around Federal Reserve and ECB asset purchase announcements as they have also been limited. Furthermore, the only significant movements seen in the CHF-EUR exchange rate were around asset purchase announcements by the SNB, which implemented their policy in order to depreciate the Swiss Franc against the euro.

Therefore, large significant movements in the exchange rate, as seen in Glick and Leduc (2012, 2015) and Neely (2015), are not as readily observed for the SOE in our sample. This finding prompts further and more detailed research into the exchange rate channel.

Appendix: Figures and Tables

Table A1. Changes on Bond Yields on Fed Asset Purchase Announcement Days

Program	Date	10y yield	Expectations	Term premium	Global Term Premium	Country-Specific Term Premium
			Panel A: US			
US-QE1	25-Nov-08	-31.3***	-16.5***	-14.8***	-8.5***	-6.3**
		(0.00)	(0.01)	(0.01)	(0.01)	(0.04)
	1-Dec-08	-25.3***	-12.4**	-12.9***	-2.4*	-10.5***
		(0.00)	(0.02)	(0.01)	(0.10)	(0.01)
	16-Dec-08	-38.6**	-7.0*	-31.6***	-6.7***	-24.9***
		(0.00)	(0.09)	(0.00)	(0.00)	(0.00)
	28-Jan-09	27.1	12.7	14.4	2.6	11.8
		(1.00)	(0.98)	(0.99)	(0.91)	(1.00)
	18-Mar-09	-51.2***	-21.5***	-29.8***	-7.7***	-22.1***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Average	-23.9***	-8.9*	-14.9***	-4.5**	-10.4***
		(0.01)	(0.05)	(0.01)	(0.02)	(0.01)
US-QE2	10-Aug-10	-14.9**	-4.6	-10.3**	-1.8	-8.5**
		(0.03)	(0.17)	(0.02)	(0.18)	(0.01)
	27-Aug-10	4.4	0.4	4.0	0.1	3.9
		(0.75)	(0.56)	(0.84)	(0.55)	(0.89)
	21-Sep-10	-16.8**	-5.1	-11.7**	-4.9**	-6.8**
		(0.02)	(0.14)	(0.01)	(0.01)	(0.03)
	15-Oct-10	0.8	-1.5	2.4	2.7	-0.4
		(0.58)	(0.36)	(0.75)	(0.91)	(0.46)
	3-Nov-10	-12.4*	-5.1	-7.2**	-1.3	-6.0**
		(0.06)	(0.14)	(0.05)	(0.26)	(0.04)
	Average	-7.8	-3.2	-4.6	-1.0	-3.5
		(0.15)	(0.24)	(0.12)	(0.29)	(0.12)
US-MEP	21-Sep-11	-26.4***	-1.7	-24.7***	-6.5***	-18.3***
		(0.00)	(0.34)	(0.00)	(0.00)	(0.00)
	20-Jun-12	-0.5	1.5	-2.0	1.2	-3.3
		(0.50)	(0.66)	(0.30)	(0.77)	(0.13)
	Average	-13.5**	-0.1	-13.4***	-2.6*	-10.8***
		(0.04)	(0.51)	(0.01)	(0.08)	(0.01)
US-QE3	22-Aug-12	-14.1**	-4.9	-9.2**	-5.4***	-3.8
		(0.04)	(0.15)	(0.03)	(0.01)	(0.11)
	31-Aug-12	-7.0	-3.5	-3.5	0.2	-3.8
		(0.18)	(0.22)	(0.18)	(0.60)	(0.11)
	13-Sep-12	11.5	1.9	9.6	3.5	6.1
		(0.92)	(0.70)	(0.97)	(0.95)	(0.96)
	12-Dec-12	8.9	2.3	6.5	1.6	5
		(0.87)	(0.74)	(0.92)	(0.82)	(0.93)
	Average	-0.2	-1.0	0.8	0	0.9
		(0.52)	(0.41)	(0.62)	(0.52)	(0.63)

P-values are presented in parentheses and significance levels are at the *10% **5% and ***1% levels. We follow Glick and Leduc (2012) in reporting *p*-values computed as the fraction of two-day changes in the sample from January, 1, 2000 to November 30, 2016 that were smaller than the change on the announcement day. Principal Component Analysis is used to seperate the yield curve into level, slope and curvature, which is then decomposed further into term premia and expectation components using a VAR. Following, we separate the term premia into global and local factors using a one-factor model.

Table A1. Changes on Bond Yields on Fed Asset Purchase Announcement Days (continued)

Program	Date	10y yield	Expectations	Term premium	Global Term Premium	Country-Specific Term Premium
			Panel B: Average (ex-US)			
	25-Nov-08	-10.8**	0	-10.9***	-11.5***	0.6
		(0.02)	(0.54)	(0.00)	(0.00)	(0.91)
	1-Dec-08	-15.4***	-14.1***	-1.4	-3.3*	1.9
		(0.00)	(0.00)	(0.30)	(0.10)	(1.00)
	16-Dec-08	-19.8***	-14.6***	-5.2**	-9.0***	3.8
US-QE1		(0.00)	(0.00)	(0.02)	(0.00)	(1.00)
	28-Jan-09	0.4	-1.2	1.7	3.5	-1.9***
		(0.57)	(0.34)	(0.77)	(0.91)	(0.00)
	18-Mar-09	-10.4**	-3.2	-7.2***	-10.5***	3.3
		(0.02)	(0.14)	(0.01)	(0.00)	(1.00)
	Average	-11.2**	-6.6**	-4.6**	-6.2**	1.6
		(0.01)	(0.03)	(0.04)	(0.02)	(0.99)
	10-Aug-10	-7.2*	-5.8**	-1.3	-2.4	1.1
		(0.06)	(0.04)	(0.30)	(0.18)	(0.97)
	27-Aug-10	0.7	1.0	-0.3	0.1	-0.4
		(0.60)	(0.68)	(0.47)	(0.54)	(0.20)
	21-Sep-10	-11.4**	-5.6**	-5.8**	-6.7**	0.9
US-QE2		(0.01)	(0.05)	(0.02)	(0.01)	(0.95)
	15-Oct-10	6.3	2.4	3.9	3.7	0.2
		(0.91)	(0.82)	(0.93)	(0.91)	(0.68)
	3-Nov-10	-2.2	-1.2	-0.9	-1.7	0.8
		(0.35)	(0.34)	(0.36)	(0.25)	(0.94)
	Average	-2.8	-1.8	-0.9	-1.4	0.5
		(0.30)	(0.26)	(0.36)	(0.29)	(0.87)
	21-Sep-11	-10.5**	-4.0	-6.4**	-8.8***	2.3
		(0.02)	(0.10)	(0.01)	(0.00)	(1.00)
US-MEP	20-Jun-12	5.1	2.7	2.5	1.7	0.8
		(0.88)	(0.85)	(0.85)	(0.77)	(0.94)
	Average	-2.7	-0.7	-2.0	-3.5*	1.6
		(0.31)	(0.42)	(0.21)	(0.08)	(0.99)
	22-Aug-12	-10.9**	-4.3*	-6.6***	-7.4***	0.8
		(0.02)	(0.09)	(0.01)	(0.01)	(0.94)
	31-Aug-12	0.9	-0.1	1.0	0.3	0.7
		(0.61)	(0.51)	(0.68)	(0.59)	(0.91)
US-QE3	13-Sep-12	5.6	1.7	3.9	4.8	-0.9*
		(0.89)	(0.76)	(0.93)	(0.95)	(0.05)
	12-Dec-12	3.6	2.1	1.5	2.1	-0.6
		(0.80)	(0.80)	(0.76)	(0.82)	(0.11)
	Average	-0.2	-0.2	-0.1	0	0
		(0.52)	(0.50)	(0.52)	(0.52)	(0.47)

P-values are presented in parentheses and significance levels are at the *10% **5% and ***1% levels. We follow Glick and Leduc (2012) in reporting *p*-values computed as the fraction of two-day changes in the sample from January, 1, 2000 to November 30, 2016 that were smaller than the change on the announcement day. Principal Component Analysis is used to seperate the yield curve into level, slope and curvature, which is then decomposed further into term premia and expectation components using a VAR. Following, we separate the term premia into global and local factors using a one-factor model.

Table B1. Changes in Germany Bund Yields on ECB Asset Purchase Announcement Days

Program	Date	10y Yield	Expectations	Term Premium	Global Term Premium	Country-Specific Term Premium
			Panel A: Germany			
ECB - QE	8-Aug-11	-2.1	-8.6**	6.6	-3.9*	10.4
		(0.38)	*(0.03)*	*(0.95)*	*(0.10)*	*(1.00)*
	22-Jan-15	-9.2*	-2.5	-6.7**	-3.7	-2.9
		(0.06)	*(0.24)*	*(0.04)*	*(0.11)*	*(0.12)*
	9-Mar-15	-6.9	-1.7	-5.2*	-6.1**	0.9
		(0.12)	*(0.31)*	*(0.09)*	*(0.03)*	*(0.67)*
	10-Mar-16	7.4	6.7	0.6	4	-3.3*
		(0.89)	*(0.95)*	*(0.60)*	*(0.90)*	*(0.09)*
	8-Jun-16	-5.6	-0.7	-5*	-5.1**	0.1
		(0.17)	*(0.43)*	*(0.09)*	*(0.05)*	*(0.53)*
	Average	-3.3	-1.3	-1.9	-3	1
		(0.30)	*(0.35)*	*(0.30)*	*(0.16)*	*(0.68)*
			Panel B: Average Ex-Germany			
ECB- QE	8-Aug-11	-15.8***	-9**	-6.8**	-3*	-3.8***
		(0.01)	*(0.01)*	*(0.01)*	*(0.10)*	*(0.00)*
	22-Jan-15	-7.3*	-5.4*	-1.8	-2.9	1.1
		(0.08)	*(0.06)*	*(0.23)*	*(0.11)*	*(0.94)*
	9-Mar-15	-9.5**	-4.4*	-5.1**	-4.8**	-0.4
		(0.03)	*(0.09)*	*(0.03)*	*(0.03)*	*(0.26)*
	10-Mar-16	9.3	5.4	3.9	3.1	0.8
		(0.96)	*(0.95)*	*(0.92)*	*(0.90)*	*(0.88)*
	8-Jun-16	-5.1	-1.2	-3.9*	-3.9**	0
		(0.16)	*(0.35)*	*(0.06)*	*(0.05)*	*(0.51)*
	Average	-5.7	-2.9	-2.8	-2.3	-0.5
		(0.13)	*(0.17)*	*(0.14)*	*(0.16)*	*(0.22)*

P-values are presented in parentheses and significance levels are at the *10% **5% and ***1% levels. We follow Glick and Leduc (2012) in reporting *p*-values computed as the fraction of two-day changes in the sample from January, 1, 2000 to November 30, 2016 that were smaller than the change on the announcement day. Principal Component Analysis is used to seperate the yield curve into level, slope and curvature, which is then decomposed further into term premia and expectation components using a VAR. Following, we separate the term premia into global and local factors using a one-factor model.

Table C1. Changes in Exchange Rates on Fed, ECB, BoE, SWE and SWI Asset Purchase Announcement Days

Program	Date	GBP-USD Exchange Rate %Δ	Program	Date	SEK-EUR Exchange Rate %Δ	Program	Date	CHF-EUR Exchange Rate %Δ
UK-QE	11-Feb-09	-3***	SWE-QE	12-Feb-15	-0.9*	SWI- QE	12-Mar-09	-3.5***
		(0.00)			*(0.06)*			*(0.00)*
	05-Mar-09	0.3		18-Mar-15	-0.4		03-Aug-11	0.6
		(0.67)			*(0.23)*			*(0.93)*
	07-May-09	0.1		29-Apr-15	0.1		10-Aug-11	-3.3***
		(0.55)			*(0.62)*			*(0.00)*
	06-Aug-09	-1.7**		02-Jul-15	-1.5		17-Aug-11	0.6
		(0.03)			*(0.01)*			*(0.92)*
	05-Nov-09	0.2		28-Oct-15	0.1			
		(0.60)			*(0.59)*			
	06-Oct-11	1.2		21-Apr-16	0.5			
		(0.95)			*(0.82)*			
	09-Feb-12	-0.4						
		(0.28)						
	05-Jul-12	-0.5						
		(0.27)						
	04-Aug-16	-2**						
		(0.02)						
	Average	-0.6		Average	-0.1		Average	-1.4**
		(0.19)			*(0.45)*			*(0.01)*
US-QE1	25-Nov-08	2.1			0.2			-0.4
		(0.99)			*(0.65)*			*(0.13)*
	01-Dec-08	-2.7***			-1.4**			0.6
		(0.01)			*(0.02)*			*(0.93)*
	16-Dec-08	0.4			0.2			1.8
		(0.72)			*(0.63)*			*(0.99)*
	28-Jan-09	1.1			1.3			0.2
		(0.92)			*(0.98)*			*(0.70)*
	18-Mar-09	4			1.1			-0.1
		(1.00)			*(0.97)*			*(0.36)*
	Average	1			0.3			0.4
		(0.91)			*(0.72)*			*(0.88)*
ECB-QE	08-Aug-11	-1*			-0.9*			2.8
		(0.09)			*(0.06)*			*(1.00)*
	22-Jan-15	-0.6			2			1.2
		(0.21)			*(1.00)*			*(0.98)*
	09-Mar-15	0.1			0.5			-0.2
		(0.57)			*(0.83)*			*(0.26)*
	10-Mar-16	1.2			-0.3			-0.1
		(0.95)			*(0.25)*			*(0.37)*
	08-Jun-16	-0.6			-0.1			0.5
		(0.21)			*(0.39)*			*(0.90)*
	Average	-0.2			0.2			0.8
		(0.39)			*(0.69)*			*(0.96)*

P-values are presented in parentheses and significance levels are at the *10% **5% and ***1% levels. We follow Glick and Leduc (2012) in reporting *p*-values computed as the fraction of two-day changes in the sample from January, 1, 2000 to November 30, 2016 that were smaller than the change on the announcement day.