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Quantitative Easing and Long-Term Yields in Small Open Economies

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

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Abstract

We compare the effectiveness of Federal Reserve's asset purchase programs in lowering long-term yields with that of similar programs implemented by the Bank of England, the Swedish Riksbank, and the Swiss National Bank's reserve expansion program. We decompose government bond yields into (i) an expectations component, (ii) a global, 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's asset purchases, the programs implemented in these smaller economies have not been able to affect the global term premium and, 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.

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CONTENTS

GLOSSARY

APF	Asset Purchase Facility
AR	Autoregressive
BoE	Bank of England
ECB	European Central Bank
GDP	Gross Domestic Product
LSAP	Large Scale Asset Purchases
MD	Minimum Distance
MPC	Monetary Policy Commitee
OLS	Ordinary Least Squares
QE	Quantitative Easing
SNB	Swiss National Bank
SOEs	Small Open Economies
VAR	Vector Autoregression

I. 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 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 Purchases (LSAP) programs, or Quantitative Easing (QE), with the aim of lowering long-term yields and thus encouraging consumption, 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 mainly focused on the impact of the Federal Reserve's LSAP program (see, e.g., Gagnon et al., 2011, Rudebusch and Christensen, 2012, and Bauer and Rudebusch, 2014, among others). The question therefore remains as to whether the United States experience in terms of the ability of asset purchases to affect long-term yields is of relevance for the central banks of small open economies (SOEs). In this paper, we attempt to answer this question by analyzing the channels through which these programs affect the stance of monetary policy and thereby evaluating the effectiveness of QE programs in small open economies such as the United Kingdom, Sweden, and Switzerland.

Central bank asset purchases lower long-term yields via 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, such as maturity, credit, etc. This not only tends to bid up the price of the purchased security, thus lowering its yield, but also bids up the price of close substitutes.[3] This is referred to as the *portfolio balance* channel of central bank asset purchases.

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

[2] Other factors such as decline in macroeconomic volatility, inflation uncertainty and fiscal balance also determine long-term yields, Orr, Edey and Kennedy (1995). However, as shown in Bauer, Rudebusch, and Wu (2014), estimated term premia have a positive relationship with inflation uncertainty.

[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 the 1960s. See, i.e., 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 affect the full the term structure of interest rates.

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 level, i.e., towards the now relatively underpriced foreign debt of similar credit quality.

When broadening the analysis of a central bank's asset purchases to an international context, research has highlighted the role of international spillovers. For example, Bauer and Neely (2014) and Neely (2015) find evidence of such spillovers on international bond prices due to the Federal Reserve's asset purchase program.

This international spillover depends on two factors. First, the size of asset purchases relative to the size of pool of substitutable assets becomes particularly important in affecting the price of similar assets. Second, the degree of substitutability with foreign bonds is also important. Put differently, international investors in the bonds issued by small open economies are highly price sensitive, due to the existence of a large set of similar, highly substitutable, assets. This sensitivity, in turn, could limit the effectiveness of the asset purchase program. In contrast, if U.S. Treasury bonds are special in certain ways and cannot be substituted easily, due to the dominant reserve currency[4] status of the dollar for instance, this price sensitivity is to a large extent eliminated.

Furthermore, the exchange rate acts as an additional channel of transmission. The expected return on international investments depends 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). The analysis in this paper abstracts from the transmission of QE through the exchange rate. This is not to deny that the exchange rate channel is potentially an important one, particularly for small open economies. However, our exercise focuses solely on the ability of asset purchases to affect long-term bond yields by limiting their supply.

The focus of this paper, therefore, is to understand the differences in the way QE affects long-term yields in small open economies, specifically the United Kingdom, Sweden, and Switzerland, compared to a large country like the United States, and the extent to which these differences limit the effectiveness of asset purchases in small open economies. Our analysis does not suggest that asset purchases are not expansionary in small open economies, rather, they have a limited effect on lowering the long-term yields, in contrast to the large economy in our sample, the United States. Moreover, it is important to note that the structure of these economies and their quantitative easing programs differ, however, we feel this provides a

[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.

suitable range to assess their asset purchases and the impact they have had on bond yields in comparison to the U.S.

In order to shed light on the effectiveness of asset purchase programs in small open economies we compare the responses of long-term yields on government securities to the asset purchase announcements by the Federal Reserve with those by the BoE, the Riksbank and the SNB's reserve expansion program. Using an event study methodology, 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) and Dahlquist and Hasseltoft (2012), 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.

Our analysis suggests that in general the changes in long-term rates around asset purchase announcements by the BoE[5], the Riksbank and the SNB are substantially smaller than the changes observed after the first round of asset purchases implemented by the Federal Reserve. This result is supported by Bauer and Neely (2014), Christensen and Rudebusch (2012) and Christensen and Krogstrup (2016a) for individual countries, however, the lack of comparasion between countries and decomposition of the term premia into global and local factors motivates this study. Specifically, our results suggest that these programs do not affect the global term premium component of the yields. While QE programs in SOEs 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)[6], they are relatively small once we take into account the size of the pool of substitutable assets.[7] Consequently, their impact on long-term interest rates has been limited.

Moreover, we find evidence for the diminishing effectiveness of QE, as discussed in IMF (2013) and Chodorow-Reich (2014), for the U.S. and U.K. Such that in these countries quantitative easing had a relatively larger effect on the 10-year bond yield in the first stage of

[5] The strength of the first two BoE announcements in our sample before the first round of asset purchases by the Federal Reserve, as seen in Table 4, however are significant. The February 2009 annoucement likely signals of the impending rate cut for the BoE and therefore a signicant change in expectations is to be expected. Whereas, the March 5, 2009, BoE announcement works through term-premia, global and local, potentially motivated by the impending start of the Federal Reserve's purchase of U.S. Treasury bonds.

[6] 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.

[7] 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 percent and 1 percent, respectively, of the size of U.S. Treasury bond market.

announcements than it did towards the end of our sample. However, as noted in Haldane et al. (2016), quantitative easing is likely to have a larger effect during times of market stress and turmoil and therefore in the latter stages of quantitative easing announcements, as the markets recover, it is unsurprsing to find it becoming less effective.

The remainder of this paper is organized as follows. Section 2 discusses the channels of transmission of asset purchases to long-term interest rates. In section 3, we present our empirical methodology to decompose long-term interest rates into an expectations 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 Federal Reserve, the BoE, the Riksbank and the SNB's reserve expansion. Section 5 concludes.

II. 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., 2014; Bauer and Neely, 2014, among many others).[8] 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:

$$y_{j,t}^{(10)} = \frac{1}{10}\sum_{j=1}^{10} E_t r_{j,t+h-1} + tp_{j,t}^{(10)} \quad (1)$$

where $y_{j,t}^{(n)}$ is the yield at time t on a n-year zero coupon bond of country j.[9] The first term is the average of the expected one-year interest rate over the next ten 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, $r_{j,t} = y_{j,t}^{(1)}$).[10] 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

[8] 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 (2015).

[9] 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.

[10] 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.

leads market participants to revise their expectations of future short-term rates it can affect long-term 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 views on current or future economic conditions, changes in the central bank's reaction function, and/or changes in the policy objectives).[11]

More importantly for the case of analyzing the international effects of QE, the announcement of an asset purchase program by large central banks such as the Federal Reserve or the ECB 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. As we will discuss below, our framework allows us to go beyond the work by Bauer and Neely (2014) and to assess whether asset purchases by central banks in small open economies can also lead to revisions in the expected monetary policy path for other central banks around the world.

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, i.e., Tobin 1961, 1963, and 1969). 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 such as maturity, credit, liquidity etc. This not only tends to bid up the price of the purchased bond, thereby lowering its yield, but also bids up the price of a wider set of closely substitutable 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 quantity of private holdings of long-term bonds in determining bond prices (see, among others, Gagnon et al., 2011, and Krishnamurthy and Vissing-Jorgensen, 2011, among others).

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

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 have preferences for a certain maturity of bonds, referred to as preferred habitat. At the same time, risk-averse arbitrageurs integrate the market by trading across maturities. In this model, a reduction in the supply of the particular security of interest to the preferred habitat investors creates a shortage that increases its price. Consequently, arbitrageurs sell the scarce security and rebalance their portfolio towards other substitutable bonds which are now relatively under-priced. 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.[12]

In a world with global capital markets, the set of substitutable securities includes foreign bonds and, as a consequence, some of the portfolio rebalancing occurs at the international level creating demand towards the now relatively under-priced 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 leakage abroad 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 the existence of a large set of similar, highly substitutable, bonds to its domestic securities. This could, in principle, limit the effectiveness of asset purchase programs in lowering interest rates in small open economies, as opposed to the case of the United States, where treasuries benefit from specialness given the reserve-currency status of the dollar or the ECB, where euro-denominated bonds may enjoy better liquidity or higher acceptance as collateral. We study the validity of this hypothesis below.

C. Event-Study Methodology

Consistent with the literature on the evaluation of central bank 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.[13] As in

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[12] 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 large-scale asset purchase program. The logic relies on the fact that only banks can hold reserves, whereas central banks can purchase assets from bank 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. They refer to this as a reserve-induced portfolio balance channel. In reality, the distinction with the traditional, supply-induced, and portfolio balance channel is unobservable. Therefore, what we measure as the portfolio balance channel does not distinguish between the two mechanisms.

[13] 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 in order to guarantee that the announcement is reflected in all the yields across all the countries in our sample. However, our results our robust to one-day changes in yields.

Bauer and Rudebusch (2014), we focus on announcements rather than asset purchases themselves given that forward-looking investors will react immediately to news of futures 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 purchases announcements given that market participants might have formed expectations of increasing bond purchases prior to the official announcements.[14] It also assumes that there are no market failures that would prevent the full price effect to take hold at the time of announcement, before any purchases have actually taken place. Second, in defining the window for our event-study, we are implicitly assuming that the two-day window is short enough to abstract from any other event affecting the long-term yields.

As noted by Bauer and Rudebusch (2014) and Joyce et al. (2014), 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 due to the existence 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 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.

III. 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). We then further decompose the term-premia into a global and country-specific component, by extracting the first principal component of their co-movements across our set of countries. This section further clarifies our methodology.

A. Data

Our dataset consists of end-of-month observations over the period January 1995 to June 2016 of the term structures of zero-coupon bond yields for the United States, the United Kingdom, Germany, Canada, Sweden and Switzerland. We consider all annual maturities from one to ten years.

[14] 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.

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 percent of the variation of yields in each country, and have the traditional interpretation of level, slope and curvature (Litterman and Scheinkman 1991).

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, as described by:

$$(\mathbf{f}_{j,t} - \mu_j) = \mathbf{\Phi}_j(\mathbf{f}_{j,t-1} - \mu_j) + \varepsilon_{j,t} \tag{2}$$

where $\mathbf{f}_{j,t}$ is the matrix of the first three principal components of the cross-section of yields in country j. In other words, $\mathbf{f}_{j,t} = \mathbf{P}_j^{'}\mathbf{y}_{j,t}$ where $\mathbf{y}_{j,t}$ is a vector of all the yields in a given country, and $\mathbf{P}_j$ is a full-rank matrix. $\varepsilon_{j,t} \sim iid \quad N(0, \mathbf{\Sigma}_j)$.

The expectations component of the n-year yield would then be obtained as follows. First, 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

$$r_{j,t} = \delta_{0,j} + \delta_j^{'}\mathbf{f}_{j,t}, \tag{3}$$

Second, the h step-ahead forecast of $\mathbf{f}_{j,t}$ given the time t information set is given by

$$E_t\mathbf{f}_{j,t+h} = \left(I + \sum_{k=1}^{h-1}\mathbf{\Phi}_j^k\right)\mu_j + \mathbf{\Phi}_j^h\mathbf{f}_{j,t} \tag{4}$$

Putting the two together, the expectations component of the n-year yield can be derived as:

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

where estimates $\delta_{0,j}$, $\delta_j^{'}$, μ_j and $\mathbf{\Phi}_j$ are obtained using ordinary least squares regressions. Similarly, one could 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:

$$tp_{j,t}^{(n)} = y_{j,t}^{(n)} - \delta_{0,j} - \delta_j^{'}(I - \mathbf{\Phi}_j^n)\mu_j - \frac{1}{n}\sum_{i=1}^{n}\delta_j^{'}\mathbf{\Phi}_j^{i-1}\mathbf{f}_{j,t}. \tag{6}$$

C. A Near Cointegrated Panel Vector Autoregression

Estimating term premium component as the residual of the observed 10-year bond yield from the VAR-implied expectations component suffers from two main 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 suffer from the well-documented 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). Moreover, the dynamic term structure model of Kim and Wright (2005) also suffers from this issue and hence places greater weight on the term premia estimates. We conduct a robustness check using the data of Kim and Wright (2005) and find that our results still hold[15]. Moreover, we confirm this bias towards the term premia as we find – overall - larger negative coefficients for the term premium, and more specifically the country term premium component, than our own estimates.

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. In other words, 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:

$$\mathbf{\Phi}_j = \mathbf{\Phi} \qquad \forall j. \tag{7}$$

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.

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:

$$\mathbf{f}_{j,t} = \mathbf{P}'\mathbf{y}_{j,t} \tag{8}$$

where $\mathbf{P} = \frac{1}{J}\sum_{j=1}^{J}\mathbf{P}_j$

[15] Kim and Wright (2005) provide data for the U.S. online. Our results are therefore only robust to their methodology considering data and findings for the United States.

Second, we impose that the level of interest rates in country j follows a highly persistent autonomous autoregressive (AR)(1) process. In other words, we assume that neither the slope nor curvature factors have predictable power over changes in the level of interest rates.[16] 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). Duffee (2011) shows that a model similar to ours where the level follows a random walk process does well in out-of-sample forecasting of U.S. Treasury yields.[17]

While restricting the largest root of the VAR to be equal to one, as in Duffee (2011), should help both in reducing estimation uncertainty and in avoiding the downward bias in the estimated persistence of the system, we find that the estimated term premia based on this assumption play almost no role in explaining the variability in the long-end of the yield curve.

To address this issue, we tackle the persistence bias in our system by using as our autoregressive parameter for the level factor a weighted average of the estimates from two VAR models. In the first model, the level follows a stationary AR process, with an unrestricted autoregressive coefficient, whereas in the second, the level factors follows a random walk. This model combination approach has been shown by Hansen (2010) and Jardet et al. (2011, 2013) to perform well for time series with high persistence.[18]

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

$$(\mathbf{f}_{j,t} - \mu_j) = \mathbf{\Phi}(\mathbf{f}_{j,t-1} - \mu_j) + \varepsilon_{j,t} \tag{9}$$

where

$$\underbrace{\begin{pmatrix} l_{j,t} - \mu_{l,j} \\ s_{j,t} - \mu_{s,j} \\ c_{j,t} - \mu_{c,j} \end{pmatrix}}_{\mathbf{f_{j,t}}} = \underbrace{\begin{pmatrix} \tilde{\phi}_{11} & 0 & 0 \\ 0 & \phi_{22} & \phi_{23} \\ 0 & \phi_{32} & \phi_{33} \end{pmatrix}}_{\mathbf{\Phi}} \underbrace{\begin{pmatrix} l_{j,t-1} - \mu_{l,j} \\ s_{j,t-1} - \mu_{s,j} \\ c_{j,t-1} - \mu_{c,j} \end{pmatrix}}_{\mathbf{f_{j,t-1}} - \mu_{\mathbf{j}}} + \underbrace{\begin{pmatrix} \varepsilon_{j,l,t} \\ \varepsilon_{j,s,t} \\ \varepsilon_{j,c,t} \end{pmatrix}}_{\varepsilon_{\mathbf{j,t}}} \tag{10}$$

[16] 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 portfolio balance effects should pull bond yields in the same direction).

[17] 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.

[18] An alternative approach is proposed by Bauer, Rudebusch, and Wu (2012) who correct the bias using bootstrap methods. The disadvantage of this method is that the bias-corrected estimates lead to a system with explosive roots that requires the use of the stationary adjustment of Kilian (1998). Such an adjustment requires an arbitrary decision on how close to one the largest eigenvalue of the system needs to be.

for $j = 1, \ldots, J$. As described above, $\tilde{\phi}_{11} = \omega \times 1 + (1-\omega)\phi_{11}$, 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 particular structure for the cross-correlation of the error terms across countries.

D. Estimation

We calibrate $\tilde{\phi}_{11}$ such that the impulse response of the level factor to a one-standard deviation shock to the level reaches 0.60, at the five-year horizon, in line with the estimated persistence of the system in Bauer, Rudebusch and Wu, 2012, 2014).[19] This implies $\tilde{\phi}_{11} = 0.996$.

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 as a larger VAR in the whole set of slope and curvatures where exclusion restrictions on the parameters have been imposed. This larger-scale VAR can be expressed as:

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

$$\left(\tilde{\mathbf{f}}_t - \tilde{\mu}\right) = \mathbf{A}(\beta)\left(\tilde{\mathbf{f}}_{t-1} - \tilde{\mu}\right) + \mathbf{u}_t \quad (12)$$

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

$$vec\left[\mathbf{A}(\beta)\right] = \mathbf{G}\beta \quad (13)$$

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

The MD estimate for the restricted coefficients, $\hat{\beta}$, is then as follows:

$$\hat{\beta} = \text{argmin}\left[vec(\hat{\mathbf{A}}) - \mathbf{G}\beta\right]' \mathbf{W}\left[vec(\hat{\mathbf{A}}) - \mathbf{G}\beta\right] \quad (14)$$

[19] This is equivalent to putting an 81.6 percent weight in the unit root model, given that the unconstrained estimate (using the minimum distance approach detailed below) of ϕ_{11} is 0.977. In general, 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.

$$\hat{\beta} = \left(\mathbf{G}'\mathbf{W}\mathbf{G}\right)^{-1}\left[\mathbf{G}'\mathbf{W}vec(\hat{\mathbf{A}})\right]$$

where $\hat{\mathbf{A}}$ is the unrestricted estimate of equation 12, and $\mathbf{W}$ is defined by a suitable weighting matrix. As in the case of generalized method of moments estimation, asymptotic efficiency gains can be achieved by selecting an appropriate weighting matrix. Specifically, we use the optimal weighting matrix, which is the inverse of the asymptotic covariance of $vec(\hat{\mathbf{A}})$.[20]

Finally, $\delta_{0,j}$ and δ_j' are estimated by an OLS regression of the one-year yields on a constant and the country j's factors.[21]

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 the estimated term-premia at the 10-year horizon for all the countries. The term premia shows a high level of correlation across countries. Specifically, the average correlation across term premia estimates is 0.70 for the whole sample and increases to 0.85 in the post-2007 sample. This high correlation in the term premium component across countries is consistent with Rey's (2013, 2015) assertion of the existence of a global financial cycle, an important component of which is the prices of risky assets around the world (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:

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

where $gtp_t^{(10)}$ 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 (89.5 percent and 91.5 percent, respectively) and the lowest for the United States and the United Kingdom (43.6 percent and

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[20] 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 (FGLS) estimator of the parameters of the SUR system (see Moon and Perron, 2008).

[21] Note that as a difference to other papers in the literature (see, i.e., Bauer and Rudebusch, 2014, or Bauer and Neely, 2014) we do not impose a no-arbitrage restriction. Our model can be thought of as the reduced form of such a no-arbitrage model. In line with the results of 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 to change our results.

51.8 percent). The R^2 for Switzerland and Sweden fall in between, with values of 77.6 and 74.1 percent, respectively.

Note that the principal components are not unique and can be defined relative to any dimension. In other words, one could define the U.S. monetary policy to be one principal component, in which case the correlation with this factor for the United States by definition would be 1. In this case, the correlation of term-premia with the global factor for other countries would fall, yet their country-specific components would show a significant correlation with each other. Our interpretation of the low correlation for the United States is not that the U.S. monetary policy is not important in driving the global cycle, but rather that the U.S. term premia also have a significant domestic component.

We interpret these results as indirect evidence that the United States and the United Kingdom 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 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, 2015). This reserve currency status of the US dollar makes it hard to substitute dollar-denominated assets with assets denominated in other currencies.

IV. Event Study of Central Bank Asset Purchase Programs

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 Federal Reserve (section 4.1), the BoE (section 4.2), the Swedish Riksbank (section 4.3) and the asset purchase and reserve expansion programs announced by the Swiss National Bank (section 4.4). Details on these announcements can be found in Tables 1, 3, 5, and 7, respectively.

We analyze two-day changes in the 10-year yield and its components around central bank asset purchase announcements.[22] 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, 6, and 8, respectively. The tables show the changes in the 10-year yield between the day before and after the announcement, as well as its decomposition into the expectations component, and the global and country-specific components of the term-premium. Panel (a) of each table presents the results for the yields of the country embarking on the asset purchase program.

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[22] For example, the term premium component can be expressed as an affine function of the factors:

$tp_{j,t}^{(n)} = y_{j,t}^{(n)} - a_j^{(n)} - \mathbf{b}_j^{(n)'} \mathbf{f}_{j,t}$ with $a_j^{(n)} = \delta_{0,j} + \delta_j^{'} (I - \mathbf{\Phi}_j^j) \mu_j$ and $\mathbf{b}_j^{(n)'} = \frac{1}{n} \sum_{j=1}^{n} \delta_j^{'} \mathbf{\Phi}_j^{j-1}$ (cf. equation 6).

Thus we obtain a daily estimate of $t\hat{p}_{j,t}^{(n)}$ using daily data on $y_{j,t}^{(n)}$ and $\mathbf{f}_{j,t}$, and the estimates for $a_j^{(n)}$ and $\mathbf{b}_j^{(n)}$ obtained from our yield-decomposition, based on the monthly data.

Panel (b) presents the decomposition for the average of the yields for the rest of the countries. 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 June 30, 2016 that were smaller than the change on the announcement day.[23]

A. United States

We start by analyzing the case of the Federal Reserve's LSAP programs. Even though this asset purchase program has been widely studied so far (see, e.g., Gagnon et al., 2011, Krishnamurthy and Vissing-Jorgensen, 2011, Hamilton and Wu, 2012, and Glick and Leduc, 2015, among others), we revisit the effectiveness of their program in bringing down long-term interest rates through the lens of our model for two main reasons. First, the Federal Reserve's LSAP program provides a natural benchmark against which we can measure the effectiveness of the asset purchase programs implemented in other (smaller) countries. Second, by decomposing term premia into a global and country-specific component, we can 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 of asset purchases (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, and 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.

Following QE2 and reports that economic growth remained slow the Federal Reserve decided to implement the Maturity Extension Program[24], 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.

[23] 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.

[24] 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.

Due to the nature of this program it should depress long-term bond yields only through the term premia channel.

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.

Specifically, we consider fourteen asset purchase announcements which encompass the three rounds of asset purchases implemented by the Federal Reserve. These dates, and their specific details, are described in Table 1.

Results

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 et al. (2014). These dates are similar to those used by Gagnon et al. (2010), 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 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 Panel (a) of Table 2). 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 a imminent rate cut of the Fed Funds rate (as it indeed happened when the Fed Funds rate was cut from 50 bps to a range of 0 to 25 bps at the December 2008 FOMC meeting). Importantly, the November 2008 Fed's QE announcement also had an impact on the 10-year yields of the rest of the countries, which dropped 11 bps on average, 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), Table 2).

Later in March, 18, 2009, with the Fed Funds rate close to zero, the FOMC decided to broaden their purchase program to include longer term Treasury securities. This led to a fall in U.S. 10-year rates of 51 bps, where 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 their effective zero lower bound for longer than previously anticipated, and the expectations component fell by another 21 bps. As in the case with the November 2008 announcement. There were also 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 reveal strong signaling effects for U.S. bond yields, a result consistent with Bauer and Rudebusch (2014). Specifically, the expectations component tend to capture between 20 and 50 percent 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 percent 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 2).

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 percent). 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 premium seems to be explained by the global term premium component. Importantly, the results regarding the international portfolio balance channel are reminiscent of Rey's (2015) hypothesis that there is 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 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).

As expected we find for the Maturity Extension Program that the intial announcement and implimentation 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'.

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, and consistent with the evidence in Bauer and Neely (2014), we don't find 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. (2016) hypothesis that the impact of QE programs seems to be larger the weaker the economy and the more segmented financial markets given that the financial markets were most dislocated in the aftermath of the 2007–08 crises than in

2010-2012. 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. United Kingdom

We now turn to the results regarding the response of long-term yields to the BoE's asset purchase announcements. We start by providing a quick summary of the BoE's QE program.

The BoE QE program

The BoE's initial response to the financial crisis included cutting its policy rate from 5 percent in October 2008 to 0.5 percent in March 2009 and a wide range of measures directed towards supporting functioning of the financial market by providing liquidity support.[25] 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, authorized to purchase up to £50 billion of private sector assets such as 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 Commitee (MPC) decided, after cutting its policy rate from 1 percent to 0.50 percent, that further monetary stimulus was still needed and 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) by expanding the range of eligible assets to include gilts. Specifically, the BoE's MPC announced that it would purchase £75 billion of assets over three months including gilts with a residual maturity of between 5 and 25 years. The asset purchase program's size was subsequently increased, reaching £375 billion by the end of 2012, approximately 30 percent of the stock of outstanding nominal government debt in the United Kingdom[26]. In addition, the maturity buying range was also extended to include gilts with a residual maturity greater than three years in August 2009.

Results

Overall, we consider eight asset purchase announcements for the BoE QE program. These dates, and their specific details, are described in Table 3. We follow the set of events analyzed in Christensen and Rudebusch (2012) and Joyce et al. (2014), with two differences: first, we include asset purchases announcements in 2011 and 2012 that followed the publication of these papers, and second, we exclude the announcement on February 4, 2010, given that the

[25] Further details of the BoE's QE program can be found in, e.g., Cross et al. (2010) and Joyce et al. (2014).

[26] This has subsequently been increased to £435 billion following an announcement by the BoE on 4 August 2016 to expand their asset purchases.

announcement indicated maintaining the level of asset purchases at £200 billion. Our results remain qualitatively the same if we use the original event sets employed in these two papers.

Table 4 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 in February and March 2009 had a significantly larger impact on 10-year yields compared to 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 February 11, 2009, and March 5, 2009, respectively (see panel (a) of Table 4). These two announcements differ however in the channel through which they affected the yields.

Following the February 2009 announcement, almost the entire change in the yields 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 percent level. This outcome can potentially be explained by the fact that the policy rate was still 50 bps above what was considered the effective lower bound at the time. Furthermore, at the time of the announcement neither any purchases were made, nor any details regarding future purchases were announced. As such, the February 2009 inflation report could be 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-premia significantly fell subsequent to the launch of the BoE QE program on March 2009. The 56 bps drop in term-premia, roughly 80 percent of the total drop in long-term yields, is mainly due to the fall in the country-specific term-premium (41 bps). While the fall of the global component of the term premium is small (15 bps) compared to the overall reduction in 10-year Gilt yields, it is still both economically important and statistically significant and the main contributor to the fall in the yields of the rest of the countries that day (see panel (b) of Table 4). In fact, 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). Moreover, the importance of the U.K financial sector to the global economy may have motivated this effect through the global term premium.

Similarly 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 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 et al. (2016) propose a model where, due to institutional and informational frictions, capital across asset classes move 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.

Apart from the February 2009 Inflation Report and the March 2009 monetary policy decision, which had an effect on global yields of similar magnitude to the Fed's QE announcements, the BoE asset purchase announcements did not significantly affect the 10-year yields in the rest of the world.

C. Sweden

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

The Riksbank 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, the Riksbank announced in February 2015 the purchases of government bonds with maturities up to five years for the amount of SEK 10 billion.[27] Simultaneously, the Riksbank cut its repo rate by 10 bps to -0.10 percent, 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 basis points, to increase purchases of government bonds by SEK 30 billion and to extend the maturity of bonds purchased to beyond 5 years. Further asset purchases were announced on five other occasions between 2015 and 2016, and the repo rate was eventually lowered to -0.50 percent. The subsequent purchases were significantly larger than the initial SEK 10 billion (ranging between SEK 45 to 200 billion), and reached SEK 245 billion by April 2016, approximately 40 percent of the stock of outstanding nominal government debt in Sweden.[28]

Results

Table 5 provides specific details on the six Riksbank's asset purchase announcements. Our results indicate that changes in the yields were the largest on dates when, in addition to announcements regarding an increase in the size of the asset purchase program, the policy rate was also cut. This is the case of the initial QE announcement on February 2015 when Swedish yields fell 15 bps, as well as the announcements on March 2015 and July 2015, when yields fell 13 bps and 17 bps respectively (see panel (a) of Table 6). Not surprisingly, most of the fall in Swedish yields on these three dates is mainly due to the expectations component of interest

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[27] 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.

[28] Further details of the Riksbank's QE program can be found in De Rezende (2016).

rates (-13.5, -7, and -13 bps, respectively). The fall of the term premium for the March 2015 announcement is mainly due to a fall in the global component of the term premium (which, although statistically significant, is almost 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 (3 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.[29] However, three factors suggest that the QE specific effects were small in the case of Riksbank's program: First, the drop in yields around the announcement days when there was no policy rate cut were small, or indeed the yields rose on certain occasions. Second, most of the effect on long-term yields were due to the signaling channel, a channel which should be more strongly associated with rate cuts. Third, whenever term-premia were affected, the reduction was due to a lowering of the global term-premia.[30]

Contrary to the experience of the U.S. asset purchase program, and to a lesser extent the U.K. program, the effects of the Riksbank asset purchase announcements are almost entirely associated with Swedish yields (see panel (b) of Table 6). Only on one occasion (March 2015) the average 10-year yields in the rest of the world fell 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.

D. 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, as opposed to the experiences in the United States, United Kingdom, and Sweden, the SNB so far has not bought Swiss government bonds. Moreover, the following response of the SNB was motivated by an appreciation of their currency since the financial crisis of 2007. This appreciation acts as a tightening of monetary conditions and therefore "the SNB has decided to purchase foreign currency on the foreign exchange market, to prevent any further appreciation of the Swiss franc against the euro" (Swiss National Bank, 2009). This is a special case in our sample as the central bank is reacting to strong upward pressure on their currency value against the euro and current financial market developments that are "increasing the downside risks to price stability in Switzerland" (Swiss National Bank, 2011). Still, we

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

[30] 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.

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 SNB QE 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.[31] These alternative 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 lowering the upward pressures on exchange rate.

While the SNB did not specify neither the intended size of the asset purchase program, nor the specific bonds targeted at the time of the announcement, it was eventually made public that the SNB had purchased covered and nonbank corporate bonds. The purchases were officially discontinued in September 2009, and the program was announced as completed in December 2009. 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 (equivalent to $2.6 billion at the time or 0.5 percent of Swiss gross domestic product (GDP), a small program if compared with the sized of the program embarked by the Federal Reserve.

Expansion of reserves

Against the backdrop of the market turmoils 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 in 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.[32] At the same time, the SNB announced an intention to expand its balance sheet through purchases of short-term debt securities, and repo operations. No long-term swiss franc bonds were purchased. The objective of this policy was to put downward pressure on money market interest rates and thus counter the appreciation in Swiss franc.

As the exchange rate continued to appreciate after this announcement, the SNB further 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

[31] Further details of the SNB QE program can be found in Kettemann and Krogstrup (2014) and Mirkov and Sutter (2011), among others.

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

from CHF 30 to 200 billion, an increase equivalent to approximately 30 percent of Swiss GDP in 2011.[33]

Results

Table 7 contains the specific details of the four dates that we focus on this paper (the announcement of the Swiss QE program in 2009 and the three SNB's reserve expansion announcements in 2011).

The change in long-term yields around the announcement studied were limited (see panel (a) of Table 8). The drop in the yields around the March 2009 announcement was small, 5 bps, and not statistically significant at 5 percent level.

While the Swiss QE program did not include the purchase of government bonds, we would have expected spillover effects from private sector bonds and a reduction in yields. We attribute these minimal effects to the lack of specific information about the intended size of the QE program and the specific bonds targeted. Moreover, this lack of specific information may also have weakened the effect found for the signalling channel of quantitative easing for the March 2009 announcement.

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 percent—of this reduction in yields is due to lower term-premia. This result is consistent with Christensen and Krogstrup's (2016a), who also study the reserve expansion program by the SNB.

What is more surprising is that our model seems to attribute 60 percent of the drop in the term premium component to global factors. One potential explanation is the major sell-off in European bank stocks and an increase in market volatility that occurred on August 18, 2011, due to market rumors that the ECB dollar facility was tapped for the first time since early 2011 (see Appendix H in Christensen and Krogstrup, 2016, for a list of important events in August and September 2011). This sell-off in European stocks could have led international investors to purchase government bonds around the world in an episode of flight-to-quality, thereby lowering the yields. Indeed, figure 5 shows that with the exception of Canadian bonds, term premia dropped noticably for all other five countries in our sample. Indeed, our decomposition of the term premium into a global and country-specific component allows us to control for the effects of such global events when analyzing the impact of asset purchase in small open economies.

[33] Furthermore, following the August announcement, in September 2011 the SNB announced an exchange rate cap to stop the Swiss franc from appreciating further against the euro. This involved creating new francs and using them to purchase euros. The SNB dropped the cap in early 2015 as it was no longer justified.

V. Final remarks

In this paper we have examined the asset purchase programs by the Federal Reserve, the Bank of England, the Swedish Riksbank and the Swiss National Bank and their ability to reduce long-term yields. Our analysis suggests that, in general, the changes in long-term rates around asset purchase announcements by the BoE, the Riksbank and the SNB are smaller than the changes observed after the first round of asset purchases implemented by the Federal Reserve. Furthermore, our results suggest that unlike the United States announcements, and to some extent those in the United Kingdom, the QE programs in Sweden and Switzerland do not affect the global term premium component of the yields. Our explanation for this observation is the relatively small size of the purchases compared to 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.

Although their impact on long term premia has been limited, QE programs in SOEs have been more successful in affecting domestic financial conditions, through their effect on exchange rate and indeed expectations about long-term rates. To the extent that central banks are using QE as a tool to ease monetary policy these other transmission channels matter for judging the effectiveness of QE.

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

Figure 1. Estimated Factors

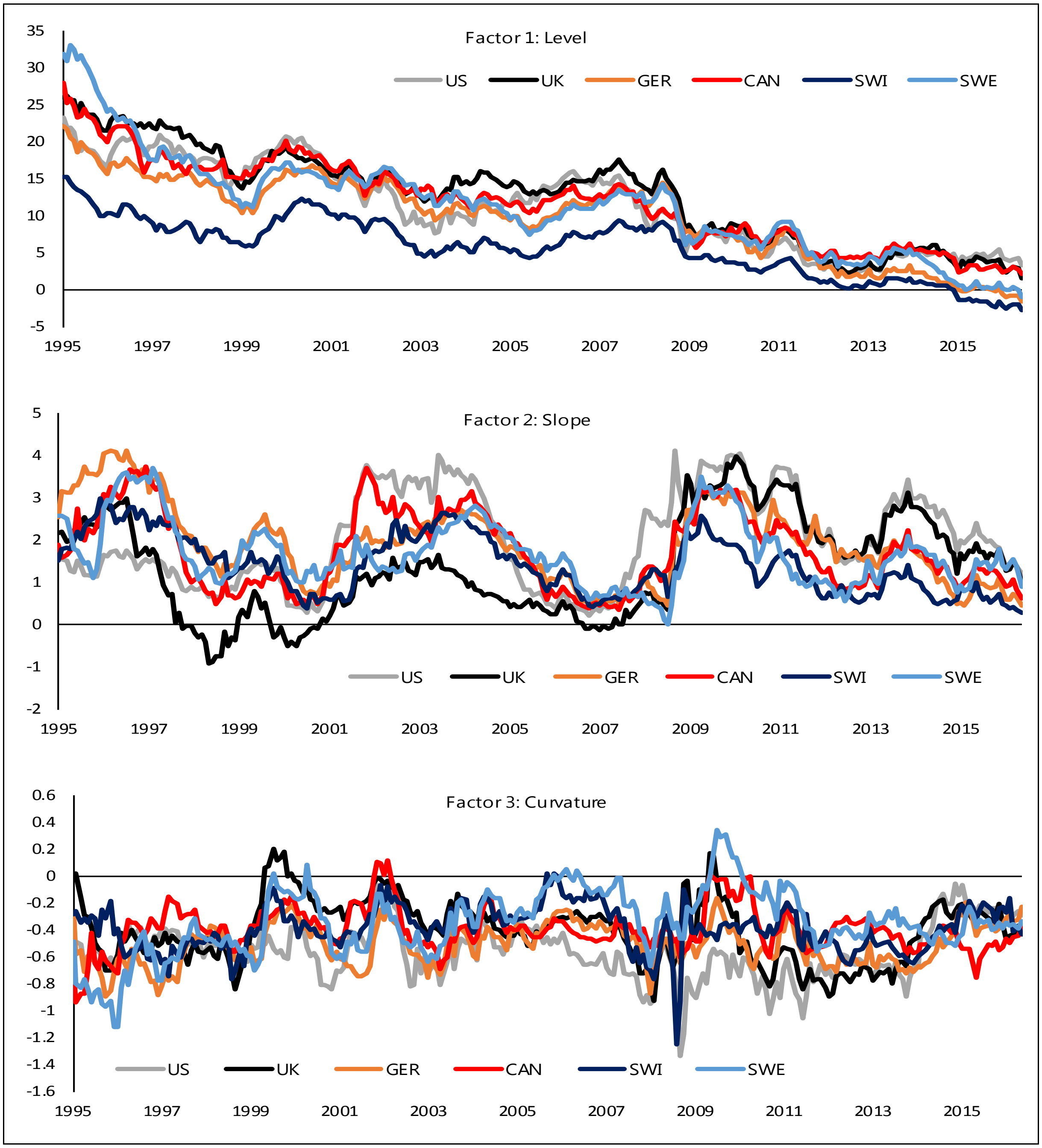
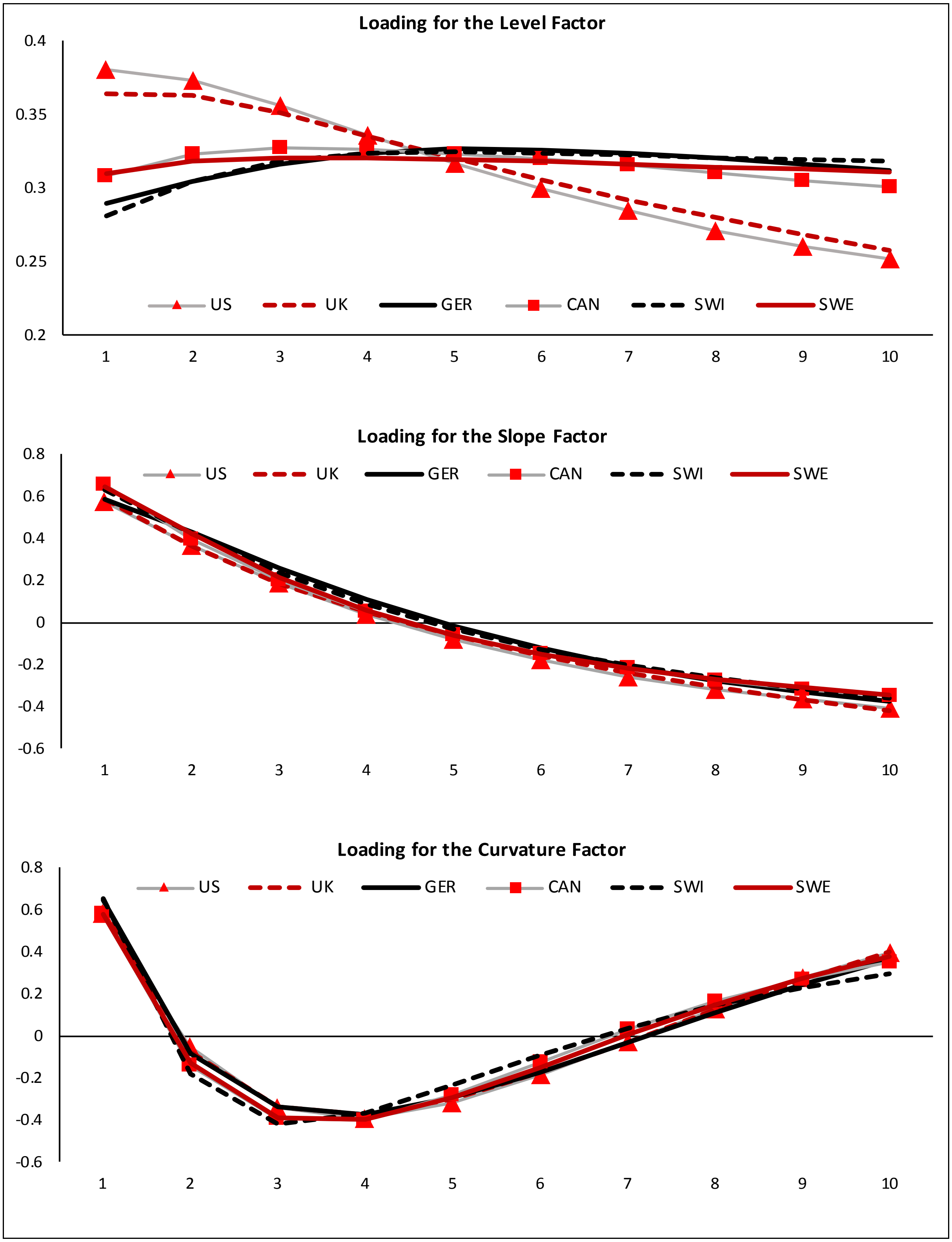
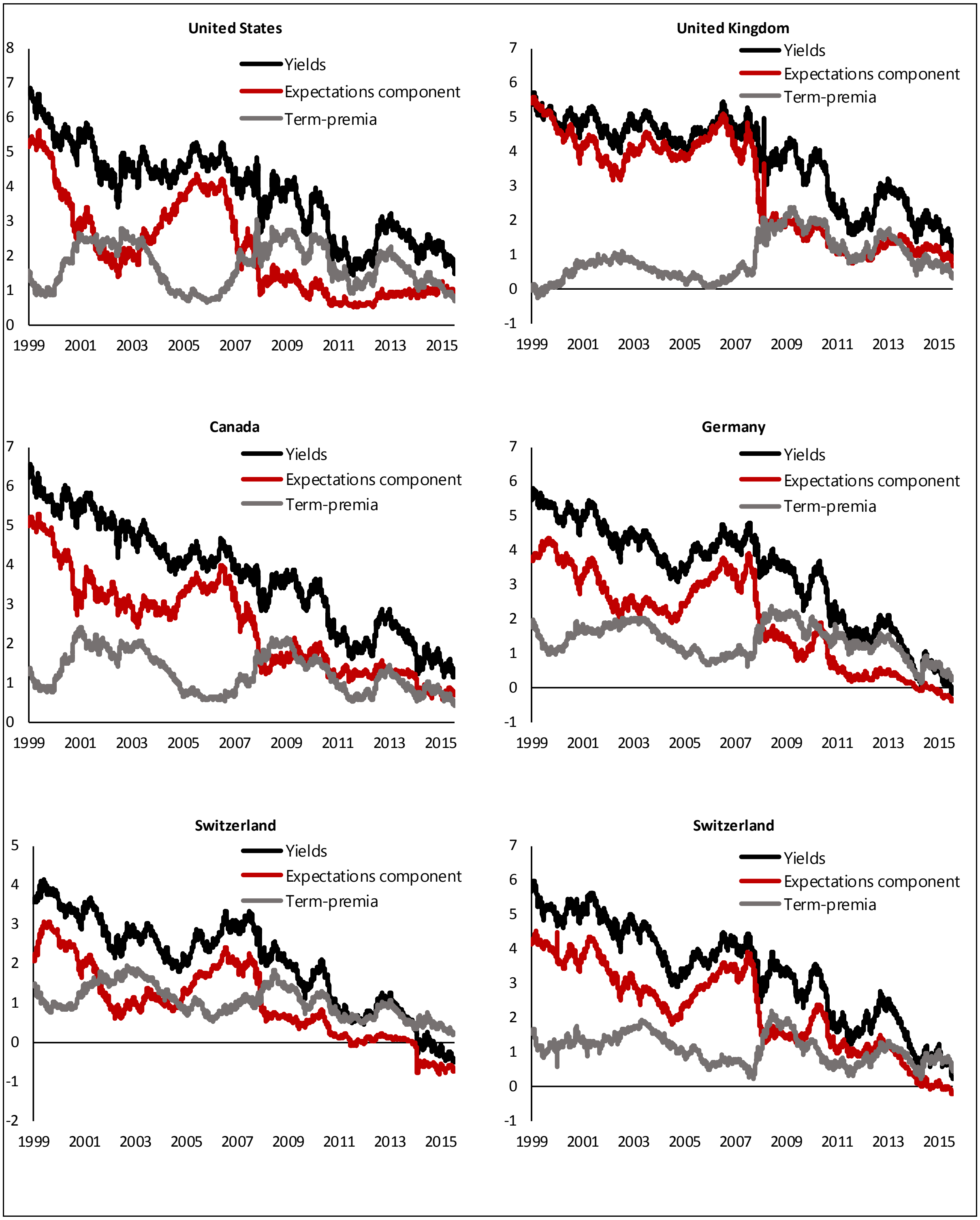


Figure 2. Factor Loadings on Principal Components



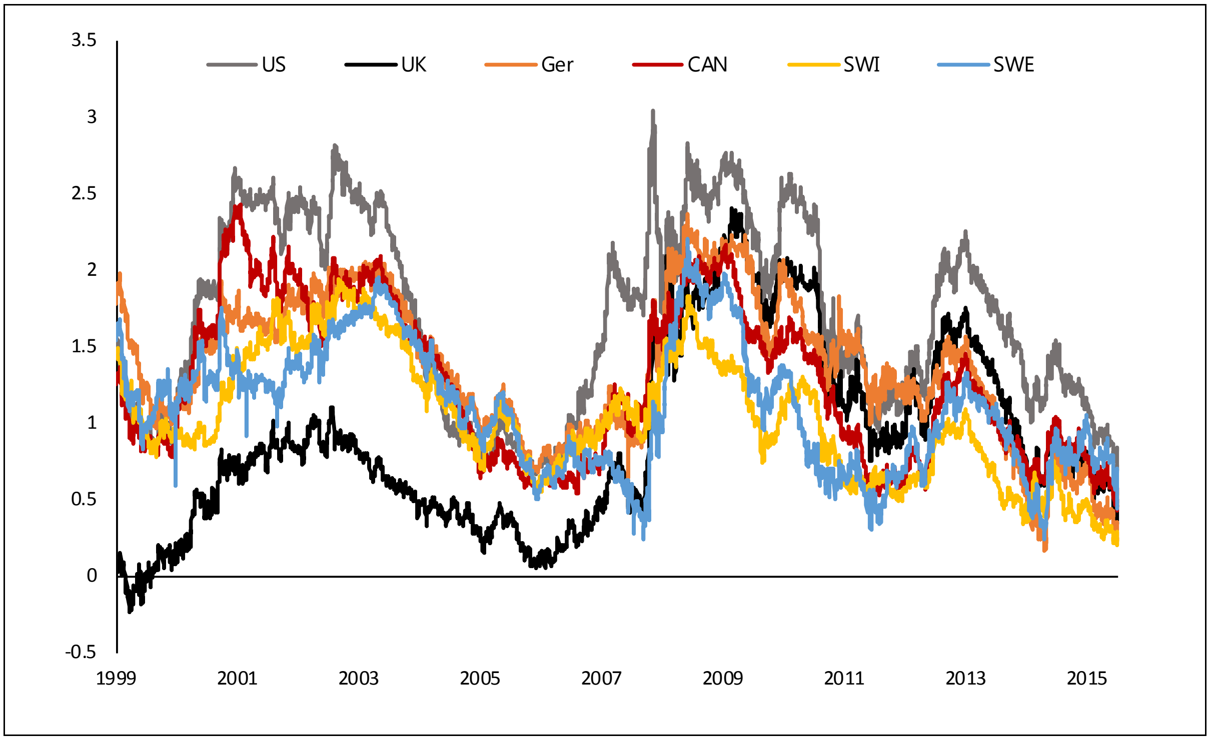
This figure represents the factor loadings for the three factors found using Principal Component Analysis on the bond yields at different maturities for 6 countries in our sample as outlined in Equation (2) above.

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.

Figure 4. Global Component of Countries' Term Premia



The global component of countries' term premia represented in Figure 4 above is calculated using a one-factor model to decompose the term premia into global and local factors. This model is outlined in Equation (15). The computations and figures were constructed using daily data from 12/31/1999-06/30/2016.

Figure 5. Movements in Yields and Premia

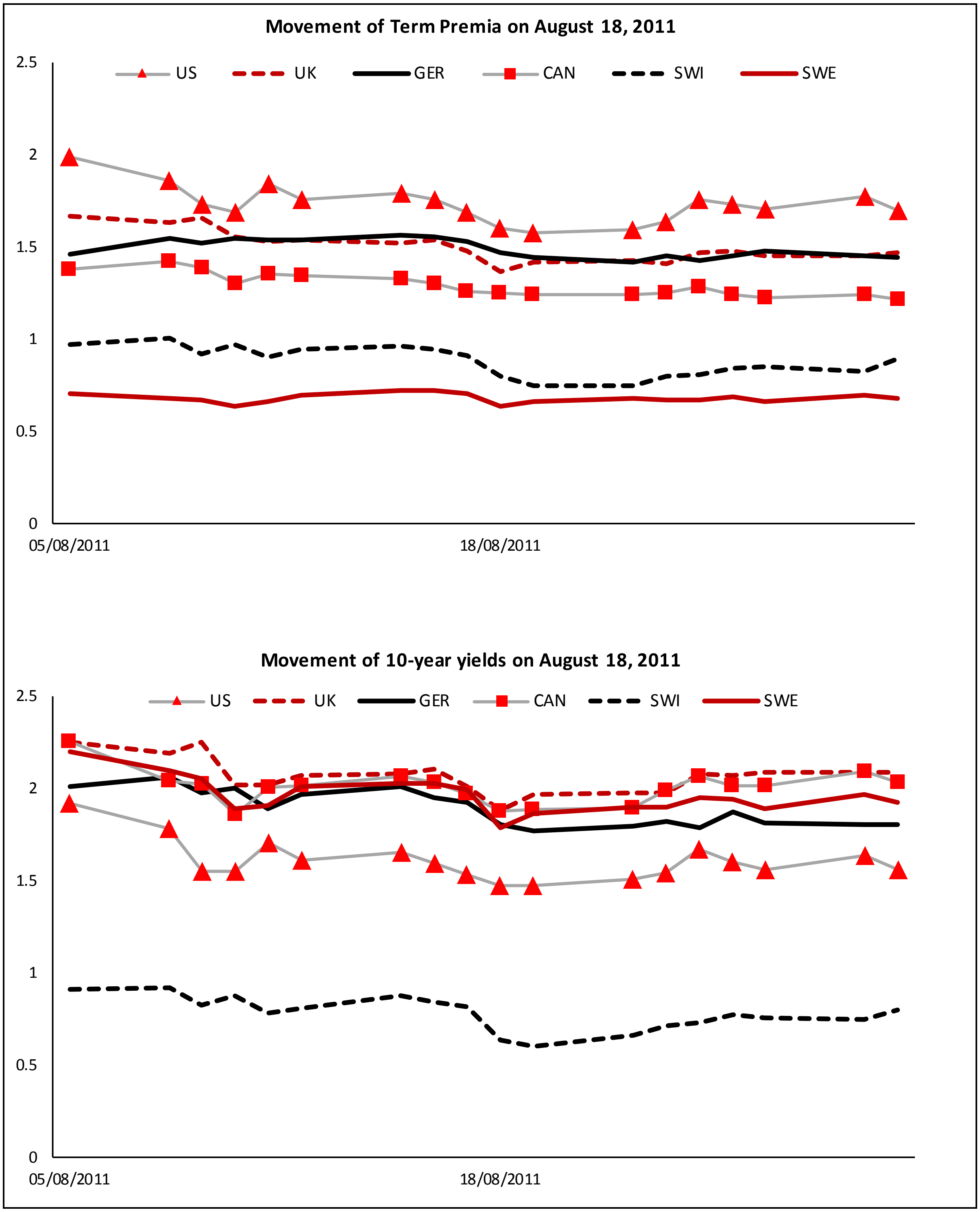


Table 1. Federal Reserve’s Asset Purchase Announcements

Date	Program	Event	Description
25-Nov-08	QE1	Initial LSAP announcement	Federal Reserve announces purchases of up to $100 billion in agency debt and up to $500 billion in agency MBS.
1-Dec-08	QE1	Bernanke's speech	Chairman Bernanke mentions that Fed could purchase long-term Treasuries
16-Dec-08	QE1	FOMC statement	Statement indicates that the FOMC is considering expanding purchases of agency securities and initiating purchases of Treasury securities. Also, Fed funds rate target reduced from 1% to a 0-25bp target rate
28-Jan-09	QE1	FOMC statement	FMOC indicates that FOMC 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: 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-2012	MEP	FOMC statement	Extension to the MEP program by adding additionally $267 billion thereby extending it throughout 2012.
22-Aug-12	QE3	FMOC 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 odds of further QE.
13-Sep-12	QE3	FOMC statement	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 MEP 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 2. Changes on Bond Yields on Fed Asset Purchase Announcement Days

Table 2

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**	-2.3	-10.6**
		(0.00)	(0.02)	(0.01)	(0.11)	(0.01)
	16-Dec-08	-38.6**	-6.9	-31.7***	-6.6***	-25.1***
		(0.00)	(0.10)	(0.00)	(0.00)	(0.00)
	28-Jan-09	27.1	12.8	14.4	2.6	11.7
		(1.00)	(0.98)	(0.99)	(0.91)	(1.00)
	18-Mar-09	-51.2***	-21.4***	-29.8***	-7.7***	-22.1***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Average	-23.9***	-8.9*	-15**	-4.5**	-10.5**
		(0.01)	(0.05)	(0.01)	(0.02)	(0.01)
US-QE2	10-Aug-10	-14.9**	-4.6	-10.3**	-1.7	-8.6**
		(0.03)	(0.17)	(0.02)	(0.18)	(0.01)
	27-Aug-10	4.4	0.4	4	0	4
		(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)	(0.15)	(0.01)	(0.01)	(0.03)
	15-Oct-10	0.8	-1.6	2.4	2.7	-0.3
		(0.58)	(0.36)	(0.75)	(0.91)	(0.46)
	3-Nov-10	-12.4*	-5.1	-7.3	-1.3	-6**
		(0.06)	(0.15)	(0.05)	(0.25)	(0.04)
	Average	-7.8	-3.2	-4.6	-1	-3.5
		(0.16)	(0.25)	(0.13)	(0.29)	(0.12)
US-MEP	21-Sep-11	-26.4***	-1.6	-24.8***	-6.4***	-18.4***
		(0.00)	(0.36)	(0.00)	(0.00)	(0.00)
	20-Jun-12	-0.5	1.5	-2	1.2	-3.2
		(0.50)	(0.67)	(0.30)	(0.77)	(0.14)
	Average	-13.5*	-0.1	-13.4**	-2.6*	-10.8**
		(0.05)	(0.52)	(0.01)	(0.08)	(0.01)
US-QE3	22-Aug-12	-14.1**	-4.8	-9.2**	-5.5**	-3.8
		(0.04)	(0.16)	(0.03)	(0.01)	(0.11)
	31-Aug-12	-7	-3.5	-3.5	0.3	-3.8
		(0.18)	(0.23)	(0.19)	(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)	(0.73)	(0.92)	(0.82)	(0.93)
	Average	-0.2	-1	0.9	0	0.9
		(0.52)	(0.42)	(0.62)	(0.53)	(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 June 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 (seen in equation (2)), which is then decomposed further into term premia and expectation components using a VAR as presented in equations (5) and (6). Following, we separate the term premia into global and local factors using a one-factor model as seen in equation (15). Detailed methodology is provided in the main text above.

Table 2. Changes on Bond Yields on Fed Asset Purchase Announcement Days (continued)

Table 2 (continued)

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 B: Average (ex-US)						
US-QE1	25-Nov-08	-10.8**	0.1	-10.9***	-11.6***	0.7
		(0.02)	(0.55)	(0.00)	(0.00)	(0.91)
	1-Dec-08	-15.4***	-14.1***	-1.3	-3.2	1.9
		(0.00)	(0.00)	(0.30)	(0.11)	(1.00)
	16-Dec-08	-19.8***	-14.7***	-5.2**	-9***	3.9
		(0.00)	(0.00)	(0.02)	(0.00)	(1.00)
	28-Jan-09	0.4	-1.2	1.7	3.6	-1.9***
		(0.58)	(0.34)	(0.78)	(0.91)	(0.00)
	18-Mar-09	-10.4**	-3.2	-7.2**	-10.5***	3.3
		(0.02)	(0.15)	(0.01)	(0.00)	(1.00)
	Average	-11.2**	-6.6**	-4.6**	-6.1**	1.6
		(0.01)	(0.03)	(0.04)	(0.02)	(0.99)
US-QE2	10-Aug-10	-7.2*	-5.9**	-1.3	-2.4	1.1
		(0.06)	(0.04)	(0.30)	(0.18)	(0.97)
	27-Aug-10	0.7	1	-0.3	0.1	-0.4
		(0.60)	(0.68)	(0.47)	(0.55)	(0.20)
	21-Sep-10	-11.4**	-5.6*	-5.8**	-6.7**	0.9
		(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)	(0.67)
	3-Nov-10	-2.2	-1.2	-0.9	-1.8	0.8
		(0.35)	(0.34)	(0.36)	(0.25)	(0.94)
	Average	-2.8	-1.9	-0.9	-1.4	0.5
		(0.30)	(0.27)	(0.36)	(0.29)	(0.87)
US-MEP	21-Sep-11	-10.5**	-4	-6.5**	-8.8***	2.3
		(0.02)	(0.10)	(0.01)	(0.00)	(1.00)
	20-Jun-12	5.1	2.7	2.5	1.7	0.8
		(0.88)	(0.84)	(0.86)	(0.77)	(0.94)
	Average	-2.7	-0.7	-2	-3.6*	1.6
		(0.31)	(0.43)	(0.21)	(0.08)	(0.99)
US-QE3	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	0.4	0.6
		(0.61)	(0.51)	(0.69)	(0.60)	(0.90)
	13-Sep-12	5.6	1.7	3.9	4.8	-0.9*
		(0.89)	(0.75)	(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)	(0.51)	(0.52)	(0.53)	(0.46)

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 June 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 (seen in equation (2)), which is then decomposed further into term premia and expectation components using a VAR as presented in equations (5) and (6). Following, we separate the term premia into global and local factors using a one-factor model as seen in equation (15). Detailed methodology is provided in the main text above.

Table 3. 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 five and twenty-five years. Also, policy rate cut from 1% to a 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.

Table 4. Changes on Bond Yields on BoE Asset Purchase Announcement Days

Table 4

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: UK						
	11-Feb-09	-35***	-29.2***	-5.8*	-5.6**	-0.2
		(0.00)	*(0.00)*	*(0.06)*	*(0.02)*	*(0.46)*
	5-Mar-09	-67***	-11.1**	-55.9***	-14.9***	-41***
		(0.00)	*(0.01)*	*(0.00)*	*(0.00)*	*(0.00)*
	7-May-09	10	4.5	5.5	8.4	-2.9
		(0.93)	*(0.89)*	*(0.92)*	*(0.99)*	*(0.10)*
	6-Aug-09	-3	-1.2	-1.8	0.9	-2.7
		(0.31)	*(0.39)*	*(0.30)*	*(0.69)*	*(0.12)*
UK-QE	5-Nov-09	10	-0.2	10.2	3	7.2
		(0.93)	*(0.50)*	*(0.99)*	*(0.89)*	*(0.99)*
	6-Oct-11	12	4.1	7.9	6.3	1.6
		(0.95)	*(0.86)*	*(0.97)*	*(0.98)*	*(0.76)*
	9-Feb-12	-5	-4.4	-0.6	-0.8	0.3
		(0.22)	*(0.14)*	*(0.44)*	*(0.37)*	*(0.56)*
	5-Jul-12	-11*	-7.2*	-3.8	-3.8*	0
		(0.05)	*(0.05)*	*(0.14)*	*(0.06)*	*(0.50)*
	Average	-11.1**	-5.6	-5.5*	-0.8	-4.7**
		(0.04)	*(0.10)*	*(0.06)*	*(0.38)*	*(0.03)*
Panel B: Average Ex-UK						
	11-Feb-09	-12.9**	-7**	-5.9**	-5.8**	-0.1
		(0.01)	*(0.03)*	*(0.02)*	*(0.02)*	*(0.45)*
	5-Mar-09	-12.9**	-4.7*	-8.2**	-15.5***	7.3
		(0.01)	*(0.08)*	*(0.00)*	*(0.00)*	*(1.00)*
	7-May-09	13.7	4.2	9.5	8.7	0.7
		(0.99)	*(0.92)*	*(1.00)*	*(0.99)*	*(0.94)*
	6-Aug-09	4.3	2.8	1.5	0.9	0.5
		(0.83)	*(0.84)*	*(0.76)*	*(0.69)*	*(0.88)*
UK-QE	5-Nov-09	1.2	-0.4	1.6	3.1	-1.5**
		(0.64)	*(0.48)*	*(0.76)*	*(0.89)*	*(0.01)*
	6-Oct-11	13.2	6.4	6.8	6.6	0.2
		(0.99)	*(0.97)*	*(0.98)*	*(0.98)*	*(0.67)*
	9-Feb-12	-1.5	-0.5	-1	-0.9	-0.1
		(0.41)	*(0.46)*	*(0.36)*	*(0.37)*	*(0.38)*
	5-Jul-12	-9.5**	-5.3*	-4.2*	-3.9*	-0.3
		(0.03)	*(0.06)*	*(0.05)*	*(0.06)*	*(0.26)*
	Average	-0.6	-0.6	0	-0.8	0.8
		(0.50)	*(0.45)*	*(0.54)*	*(0.38)*	*(0.95)*

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 June 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 (seen in equation (2)), which is then decomposed further into term premia and expectation components using a VAR as presented in equations (5) and (6). Following, we separate the term premia into global and local factors using a one-factor model as seen in equation (15). Detailed methodology is provided in the main text above.

Table 5. Swedish Riksbank Asset Purchase Announcements

Date	Program	Event	Description
12-Feb-15	SWE-QE	Repo rate decision	The Executive Board announced cutting the repo rate from 0% to -0.10% and that the Riksbank will 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 by15 basis points to −0.25% and buying government bonds for SEK 30 billion.
29-Apr-15	SWE-QE	Repo rate decision	The Executive Board of decided to extend the purchases 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 basis point to -0.35 per cent and to extend the purchases 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 has 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 has decided to extend the government bond purchasing program to a total of SEK 245 billion.

Table 6. Changes on Bond Yields on Swedish Riksbank Asset Purchase Announcement Days

Table 6

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: Sweden						
	12-Feb-15	-15.1**	-13.5**	-1.6	0.7	-2.3
		(0.02)	*(0.01)*	*(0.32)*	*(0.65)*	*(0.14)*
	18-Mar-15	-12.7**	-7.2**	-5.5*	-5**	-0.5
		(0.03)	*(0.04)*	*(0.06)*	*(0.03)*	*(0.41)*
	29-Apr-15	13.2	6.4	6.7	7.7	-1
		(0.97)	*(0.95)*	*(0.96)*	*(0.98)*	*(0.31)*
SWE-QE	2-Jul-15	-16.9**	-13.3**	-3.6	-0.4	-3.2*
		(0.01)	*(0.01)*	*(0.13)*	*(0.46)*	*(0.08)*
	28-Oct-15	-1.8	0.9	-2.7	2.4	-5.1**
		(0.40)	*(0.64)*	*(0.20)*	*(0.83)*	*(0.03)*
	21-Apr-16	13.9	3.2	10.6	6.7	4
		(0.98)	*(0.84)*	*(0.99)*	*(0.98)*	*(0.95)*
	Average	-3.2	-3.9	0.7	2	-1.3
		(0.30)	*(0.15)*	*(0.62)*	*(0.81)*	*(0.26)*
Panel B: Average Ex-Sweden						
	12-Feb-15	0.9	-0.6	1.6	0.7	0.9
		(0.62)	*(0.44)*	*(0.76)*	*(0.65)*	*(0.94)*
	18-Mar-15	-8.3*	-3.8	-4.5**	-4.7**	0.2
		(0.05)	*(0.12)*	*(0.04)*	*(0.03)*	*(0.63)*
	29-Apr-15	11.7	4.4	7.3	7.2	0.1
		(0.98)	*(0.92)*	*(0.98)*	*(0.98)*	*(0.61)*
SWE-QE	2-Jul-15	-1.5	-1.6	0.1	-0.4	0.4
		(0.40)	*(0.30)*	*(0.54)*	*(0.46)*	*(0.81)*
	28-Oct-15	8.1	4.6	3.5	2.2	1.3
		(0.94)	*(0.93)*	*(0.91)*	*(0.83)*	*(0.98)*
	21-Apr-16	8.9	3.5	5.5	6.2	-0.7*
		(0.95)	*(0.88)*	*(0.96)*	*(0.98)*	*(0.09)*
	Average	-0.6	-0.6	0	-0.8	0.8
		(0.50)	*(0.45)*	*(0.54)*	*(0.38)*	*(0.95)*

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 June 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 (seen in equation (2)), which is then decomposed further into term premia and expectation components using a VAR as presented in equations (5) and (6). Following, we separate the term premia into global and local factors using a one-factor model as seen in equation (15). Detailed methodology is provided in the main text above.

Table 7. 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 purchasing 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 basis points. 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 8. Changes on Bond Yields on SNB Asset Purchase Announcement Days

Table 8

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: Switzerland						
	12-Mar-09	-5.6*	-10.6**	5	-0.5	5.5
		(0.09)	*(0.01)*	*(0.94)*	*(0.41)*	*(0.97)*
	3-Aug-11	-1.8	-3.2	1.4	-0.2	1.6
		(0.35)	*(0.11)*	*(0.71)*	*(0.50)*	*(0.74)*
SWI-QE	10-Aug-11	-5.5	-3.8*	-1.7	-1.1	-0.6
		(0.10)	*(0.09)*	*(0.28)*	*(0.30)*	*(0.41)*
	17-Aug-11	-20.3***	-5.6**	-14.7***	-8.9**	-5.8**
		(0.00)	*(0.04)*	*(0.00)*	*(0.00)*	*(0.03)*
	Average	-8.3**	-5.8**	-2.5	-2.7	0.2
		(0.04)	*(0.04)*	*(0.20)*	*(0.10)*	*(0.54)*
Panel B: Average Ex-Switzerland						
	12-Mar-09	-4.3	-2.3	-2	-0.7	-1.3**
		(0.22)	*(0.25)*	*(0.23)*	*(0.41)*	*(0.02)*
	3-Aug-11	-6.7	-5.6*	-1.1	-0.2	-0.9*
		(0.11)	*(0.07)*	*(0.35)*	*(0.50)*	*(0.05)*
SWI-QE	10-Aug-11	-4.8	-4	-0.8	-1.3	0.5
		(0.19)	*(0.13)*	*(0.40)*	*(0.30)*	*(0.85)*
	17-Aug-11	-19.5***	-8.8**	-10.7***	-10.9***	0.2
		(0.00)	*(0.02)*	*(0.00)*	*(0.00)*	*(0.64)*
	Average	-8.8*	-5.2*	-3.7*	-3.3	-0.4
		(0.05)	*(0.08)*	*(0.09)*	*(0.10)*	*(0.23)*

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 June 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 (seen in equation (2)), which is then decomposed further into term premia and expectation components using a VAR as presented in equations (5) and (6). Following, we separate the term premia into global and local factors using a one-factor model as seen in equation (15). Detailed methodology is provided in the main text above.

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