International spillover effects of unconventional monetary policy announcements by the Fed

Evidence from the eurozone

Author: Y. Hemmerlé
Department of Economics, Erasmus School of Economics, Erasmus University Rotterdam

January 17, 2017

First supervisor: Prof. Dr. J. Swank
Second supervisor: Dr. L.C.G. Pozzi

Abstract

This thesis examines the impact and channels of unconventional monetary policy announcements by the Fed on eurozone government bond markets. The results indicate that these announcements affect European bond markets through both a signalling and a portfolio balance channel. While the transmission of both channels is found to be important, the portfolio balance channel appears to be most dominant for eurozone core countries. This finding reveals that unconventional monetary policy announcements by the Fed mainly triggered a flight to safe eurozone government bonds.

This thesis is dedicated to the memory of my beloved grandfather Tammo (Tom) Tiessen. Although he was my greatest motivation in finishing this thesis the past few months, he was unable to see my graduation. This is for him.

1 Introduction

Little is known about how announcements by the U.S. Federal Reserve System (henceforth, Fed) on its unconventional monetary policy (UMP) may have influenced European bond markets. This thesis attempts at filling that gap. I find that European government bond yields were affected through both *signalling* and *portfolio balance* effects. Signalling effects occur because Fed announcements alter the expectations of investors on future (short-term) interest rates. Portfolio balance effects occur because purchases by the Fed change the composition of financial assets held by investors, who may already respond to announcements of such purchases. While both channels are found to be significant, the portfolio balance channel turns out to be the most dominant for government bond markets in the core of the eurozone.

The role of UMP has increased markedly since the outbreak of the financial crisis in 2007. The Fed has been the first and most active central bank implementing UMP, resulting in total asset purchases of over $3 trillion. These unconventional measures were needed after the Fed's traditional instrument - the federal funds rate - was close to the zero lower bound. In late 2008, the Fed initiated two types of UMP to combat a continuation of severe credit market stress and a deteriorating economic outlook. These measures included Large Scale Asset Purchases (LSAP's), mainly of mortgage backed securities and longer-term Treasury paper, and clear communication regarding its future policy rate (forward guidance). The Federal Open Market Committee (FOMC) officially announces these measures through press statements or news conferences. These announcements immediately affect asset prices, at least to the extent that such announcements affect investors' expectations of the future course of UMP by the Fed. This is because financial markets directly price in the announced measures, instead of doing so when the actual implementation takes place.

Most research on UMP announcements by the Fed focuses on their effects on US bond markets or Emerging Market Economies (EME's).[1] Nearly all these studies found significant effects on interest rates, capital flows, equity prices and exchange rates, in particular for the first round of QE. Only Neely (2015) and Bauer and Neely (2014) examine the transmission of portfolio balance and signalling effects of UMP announcements by the Fed on advanced economies.[2] They find that announcements by the Fed on its UMP lower international bond yields and depreciate the USD versus other currencies. In the case of Germany, it turns out that the portfolio balance channel is, relative to the signalling channel, the most important in reducing German bond yields. Surprisingly, the impact of UMP announcement by the Fed through both these channels has not been examined for other eurozone countries. I contribute to this literature by examining the transmission of portfolio balance and signalling effects of UMP announcements by the Fed to other core and periphery countries of the eurozone. In doing so, I use a novel general framework on the decomposition of government bond yields, in which I explicitly account for sovereign risk in eurozone government bond markets.

This thesis continues with a discussion on the transmission channels of UMP by the Fed.

[1] See for instance Gagnon et al. (2011), Fratzer et al. (2013), Moore et al. (2013) and Bowman et al. (2015).

[2] These economies include Germany, Japan, Australia, the US and Canada.

Section 3 provides a brief review of the literature. Section 4 presents the model and estimating forms. Section 5 discusses the data. Section 6 presents the results and Section 7 concludes.

2 The transmission channels of UMP: a discussion of concepts

Joyce et al. (2011) distinguish three channels through which the yield on a government bond may be affected by announcements of the Fed on UMP: a signalling channel, a portfolio balance channel and a liquidity channel. This section describes these channels in more detail.

2.1 Portfolio Balance Channel

In analysing the portfolio balance channel, the literature emphasises the importance of theories of market segmentation, imperfect asset substitutability and preferred habitat investors. A segmented (government) bond market is characterised by investor clientèle at short and long maturities. The bonds of these different maturities are not perfect substitutes. Instead, there are some ”preferred-habitat-investors” who have a preference for a particular segment (maturity) of the yield curve. Supply and demand imbalances, therefore, determine the yield in each maturity sector. These theories reflect the needs of institutional investors, like pension funds and insurance companies, to hold safe government bonds (Bauer and Rudebush, 2013).[3]

When the Fed conducts Large Scale Asset Purchases (LSAP's), this creates scarcity in the bonds being purchased. Since some (institutional) investors have underpinned demand for these bonds, the price of these bonds has to decline to restore equilibrium in the market. As a result, the yield on these bonds falls. This is the first mechanism described in the literature underlying the portfolio balance channel and is called the *local supply or scarcity channel*.

A second mechanism outlined in the literature is referred to as the *duration channel*. When the Fed purchases long-term treasuries from the market, it essentially removes duration from investors' asset portfolios.[4] The reduction in average duration risk in investors' asset portfolios lowers the premium that investors require for holding duration risk (Gagnon et al., 2011). Due to this, term premia on, especially, long-duration bonds decline and their prices rise. Note that in contrast to the local supply channel, which affects treasury-specific (maturity-specific) term premia, the duration channel affects term premia in all fixed income assets.

To the extent that the bond market operates efficiently, credible and unexpected UMP announcements should immediately be priced in by financial markets (Gagnon et al., 2011). Otherwise, arbitrage opportunities would occur by buying the UMP-targeted bonds today and sell these to the Fed in the future.

[3]This ”preferred-habitat” for safe longer-term government bonds stems from regulatory frameworks and accounting rules, as well as from ageing of the population and increasing life expectancies (ECB, 2007).

[4]If a bond has a high duration it means that an investor needs to wait a long period to receive the coupon payments and principal invested. The price of these bonds is relatively more sensitive to interest rate changes.

Portfolio balance channel and eurozone government bonds UMP announcements by the Fed not only raise the price of targeted assets but potentially also the price of their domestic and international substitutes. Institutional investors who sold their US government bonds are immediately inclined to rebalance their assets portfolio. This is because "cash", which pays almost zero nominal interest, and government bonds are not perfect substitutes. Furthermore, the liability structure of institutional investors is usually long-dated, and they prefer to match these liabilities with long-term assets. The institutional investor is thus inclined to reinvest its cash proceedings into (long-term) interest yielding securities. Since announcements of UMP by the Fed lower the yield on US government bonds, investors will re-balance towards (international) assets that are similar in nature.[5] This increases demand for these assets (e.g. eurozone government bonds), which raises their price and lower their yield.

Portfolio rebalancing and the EUR/USD exchange rate Analysing the effect of UMP announcements by the Fed on the EUR/USD exchange rate lies beyond the scope of this paper. However, note, that the effect of the portfolio balance channel can immediately impact the EUR/USD exchange rate. This is because demand for euros rises when investors rebalance their portfolio towards Euro dominated bonds. This increased demand for euros relative to U.S. dollars should lead to a depreciation of the U.S. dollar vis-a-vis the Euro, at least in the short run.[6] Both Fratzer et al. (2013) and Neely (2015) confirm this view and find that the dollar significantly depreciates vis-a-vis the Euro after UMP announcement by the Fed.

Portfolio rebalancing and the confidence channel Investors may also rebalance their asset portfolio because of changes in their risk appetite. Fratzer et al. (2013) argue that UMP announcements may alter the risk appetite of investors through the confidence channel. UMP announcements by the Fed may therefore be interpreted by the market as a signal that economic conditions are worse than expected. According to Neely (2015), this can trigger a flight to safety. On the other hand, Fratzer et al. (2013) argue that by boosting confidence, policies can trigger investors to search for yield. As a result, investors reallocate their portfolio's toward riskier bonds.

2.2 Signalling Channel

The signalling channel reflects the effect of UMP announcements on the expectation of the future path of policy rates (short-term interest rate). According to the expectation hypotheses of interest rates, the yield on a longer-term bond depends on these expectations. In this way, the signalling channel may affect both the yield on short and longer-term bonds. Note that UMP announcements by a central bank can have direct effects, indirect effects and

[5]This reflects the high degree of substitutability between government bonds in the developed countries (ECB, 2007).

[6]The long-run effect could be different, since (un)covered interest parity predicts that the dollar should appreciate relative to the Euro to compensate for the interest rate differential.

international signalling effects on the path of future policy rates (Bauer and Neely, 2014):

Direct signals: Forward Guidance Direct signals of a central bank convey direct information about the future target of the policy rate. An example of direct signalling is the forward guidance policy of a central bank. By means of forward guidance, the Fed intends to give (medium-term) certainty regarding its future interest rate policy. Communication of a lower interest rate policy for the medium-to-long-term lowers investors expectations of future policy rates. This puts downward pressure on interest rates of short and longer-term (government) bonds. As a consequence, consumption and investment decisions of consumers and firms may be influenced because saving becomes less attractive.

Indirect signals: LSAP's Indirect signals on the future policy rate can work through Large Scale Asset Purchase (LSAP) announcements. According to Bauer and Neely (2014), such announcements can reveal to the public that the central bank forecasts weaker inflation and/or lower growth than initially expected. This forecast would imply lower future policy rates for a given policy rule. Furthermore, Hausken and Ncube (2013) assert that LSAP's serve as a credible commitment to central banks' forward guidance policy. This is because raising interest rates would incur big losses on the assets purchased by central banks.

International spillovers from signalling by the Fed Policy rates can be highly correlated internationally. This can, for instance, be partly explained by central banks' common response to global surprises or the aim to stabilise the exchange rate. This may require a central bank to follow another central bank's monetary policy (Bauer and Neely, 2014). Fed signals regarding its future policy rate can, therefore, generate spillover effects to international financial markets. This view is confirmed by the results of Hausman and Wongsan (2011), who find that U.S. (conventional) monetary policy surprises explain yield changes in many countries. Moreover, Bauer and Neely (2014) argue that international signalling effects are larger for those countries whose interest rates have historically reacted strongly to U.S. conventional monetary policy surprises. They demonstrate that, among other countries, German yields between three-months and ten-year maturity significantly changed due to U.S. conventional monetary policy surprises.

2.3 Liquidity channel

The literature describes two contrary views of how the liquidity channel affects the yield on (government) bonds. Joyce et al. (2011) describe a market liquidity point of view. In normal times, government bond markets are deep and liquid. However, in periods of financial stress, these markets can be less liquid, with rising liquidity premiums as a consequence (Neely, 2015). Asset purchase programmes of central banks' guarantee a large and consistent buyer. This buyer improves the functioning of markets by raising demand for (illiquid) assets, boosting market liquidity and lower liquidity premia. Hence, in this view the liquidity channel lowers the yield on (government) bonds.

In contrast, Krishnamurthy and Vissing-Jorgensen (2011) argue that the liquidity channel increases the yield on government bonds. They assert that the most liquid government bonds trade at a negative liquidity premium (lower yield compensation for investors). This premium is especially high in crisis periods, since safe and liquid bonds are then more scarce. An expansion of liquidity in the economy reduces the special need for these liquid government bonds. This lowers the negative liquidity price premium carried by these bonds. Therefore, in this view, the liquidity channel raises the yield on (the most liquid) government bonds.

3 Related literature

The literature on the impact of UMP announcements by the Fed can be divided into studies focusing on domestic effects and those focusing on foreign effects.

3.1 Domestic effects of UMP by the Fed

The study of Gagnon et al. (2011) was one of the first that analysed the effects of UMP announcements by the Fed on US financial markets. They use an event study approach to examine the effects of 11 UMP announcements by the Fed on Treasury bond yields and MBS rates in the US. The authors combine this approach with a time series analysis and conclude that Fed UMP announcements reduced the term premium on 10-year US government bonds by 30 to 100 basis points. Subsequent studies by, for instance, Krishnamurthy and Vissing-Jorgensen (2011), Hamilton and Wu (2012), D'Amacio and King (2013) and Bauer and Neely (2014), used similar methods and also found that UMP announcements by the Fed significantly lowered medium and long-term interest rates in the US.

The studies mentioned above also aim to disentangle the channels through which UMP announcements by the Fed affect the yield on government bonds. There is no consensus in the literature which channel is dominant. For instance, D'Amico and King (2010), Gagnon et al. (2011), Joyce et al. (2011) and Joyce and Tong (2012) argue that the effects of UMP announcements mainly influence term premia of (government) bonds through the portfolio balance channel. On the other hand, Krishnamurthy and Vissing-Jorgensen (2011), Christensen and Rudebusch (2012) and Bauer and Rudebush (2013) emphasise the importance of the signalling channel in influencing (government) bond yields.

3.2 International spillover effects of UMP by the Fed

This thesis mostly relates to the study of Bauer and Neely (2014). These authors examine international spillover effects of UMP announcements by the Fed on the 10-year government bond yield of the US, Canada, Australia, Japan and Germany. They focus on the relative contributions of the signalling channel and the portfolio balance channels in influencing this yield. They use a simplified version of the framework presented in Joyce et al. (2011) and assume that the yield on a government bond can be expressed as: $y_t^n = n^-1 \sum_{i=0}^{n-1} E_t r_{t+1} + YTP_t^n$. The first term on the right hand represents the expected future policy rate, while the second term captures the yield term premium (YTP). They do not account for sovereign risk in their framework, since they mainly consider advanced economies with negligible sovereign risk. Bauer and Neely (2014) argue that the signalling channel mainly refers to the expected future policy rate and the portfolio balance channel is related to the yield term premium.

To quantify the importance of these two channels, Bauer and Neely (2014) use two econometric approaches. First, an event study approach, in which they regress differences in daily 10-year and 2-year Treasury bond yields and OIS rates on (dummies of) UMP announcements by the Fed. The changes in the OIS rate and the 2-year government bond yield represent variation in the expected future policy rate, reflecting the signalling channel. The reminder of the changes in the 10-year government bond yield is identified as the portfolio balance effect. The second approach consists of a more formal model, where they estimate a Dynamic Term Structure Model (DTSM) to distinguish the two channels.

The results of Bauer and Neely (2014) indicate that the portfolio balance channel plays the most substantial role in affecting German bond yields. This finding is consistent with the strong historical co-movement between German and U.S. government bond yields. Another main finding is that announcements by the Fed on its UMP moderately affected German bond yields through the signalling channel. This result is consistent with the significant relationship between the yield on German bonds and conventional U.S. policy rate surprises, as explained in section 2.2.

3.3 Event study methodology

Many studies discussed so far use the event study methodology to assess changes in asset prices during narrow time intervals. The literature emphasizes three reasons why this narrow time interval is needed: *i*) according to the efficient market hypotheses, UMP news by the Fed is immediately priced in by markets *ii*) to avoid the simultaneity (bias) problem that interest rates react on UMP or vice versa *iii*) to avoid the problem of omitted variable bias.[7]

To conduct an event study, one first needs to identify the event and the period over which changes in the variable of interest will be examined (Mackinlay, 1997). In the literature, this period is called the event window. To evaluate the impact of this event, one needs a measure of the abnormal return. The abnormal return is the actual ex post return of the variable of interest over the event window minus the normal return of this variable over the event window. The normal return is defined as the return that would have been expected in the absence of the event. According to Rivolta (2012), under normal circumstances, a security follows a process of the form:

$$R_t = \beta X_t + \epsilon_t \tag{1}$$

[7]See Park and Um (2015) for a more detailed explanation of these reasons.

while on event days the model is:

$$R_\tau = \beta X_\tau + \alpha Z_\tau + \epsilon_\tau \tag{2}$$

where t and τ are time indices for non-event and event days respectively, R_t represents the normal return, R_τ is the realized return, X_t (X_τ) is a vector of independent variables, β denotes the corresponding vector of coefficients, ϵ_t (ϵ_τ) is an error term with mean zero, Z_τ denotes a vector of asset characteristics that influence the return when the event takes place, and α is the corresponding vector of coefficients. In the event study methodology, one aims to measure the significance of the difference between Eqs. (1) and (2). This difference represents a measure of the abnormal return.

Broadly, there are two different ways in the event study methodology to gauge the significance of abnormal returns. The first method calculates the abnormal returns by forecasting normal (expected) returns based on Eq. (1) (e.g. by the CAPM model) and then compares these returns with actual returns observed in the data. The second approach directly estimates α from Eq. (2) under the null hypothesis that α equals zero. This second method is widely applied in the literature.[8] However, the econometric method underlying the estimation of α in Eq. (2) differs among studies. A vast majority of studies use the standard OLS approach, although Maximum Likelihood (ML) estimation using the GARCH framework is also widely applied. For instance, Joyce et al. (2011), Falagiarda and Reitz (2013) and Watfe (2015) use the GARCH framework to account for volatility clustering of bond yields in crisis periods and heteroskedasticity in the standard OLS approach.

There are two crucial assumptions in the event study methodology. First, events should contain an unexpected component. If markets are not surprised by the event, the information is already priced in, and α equals zero. Second, the effect of other news during the event window is negligible or measurable. If this is not the case, the estimate of α is contaminated by the influence of other news.

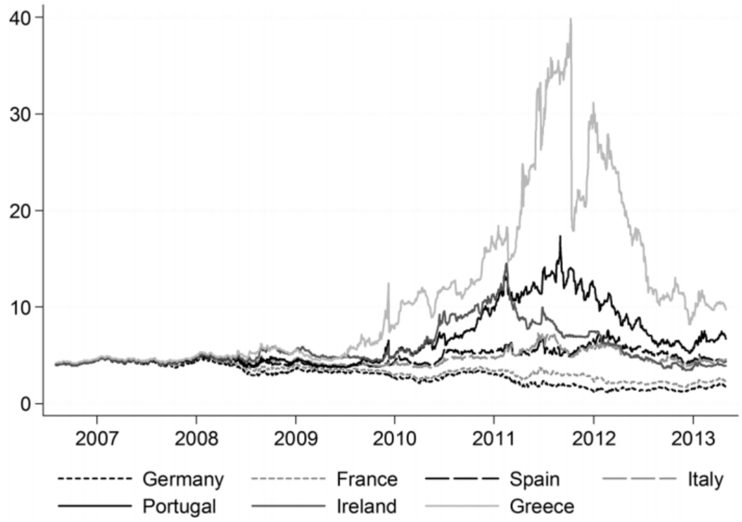
3.4 Sovereign risk premia of eurozone government bonds

As pointed out in sub-section 2.2, Bauer and Neely (2014) neglect sovereign risk in government bonds of advanced economies. However, this risk cannot be neglected in some eurozone government bond markets. This is reflected by the large sovereign yield spreads of various eurozone countries compared to the German Bund yield during the sovereign debt crisis, as shown in Figure 1.

The existing literature provides a broad and extensive view on the determinants of these sovereign yield spreads. The seminal paper of Codogno et al. (2003) identifies four determinants of sovereign risk spread. These include exchange rate risk, capital controls, liquidity risk and credit (default) risk. Since the introduction of the Euro in 1999, exchange rate risk and capital controls can be neglected.

[8] See Gagnon et al. (2011), Joyce et al. (2011), Neely (2015), and Bauer and Rudebusch (2013).

Figure 1: Sovereign spreads (in %) during the sovereign debt crisis



source: Kilponen et al. (2015)

This means that sovereign yield spreads between eurozone countries depend on liquidity risk and credit risk (country specific risk).This view is also confirmed by Ejsing et al. (2012). Nonetheless, besides country-specific risk, several studies have shown that global risk aversion and contagion risk are also important determinants of sovereign spreads or spreads to the risk-free rate.[9] In these studies, credit risk and liquidity risk are commonly measured by the CDS rate and bid-ask spread, respectively. Global risk aversion is usually proxied by the Volatility Index (VIX) or the spread between U.S. corporate bonds and U.S. Treasury bills. When accounted for, contagion risk is commonly measured by control variables of the lagged yield spread of the peripheral countries (Argyrou and Kontonikas, 2012; Kilponen et al., 2015) or measures of the CDS rates of these countries (Caceres et al., 2010; Falagiarda and Reitz, 2013.).

How does the sovereign risk of eurozone countries relate to UMP announcements by the Fed? The answer is twofold. First, UMP measures by the Fed took place during the sovereign debt crisis in the Euro area. In this period, investors experienced considerable risk aversion towards some peripheral European countries. This led to significant sovereign yield spreads of these countries vis-à-vis the German government bond yield (risk-free rate). Second, Fed announcements may (indirectly) provide new information regarding the current and future state of the economy, which may alter the risk appetite of investors (Fratzer et al., 2013). In this way, investors may interpret UMP announcements by the Fed as a signal that the global economic outlook and financial market conditions are worse than expected (Fratzer et al., 2013; Neely, 2015). As a result, investors may become even more risk-averse towards (peripheral) eurozone countries after UMP announcements of the Fed. This may increase the yield on the government bonds of these countries, without any potential effects of signalling and portfolio rebalancing.

[9] See Beber et al.(2009), De Santis (2012), Falagiarda and Reitz (2013), Kilponen et al. (2015) and Watfe (2015).

4 Methodology

This section goes into the channels through which UMP announcements by the Fed may influence European government bond markets. I first present a novel general framework on the decomposition of government bond yields. Next, it is shown how this framework is used to demonstrate how UMP announcements by the Fed may have found their way to government bond markets in the eurozone.

4.1 Yields, term premia and unconventional monetary policy

I use an adapted version of the framework presented in Joyce et al. (2011), to decompose the yield on a government bond:

$$Y_t^n = (1/n)\sum_{i=0}^{n-1} E_t r_{t+i} + TPC_t^n + TPP_t^n + TPR_t^n \tag{3}$$

Y_t^n is the n-period maturity yield on a government bond at time t. The expectation hypothesis of the term structure of interest rates is given by $(1/n)\sum_{i=0}^{n-1} E_t r_{t+i}$, where r_{t+i} is the one-period (risk-free) policy rate at time $t+i$. In this framework, the term premium on government bonds compromises three elements: *i*) TPC_t^n, a conventional term premium capturing uncertainty regarding future short-term interest rates (interest rate risk) *ii*) TPP_n^t, a scarcity premium and *iii*) TPR_t^n, a term premium related to credit risk, contagion risk, redenomination risk and global risk aversion (henceforth, sovereign risk). The main novelty here is that I incorporate TPR_t^n in Eq. (3). Several studies have neglected sovereign risk in government bond markets.[10] However, since European bond markets differ in sovereign risk, this risk cannot be neglected in this analysis.

I focus on the spillover effects of UMP announcements by the Fed to European government bond markets through both the *signalling channel* and the *portfolio balance channel.* These channels are directly effective after UMP announcements by the Fed, since monetary news is immediately priced in by financial markets.

4.1.1 The signalling channel

The *signalling channel* refers to changes in expectations of the future path of policy rates, $\Delta(1/n)\sum_{i=0}^{n-1} E_t r_{t+i}$, while it may also be related to movements in interest rate risk, ΔTPC_t^n. Like Joyce et al. (2011), I assume that changes in the rate on OIS contracts, ΔR_t^n, provide a measure of the signalling channel. Taking first differences of Eq. (3) and using this assumption yields:

$$\Delta Y_t^n = \Delta R_t^n + \Delta TPP_t^n + \Delta TPR_t^n \tag{4}$$

I directly assess changes in R_t^n in response to UMP announcements by the Fed, to determine whether these announcements affect ΔY_t^n through the signalling channel. In the case of the

[10] See for instance Joyce et al. (2011), Bauer and Rudebush (2013) and Bauer and Neely (2014).

eurozone, I assume that UMP announcements by the ECB and other (macro-economic) news may also influence ΔR_t^n:

$$\Delta R_t^n = f\left(Fed_t, ECB_t, News_t\right) \tag{5}$$

where Fed_t refers to UMP announcements of the Fed, ECB_t to UMP announcements of the ECB and $News_t$ to other (macro-economic) news. The effect of UMP announcements by the Fed through the signalling channel is captured by:

$$\frac{\partial \Delta R_n^t}{\partial Fed_t}$$

4.1.2 The portfolio balance channel

The portfolio balance effect works through ΔTPP_t^n. In response to asset purchases by the Fed, optimising investors will rebalance their asset portfolio towards international substitutes with similar risk and return characteristics. This drives up the demand for these substitutable assets, which raises their price and lower their yield through a decline in TPP_t^n. In this way, UMP announcements by the Fed potentially influence both the yield on US government bonds as well their international substitutes.

The portfolio balance effect cannot be quantified by solely observing ΔY_t^n in Eq. (4), since signalling effects and other factors may also influence ΔY_t^n after Fed UMP announcements. I therefore cancel out the effects through signalling in Eq. (4). In this way we obtain:

$$\Delta(Y_t^n - R_t^n) = \Delta TPP_t^n + \Delta TPR_t^n \tag{6}$$

where $\Delta(Y_t^n - R_t^n)$ refers to changes in the $yield-OIS$ spread. In the case of the eurozone, I assume that changes in the $yield - OIS$ spread are influenced by Fed UMP announcements, ECB UMP announcements, other (macro-economic) news and changes in sovereign risk:

$$\Delta(Y_t^n - R_t^n) = f\left(Fed_t, ECB_t, News_t, Sovereign_t\right) \tag{7}$$

where $Sovereign_t$ refers to changes in eurozone sovereign risk. $Sovereign_t$ also captures changes in sovereign risk that are due to Fed UMP announcements, ECB UMP announcements and other (macro-economic) news. This is because these announcements may alter the risk appetite of investors. The effect of UMP announcements by the Fed through the portfolio balance channel is captured by:

$$\frac{\partial \Delta(Y_t^n - R_t^n)}{\partial Fed_t}$$

Thus, to assign changes in the $yield-OIS$ spread to the portfolio balance effect (ΔTPP_t^n), one needs to control for ECB announcement, other (macro-economic) news and changes in sovereign risk.

4.2 From theory to estimating forms

I now account for time dynamics in Eqs. (5) and (7) by including the lagged values of the dependent variable and the exogenous variable (Fed UMP announcements). I do not include lagged values of the control variables because these are measured for the eurozone specifically and are therefore not expected to have a delayed effect.[11] The variables that turn out to be $I(1)$ are differenced before incorporated in the equations that follow.[12] The coefficients of the estimating form are estimated using the GARCH framework of Bollerslev (1987). This framework is employed to account for heteroskedasticity in the models and volatility clustering of the dependent variables in crisis periods.[13]

4.2.1 The effect of signalling

To determine whether UMP announcements by the Fed influenced eurozone government bond markets through the signalling channel, I estimate a dynamic version of Eq. (5) for the eurozone:

$$\begin{aligned}&\Delta R^n_{eu,t} = \alpha + \theta_1 \Delta R^n_{eu,t-1} + \beta_1 QE1_t + \beta_2 QE2_t + \beta_3 QE3_t + \beta_4 FG_t + \beta_5 OT_t + \beta_6 Taper_t + \\ &\beta_7 QE1_{t-1} + \beta_8 QE2_{t-1} + \beta_9 QE3_{t-1} + \beta_{10} FG_{t-1} + \beta_{11} OT_{t-1} + \beta_{12} Taper_{t-1} + \gamma ECB_t + \\ &\gamma_2 CESI_{eu} + \epsilon_t\end{aligned} \tag{8}$$

where $R^n_{eu,t}$ denotes the 10-year OIS rate of the eurozone ($n = 10$), ECB_t is a dummy variable capturing UMP announcements by the ECB[14] and $CESI_{eu}$ is an index of macroeconomic news in the eurozone. The variable ECB_t is expected to reduce the 10-year OIS rate of the eurozone, since it only contains announcements regarding monetary loosening. A positive value of $CESI_{eu}$ indicates better than expected macroeconomic conditions, which should raise investors' expectations of future policy rates and hence interest rate risk. The variables $QE1_t, QE2_t, ..,$ represent dummy variables of each QE programme. The $QE1_t$ dummy equals 1 on date $t + 1$, where date t is an official Fed UMP announcement day in the first phase of QE, and 0 otherwise.[15] The other dummy variables are constructed similarly to indicate the other UMP programs of the Fed. The dummy variables $QE1_{t-1}, QE2_{t-1}, ..,$ use the same announcements, but take value 1 on date $t + 2$ and 0 otherwise. I group the Fed's individual UMP announcements into 6 QE programme dummies for two reasons. First, using separate dummies for each UMP announcement by the Fed raises the possibility of multimodality in the likelihood of the GARCH estimation (Doornik and Ooms, 2003). And second, because grouping the Fed's individual UMP announcements improves the economic interpretation of the results. The relevance of the signalling channel is measured through the significance of

[11] This is also confirmed in the empirical estimations.

[12] Unit root tests for these variables can be found in Appendix A.1.

[13] The positive autocorrelation in the variance of changes in the $yield - OIS$ spread also justify the use of the GARCH framework.

[14] See Table A.2 in Appendix A.2.

[15] The reason why this dummy equals 1 the day after the official Fed announcement date t is explained in the Data section.

the beta coefficients, as outlined in section 4.1.1.

4.2.2 The effect of portfolio rebalancing

To determine whether UMP announcements by the Fed influenced eurozone government bond markets through the portfolio balance channel, I estimate a dynamic version of Eq. (7) for the eurozone countries in the sample:

$$\begin{aligned}&\Delta(Y^n_{eu,t} - R^n_{eu,t}) = \alpha_2 + \theta_2\Delta(Y^n_{eu,t-1} - R^n_{eu,t-1}) + \beta_{13}QE1_t + \beta_{14}QE2_t + \beta_{15}QE3_t + \beta_{16}FG_t \\ &+ \beta_{17}OT_t + \beta_{18}Taper_t + \beta_{19}QE1_{t-1} + \beta_{20}QE2_{t-1} + \beta_{21}QE3_{t-1} + \beta_{22}FG_{t-1} + \beta_{23}OT_{t-1}+ \\ &\beta_{24}Taper_{t-1} + \gamma_3 ECB_t + \gamma_4 CESI_{eu} + \boldsymbol{\zeta'}\Delta\boldsymbol{X_t} + \epsilon_t\end{aligned} \tag{9}$$

where $Y^n_{eu,t}$ denotes the yield on the 10-year zero coupon government bond of a eurozone country in the sample, $\boldsymbol{X_t}$ is a column vector of controls that proxy for sovereign risk and $\boldsymbol{\zeta'}$ is the corresponding row vector of coefficients. The $CESI_{eu}$ index is now expected to decrease the dependent variable in Eq. (9) since positive macro-economic news also reduces investors' risk aversion.[16] In line with Eq. (8), the ECB announcements are expected to reduce the dependent variable in Eq. (9). Recalling the assumptions of section 4.1.2, the beta coefficients capture portfolio balance effects. The control vector $\boldsymbol{X_t}$ consists of the following measures:

- Euro-area risk aversion (+/-). Higher market uncertainty increases investors' risk aversion which causes them to demand higher yields or to restructure their portfolio of assets. Usually, this is done towards bonds with a safe-haven status. This results in a decline in the yield on these bonds and a rise in the yield on risky bonds[17];
- Country specific credit risk (+). More sovereign risk leads to a more risk-averse sentiment of investors towards a country, which causes them to demand higher yields;
- Redenomination risk (+). Investors require a higher yield for the risk that a country needs to redenominate its currency;
- Contagion risk (+). More contagion risk increases investors' risk aversion towards a country, for which they want to be compensated with a higher yield.[18]

4.2.3 The GARCH framework

The GARCH model allows the error term, ϵ_t, in Eqs. (8) and (9) to possess zero mean and unconditional heteroskedastic variance:

$$\epsilon_t \sim N(0, \sigma_t^2)$$

[16]Note that the (positive) effect of the $CESI_{eu}$ index on expected future policy rates (captured by the OIS rate) is cancelled out in Eq. (9).

[17]Arghyron and Kontonikas (2012) found a negative relationship between the VIX index and the bond yield of Germany, indicating safe haven flows.

[18]The variables are further explained in Table 2 of the Data section.

The variance itself, σ_t^2, is modelled as a GARCH(p,q) process, where p refers to the number of GARCH terms and q to the number of ARCH terms. The variance is therefore modelled explicitly as a function of its past disturbances and past values.[19] In this way, it is possible to account for volatility clustering and heteroskedasticity in the models:

$$\sigma_t^2 = \omega + \sum_{i=1}^{q} \delta_i \epsilon_{t-i}^2 + \sum_{j=1}^{p} \eta_j \sigma_{t-j}^2 \tag{10}$$

The starting point for each specification is the GARCH $(1,1)$ model, under restrictions of non-negativity and stationarity, respectively:

$$\omega, \delta_i, \eta_j \geq 0$$

$$\sum_{i=1}^{q} \delta_i + \sum_{j=1}^{p} \eta_j < 1$$

The lag order of the GARCH specification is only increased if there are remaining ARCH effects in the variance equation.[20] This is tested by assessing the Ljung-Box Q statistics. Besides, I use several information criteria to check whether the overall model has improved after the lag order had been increased.[21]

The default estimation procedure of the GARCH framework uses Maximum Likelihood estimation (MLE) under the condition that error terms are (Gaussian) normally distributed. However, the estimation of Eqs. (8) and (9) reveals that errors are not normally distributed.[22] I account for this conditional non-normality by using Bollerslev-Woolridge standard errors. Using these standard errors results in Quasi Maximum Likelihood estimates (QMLE's) that are consistent and asymptotically normally distributed. In addition, these errors produce robust and consistent estimates of the standard errors of the parameters (Bollerslev and Woolridge, 1992; Weiss, 1986).

4.3 Pre-selection of UMP announcements by the Fed

Before I show how UMP announcements by the Fed influence government bond markets in the eurozone, I first determine which of these announcements to include in Eqs. (8) and (9). I adopt this approach for two reasons. Firstly, because some UMP announcements by the Fed were expected by market participants and therefore did not affect the US government bond market. I assume that these announcements do not affect the eurozone government bond markets either. Secondly, because the inclusion of these expected announcements in the QE

[19]Including the QE programme dummies, week-day dummies, the macro-economic news index or the volatility index of Euro area risk aversion in Eq. (10) did not change the results of Eqs. (8) and (9).

[20]For the restrictions of these models, see Appendix A.3.

[21]The Akaike information criterion and Bayesian information criterion.

[22]Financial returns generally have heavy tails, which often leads to a violation of the conditional normality of the (innovation) error. Normality is tested by assessing the histogram of errors, kurtosis and Jarque-Bera statistic.

programme dummies of Eqs. (8) and (9) may contaminate the significance of these dummies.

Specifically, I assume that signalling effects of UMP announcements by the Fed to eurozone government bond markets only occur if there was a signalling effect in the US government bond market. Therefore, I estimate a dynamic version of Eq. (5) by Ordinary Least Squares (OLS) for the US:

$$\Delta R^n_{us,t} = \alpha_3 + \theta_3 \Delta R^n_{us,t-1} + \boldsymbol{\phi' Fed_t} + \boldsymbol{\xi' Fed_{t-1}} + \gamma_6 ECB_t + \gamma_7 CESI_{us} + \epsilon_t \tag{11}$$

where $R^n_{us,t}$ denotes the rate on the 10-year OIS of the US ($n = 10$), $\boldsymbol{Fed_t}$ and $\boldsymbol{Fed_{t-1}}$ are 1x21 column vectors of dummy variables for each of the 21 Fed UMP announcements described in Table 2, $\boldsymbol{\phi'}$ and $\boldsymbol{\xi'}$ are the corresponding row vectors of coefficients and $CESI_{us}$ is an index of macroeconomic news in the US. The $CESI_{us}$ index has the same interpretation as the $CESI_{eu}$ index in Eq. (8) and is expected to reduce the 10-year OIS rate of the US. I did not estimate Eq. (11) with the GARCH framework because I included 21 separate dummies for each UMP announcement by the Fed in the row vectors $\boldsymbol{Fed_t}$ and $\boldsymbol{Fed_{t-1}}$.[23] Each element of $\boldsymbol{Fed_t}$ takes value 1 on its official announcement date t and 0 otherwise. Each element of $\boldsymbol{Fed_{t-1}}$ takes value 1 on the day after official announcement date t and 0 otherwise. Again, given the assumption in sub-section 4.1, the coefficients in row vectors $\boldsymbol{\phi'}$ and $\boldsymbol{\xi'}$ capture the effects of signalling. The announcements that turn out to be significant and have the right sign in Eq. (11) are used to fill the QE programme dummies in Eq. (8).

In line with the treatment of signalling effects, I only consider announcements in Eq. (9) that had a portfolio balance effect in the US. I therefore estimate a simplified dynamic version of Eq. (7) by OLS for the US. The simplification is that I neglect sovereign risk in the 10-year US government bond market because of its size and creditworthiness:[24]

$$\begin{aligned}&\Delta(Y^n_{us,t} - R^n_{us,t}) = \alpha_4 + \theta_4 \Delta(Y^n_{us,t-1} - R^n_{us,t-1}) + \boldsymbol{\phi' Fed_t} + \boldsymbol{\xi' Fed_{t-1}} + \gamma_8 ECB_t + \\ &\gamma_9 CESI_{us} + \epsilon_t\end{aligned} \tag{12}$$

where $Y^n_{us,t}$ is the yield on a 10-year zero coupon Treasury bond of the US. The coefficients in row vectors $\boldsymbol{\phi'}$ and $\boldsymbol{\xi'}$ capture portfolio balance effects because of negligible sovereign risk in the US government bond market.[25] The announcements that turn out to be significant and have the right sign in Eq. (12) are used to fill the QE programme dummies in Eq. (9).

5 Data

The data cover the period 01-01-2008 until 31-12-2015 on a daily basis. The sample consists of 11 eurozone countries, of which six so-called economic "core" countries: Germany, Finland, The Netherlands, France, Belgium and Austria and five "peripheral" countries: Greece, Spain,

[23] Including separate dummies for each Fed UMP announcement is not possible when using the GARCH framework, as explained in section 4.2.1.

[24] This is in line with Gagnon et al. (2011) and Bauer and Neely (2013).

[25] See also Joyce et al. (2011) and Krishnamurthy and Vissing-Jorgensen (2013).

Portugal, Ireland and Italy.

The dependent variables consist of the yield on zero-coupon government bonds of 10-year maturity and the rate on overnight index swaps (OIS) of 10-year maturity (Table 1). I have taken zero coupon bonds because these are not prone to the coupon bias (Pericoli and Taboga, 2015).[26] Furthermore, these bonds are commonly used in the literature for calculations of the term premium (Joyce et al., 2011; Kilponen et al., 2015; Kim and Wright, 2005). I have taken OIS rates since these are a good proxy for long-term risk-free rates.[27] The OIS rate represents an interest rate swap where one party swaps an overnight interest rate (e.g. federal funds rate or EONIA rate) for a compounded overnight interbank interest rate that has prevailed over the life of the contract (Joyce et al., 2011).

Table 1: List of variables

Variable	Explanation	Measure of	Source
Dependent variables			
$Y^n_{eu,t}$	Yield on a 10-year zero coupon government bond of a eurozone country in the sample		Datastream
$Y^n_{us,t}$	Yield on the 10-year US zero coupon government bond		Datastream
$R^n_{eu,t}$	10-year Overnight Index Swap rate of the EU		Datastream
$R^n_{us,t}$	10-year Overnight Index Swap rate of the US		Bloomberg
Control variables			
VSTOXX	Implied volatility of near term options on the EuroStoxx 50 index (eurozone equivalent of the VIX)	Euro-area risk aversion	Datastream
CDS	10-year credit default swap of an eurozone country in the sample. Defined in Datastream as "the mid-rate spread between the entity and the relevant benchmark curve"	Country specific credit risk	Datastream
Redom	Redenomination risk. Calculated as the difference between the 5-year CDS of an eurozone country dominated in dollars minus the 5-year CDS dominated in Euro of that same country (this is called the quanto CDS), and quanto CDS of Germany ($\text{Qcds}_t - \text{Qcds}_{t_{\text{Ger}}}$)	Redenomination risk	Bloomberg
CESI_j	The Citigroup Economic Surprise Index (CESI) measures the surprise content of the release of macroeconomic and fiscal news (not monetary policy news) on a daily basis. A positive value indicates a positive surprise. $j \in \{us, eu\}$.	Macroeconomic news	Datastream
ECB	Impulse dummies which equal 1 on ECB UMP announcement days and 0 otherwise. See also Table A.2 in Appendix A.2.	UMP announcements by the ECB	ECB website

Notes: Rates and yields are measured in basis points. The variables $Y^n_{eu,t}$, CDS, BAS and Redom are collected for each eurozone country in the sample. The other variables are time series observations.

[26]The coupon bias refers to the fact that high coupon bonds are less sensitive to interest rate changes of underlying treasury rates as they have less duration.

[27]As also argued by Morini (2009), Mercurio (2009), Ejsing et al. (2012) and Taboga (2014).

The measure of redenomination risk requires special attention. If an EU country experiences a credit event, EUR-dominated protection (CDS) would be worth less after the credit event due to a devaluation of the Euro. As a result, the demand for Euro-dominated CDS declines, which decreases the Euro-dominated CDS rate and hence increases the quanto CDS. However, the quanto CDS itself only reflects currency risk vis-a-vis the dollar. I therefore consider the quanto CDS spread vis-a-vis Germany since this measure reflects intra-Euro breakup risk. This spread would be close to zero if investors perceive the breakup risk of a country as minor (De Santis, 2015).

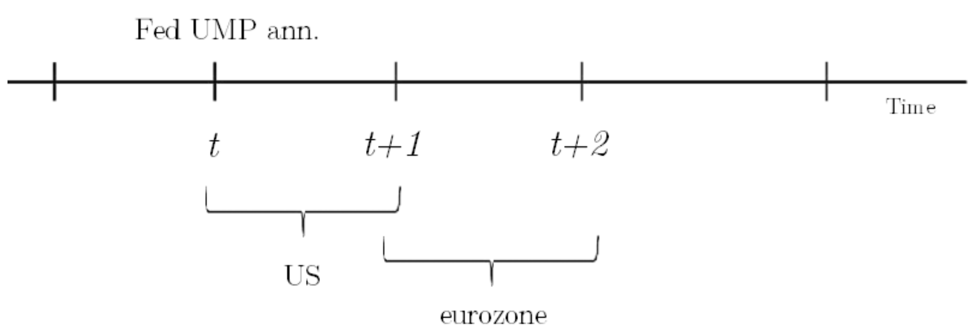
5.1 Unconventional Monetary Policy Announcements

I focus on UMP announcements by the FOMC or Chairman Ben Bernanke, as commonly used in the literature (see Table 2). These are announcements regarding different asset purchase programmes and forward guidance. Conventional monetary policy measures, like federal funds rate decisions, lie beyond the scope of this paper. Moreover, there was only one federal funds rate decision in the sample since the federal funds rate hit the lower bound on interest rates.

The sample of QE announcements have been taken from several related studies: the QE 1 and QE 3 announcements have been taken from Bauer and Neely (2014) and have been completed by those of Park and Um (2016). The QE 2 announcements have been taken from Fratzer et al. (2013). The operation twist, forward guidance and tapering announcements have been taken from Rogers et al. (2013) and have also been completed by those of Park and Um (2016).[28]

Almost all FOMC announcements took place between 13:40 and 14:15 hours EST. This coincides with 19:40 hours to 20:15 hours CET and the European financial markets were already closed at that time. I, therefore, examine the effects of UMP announcements by the Fed on European bonds markets the day following the official announcement day t and the day thereafter (to assess effects over two days).[29] In the case of the US, I examine the effects on the official announcement day t and the day thereafter (Figure 2).

Figure 2: The days on which the Fed UMP announcement effects are examined



[28]For a description of all the QE programmes see Appendix A.5.

[29]An exception is the announcement on 25-11-2008 that took place on 08:15 EST. For this announcement, I consider the effect on eurozone government bond markets on date t and date $t + 1$.

Table 2: Announcement dates

Date (t)	Program	Policy Measure	Forward Guidance and Other news
25-11-2008	QE1	Initial LSAP announcement to purchase up to $100 billion in agency debt and up to $500 billion in agency MBS.	
01-12-2008	QE1	Speech of Chairman Bernanke who states that the Fed "could purchase longer-term Treasuries [...] in substantial quantities."	
16-12-2008	QE1	FOMC statement which indicates that the Fed considers expanding the purchases of agency securities and initiating purchases of Treasury securities.	Forward Guidance announcement of the FOMC: "The Committee anticipates that weak economic conditions are likely to warrant exceptionally low levels of the Federal Funds rate for some time." Furthermore, the Fed decided to reduce the Federal Funds rate from 1 % to between 0 and 0.25 %.
28-01-2009	QE1	FOMC statement indicating that the Fed is ready to expand agency debt and MBS purchases and purchasing longer-term Treasuries.	
18-03-2009	QE1	FOMC statement which announces that the Fed will purchase "up to an additional $750 billion of agency MBS,$100 billion in agency debt and $300 billion Treasury securities."	Forward Guidance announcement of the FOMC: "Economic conditions are likely to warrant exceptionally low levels of the federal funds rate for an extended period."
10-08-2010	QE2	The Fed decides to keep its holdings of securities constant and to reinvest principal payments from LSAP purchases in Treasuries.	
27-08-2010	QE2	Bernanke hints at QE2 in his speech at Federal Reserve Bank of Kansas City Symposium.	
21-09-2010	QE2	FOMC statememt indicating that the Fed will maintain its existing policy of reinvesting principal payments from its securities holdings.	
15-10-2010	QE2	Bernanke's speech at Boston Fed: "there would appear–all else being equal-to be a case for further action".	
03-11-2010	QE2	Statement announces that the Fed intends to further purchase $600 billion in longer-term Treasury securities.	
09-08-2011	FG	"Economic conditions...are likely to warrant exceptionally low levels for the federal funds rate for at least through mid- 2013."	
21-09-2011	OT	Fed intends to purchase $400 billion in Treasuries with remaining maturities of 6–30 years and to sell an equal amount of Treasuries with remaining maturities of 3 years or less.	

(cont'd on following page)

Table 2, cont'd

Date	Program	Policy Measure	Forward Guidance and Other news
25-01-2012	FG	"Economic conditions [...] are likely to warrant exceptionally low levels for the federal funds rate for at least through late 2014."	
20-06-2012	OT	FOMC expands the Operation Twist programme by adding additionally $267 billion in purchases.	
22-08-2012	QE3	Release of the minutes of the FOMC meeting on 01-08-2012, where FOMC members judge that additional monetary accommodation is likely.	
31-08-2012	QE 3	Bernanke hints at QE 3 by stating: "The Federal Reserve will provide additional policy accommodation as needed to promote a stronger economic recovery and sustained improvement in labour market conditions in a context of price stability."	
13-09-2012	QE3	Fed launches a new $40 billion per month, open-ended, purchasing programme of agency MBS's.	FG the FOMC stating: "exceptionally low levels for the federal funds rate are likely to be warranted at least through mid-2015."
12-12-2012	QE3	Fed would purchase longer-term Treasury securities at a pace of $45 billion per month.	FG of the FOMC stating: "This exceptionally low range for the federal funds rate will be appropriate at least as long as the unemployment rate remains above 6-1/2 percent, inflation be no more than a half percentage point above the Committee's 2 percent longer-run goal, and longer-term inflation expectations continue to be well anchored. Policy is expected to remain "highly accommodative" for a "considerable time" after the end of the asset purchase programme."
22-05-2013	Tapering	Bernanke's testimony to Congress (also known as "taper tantrum") where he states: "In the next few meetings, we could take a step down in our pace of purchase."	
19-06-2013	Tapering	Bernanke's press conference: "If we see continued improvement and we have confidence that that is going to be sustained, then in the next few meetings, we could take a step down in our pace of purchases."	
18-12-2013	Tapering	Official Tapering announcement. The Fed decides to taper of securities purchased by $10 billion per month.	

Notes: The first column of this table shows the official UMP announcements by the Fed that are made on date t. FG refers to Forward Guidance and OT to Operation Twist.

6 Results

6.1 Results of pre-selection

Table 3 presents the estimation results for Eqs. (11) and (12). It turns out that QE 1 generated the most and largest announcement effects of all QE programmes. This result is in line with the findings of Gagnon et al. (2011) and Bauer and Rudebush (2013). The biggest announcement effects on the 10-year US government bond market are found for those announcements that specifically targeted this market.[30] This finding confirms the arguments of D'Amico and King (2013) and Krishnamurthy and Vissing-Jorgensen (2011), who assert that the greatest effects of asset purchases are found on those securities that are targeted by the Fed in its UMP (statements). Note that the announcement effect on 28-01-2009 needs to be interpreted with caution. According to Bauer and Neely (2014), this was a day on which markets expected the Fed to announce a purchase. However, the Fed only announced that it was *ready* to expand its purchases and depressed markets, as reflected in the rise of the 10-year US OIS.

Announcements of subsequent QE rounds generated fewer effects than QE 1. Only the official QE 2 announcement influenced the 10-year US government bond market and 10-year OIS market of the US in the second round of QE. In contrast, the official QE 3 announcement did not cause effects. An unanticipated finding is the announcement effect on 13-09-2012, on which the term premium of the 10-year US government bond increased. A possible explanation for this result might be that this announcement did not target the US government bond market. Hence, other factors may have influenced the term premium of the 10-year US government bond on this day.

Another result that draws attention is that only the initial announcements of forward guidance and operation twist caused significant effects. Subsequent measures of these programmes were not priced in by the 10-year US government bond market and 10-year OIS market of the US. Furthermore, it appears that only the tapering talks by Chairman Ben Bernanke generated announcement effects, whereas the official tapering announcement did not. This result is in agreement with Fawley and Neely (2013), who argue that the official tapering announcement was widely expected among market participants.[31]

Table 4 shows the announcements that are included in Eqs. (8) and (9). The significant but unanticipated findings of Table 4 are not incorporated in the QE programme dummies of these equations.

[30] These are the announcements on: 16-12-2008 and 18-03-2008 for QE1, 03-11-2010 for QE2, 21-09-2011 for Operation Twist. An exception is the QE 3 announcement on 12-12-2012. This announcement was potentially already priced in by the market.

[31] Kim and Wright (2005) constructed a measure for the term premium component of US government bonds. The results are largely similar if this measure is used as the dependent variable in Eq. (12) (see Table A.4 in Appendix A.6).

Table 3: Estimation Results Eqs. (12) and (11)

Variable	US TP	US OIS
Constant	0.059	−0.095
Δy_{t-1}	−0.267***	−0.068***
QE 1		
25-11-2008	4.142	−29.389***
25-11-2008 $(t+1)$	−1.899	−6.033
01-12-2008	0.284	−19.282***
01-12-2008 $(t+1)$	5.071*	−5.366
16-12-2008	0.894	−30.548***
16-12-2008 $(t+1)$	−12.920***	0.733
28-01-2009	−7.161***	13.256**
28-01-2009 $(t+1)$	−3.065	20.982***
18-03-2009	−17.389***	−38.322***
18-03-2009 $(t+1)$	−11.911***	7.639
QE 2		
10-08-2010	−1.085	−4.305
10-08-2010 $(t+1)$	−2.208	−4.024
27-08-2010	−0.260	17.874***
27-08-2010 $(t+1)$	−0.470	−12.380**
21-09-2010	−1.229	−12.582**
21-09-2010 $(t+1)$	−3.621	0.248
15-10-2010	3.193	4.264
15-10-2010 $(t+1)$	1.456	−5.798
03-11-2010	−0.211	−2.045
03-11-2010 $(t+1)$	−7.182***	−3.722
FG & OT		
09-08-2011	8.191***	−8.668
09-08-2011 $(t+1)$	2.114	−14.568**
21-09-2011	−0.099	−7.089
21-09-2011 $(t+1)$	−12.643***	−4.917
25-01-2012	−2.363	−5.459
25-01-2012 $(t+1)$	−1.170	−5.140
20-06-2012	−2.264	3.829
20-06-2012 $(t+1)$	−2.247	−2.510
QE 3		
22-08-2012	0.217	−10.419*
22-08-2012 $(t+1)$	−4.278***	−0.952
31-08-2012	2.075	−7.103
31-08-2012 $(t+1)$	−0.130	0.816
13-09-2012	7.971***	−5.310
13-09-2012 $(t+1)$	−0.834	12.160**
12-12-2012	0.063	4.113
12-12-2012 $(t+1)$	0.035	2.671
Tapering		
22-05-2013	−2.957	11.709*
22-05-2013 $(t+1)$	1.230	−1.666
19-06-2013	−7.186***	18.181***
19-06-2013 $(t+1)$	8.391***	6.099
18-12-2013	−3.518	6.574
18-12-2013 $(t+1)$	0.310	5.909
ECB	−0.515	1.801**
$CESI_{\text{us}}$	0.000	0.161***
Observations	1937	1937
R-squared (adj.)	0.135	0.096

Notes: US TP and US OIS refer to the dependent variables in Eqs. (12) and (11), respectively. The results are shown in basis points. $t+1$ in brackets implies that the effect of this announcement is measured one day after the date that is specified before the bracket. The dates without brackets measure the effect on the exact date that is specified. *, **, *** denote the 10 percent, 5 percent and 1 percent significance levels, respectively.

Table 4: Announcement set and expected effects

	QE 1	QE 2	QE 3	FG	OT	Taper
Eq. (8)						
Incorporated ann.	25-01-2008, 01-12-2008, 16-12-2008, 18-03-2009	27-08-2010, 21-09-2010	22-08-2012	09-08-2011	21-09-2011	22-05-2013, 19-06-2013
Expected effect	−	−	−	−	−	+
Eq. (9)						
Incorporated ann.	16-12-2008, 18-03-2009	03-11-2010	22-08-2012	09-08-2011	21-09-2011	19-06-2013
Expected effect	−	−	−	−	−	+

Notes: Announcements, and their expected effect, incorporated in the QE programme dummies of Eqs. (8) and (9).

6.2 Results for the eurozone

This section discusses whether UMP announcements by the Fed influenced eurozone government bond markets through the signalling channel and the portfolio balance channel. I discuss the impact of these two channels separately.

6.2.1 Signalling effects

Table 5 presents the estimation result of Eq. (8). The main conclusion is that UMP announcements by the Fed altered investors' expectations of future policy rates in the eurozone. In line with the findings for the US, the largest signalling effects are found for the announcements of QE 1 and forward guidance. The announcements of QE 2, QE 3, operation twist and tapering also significantly influenced eurozone government bond markets through the signalling channel.

Announcements of subsequent QE rounds generated smaller signalling effects (over two days) than the announcements of QE 1 and forward guidance. This result is in line with the findings of Bauer and Neely (2014) for the effects of signalling by the Fed on Germany. Moreover, this finding indicates that the role of the signalling channel was less profound in subsequent QE rounds. An explanation for this result may be that markets already expected the Fed to act and keep short-term interest rates low. Another possible explanation is that the policy rate of the eurozone was close to the zero lower bound in subsequent QE rounds. Since investors did not expect that policy rates would fall below zero, there was less capacity for downward revision of the future eurozone policy rate in later QE rounds.

Closer inspection of Table 5 shows that the forward guidance announcements generated mixed signalling effects over two days. This is reflected by a decline in the 10-year OIS rate of the eurozone the first day after the forward guidance announcements and a rise in this rate on the second day after these announcements. This finding is in line with the mixed signalling effects of forward guidance in the 10-year OIS market of the US.

Table 5: Estimation Results Eq. (8)

Variable	OIS eurozone
Constant	-0.08
Δy_{t-1}	-0.04**
QE 1 $(t+1)$	-12.15***
QE 1 $(t+2)$	-5.90
QE 2 $(t+1)$	-6.46***
QE 2 $(t+2)$	-2.08
QE 3 $(t+1)$	-6.53***
QE 3 $(t+2)$	-0.56***
FG $(t+1)$	-16.64***
FG $(t+2)$	9.08***
OT $(t+1)$	-5.89***
OT $(t+2)$	4.08***
Taper $(t+1)$	6.25**
Taper $(t+2)$	2.35
ECB	1.11
$CESI_{\mathrm{eu}}$	0.05***
ARCH	
Constant	0.13**
L.arch	0.03***
L.garch	0.96***
Observations	2088
AIC	5.62
BIC	5.66

Notes: OIS eurozone refers to the dependent variable in Eq. (8). $t+1$ $(t+2)$ implies that the announcements in the specific QE programme dummy equal 1 on the first (*second*) day after the official announcement date t described in Table 2 and 0 otherwise. Bollerslev-Woolridge standard errors have been used to compute the coefficient covariance matrix. *,**,*** denote the 10 percent, 5 percent and 1 percent significance levels, respectively.

Marginal signalling effects (over two days) are found for the operation twist announcements. This result is in agreement with the weak signalling effects of operation twist in the US government bond market. The tapering talks by Chairman Ben Bernanke also found their way to government bond markets in the eurozone. In line with expectations, these tapering talks raised expected future policy rates in the eurozone.

6.2.2 Portfolio balance effects

Table 6 shows the estimation results of Eq. (9). The most important finding is that UMP announcements by the Fed had the largest portfolio balance effects over two days in the core countries of the eurozone. The effect of the portfolio balance channel over two days is minor for the periphery countries of the eurozone. In line with the findings of Bauer and Neely (2014), the magnitude of these effects is weaker for subsequent QE rounds.

Finland, Germany and The Netherlands experienced the largest impact on term premia, (i.e. of the portfolio balance effect) over a two-day window. This finding indicates that the portfolio balance channel has the strongest impact in eurozone countries with a safe-haven status. This result supports the argument of Neely (2015) that UMP announcements by the Fed may trigger a flight to safety. Moreover, this finding also confirms the claim of Krishnamurthy and Vissing-Jorgensen (2011) who argue that QE works through a safety channel that mainly affects highly safe bonds of medium-to-long-term maturity.

The peripheral countries experienced an inconsistent impact on term premia over two days after the Fed announced its UMP. On the first day following announcements of QE 1, 2 and 3, the term premium on the 10-year government bond of nearly all peripheral countries increased. However, this was succeeded by a decline of the term premium on the second day after these announcements. This inconsistent and volatile pattern of the term premium may reflect the financial market stress in pricing peripheral government bonds in response to UMP announcements by the Fed.

Closer inspection of Table 6 reveals two other remarkable findings. Firstly, several countries experienced a decline in the term premium in response to the forward guidance announcements by the Fed. Although this effect was expected beforehand, this finding is not in line with the effects found in the 10-year government bond market of the US (Table 5). Finland, Germany, the Netherlands and Greece experienced a rise in the term premium after the Fed announced forward guidance. This result is in line with the findings presented in Table 5.

Another notable result is the response of the 10-year government bond term premium of Greece on UMP announcements by the Fed. It appears that these announcements have sometimes had very sizeable effects on the Greek term premium. Moreover, the sign of these effects is not always in agreement with the other findings. For instance, the Greek term premium increased both days after the QE 2 and FG announcements, whereas other countries either experienced a decline or mixed effects on term premia over two days.

Table 6: Estimation Results Eq. (9)

Variable	Austria	Belgium	Finland	France	Germany	Netherl.	Greece	Italy	Ireland	Portugal	Spain
Constant	−0.073	−0.046	−0.042	−0.067	0.013	−0.027	0.039	−0.044	−0.159	0.028	0.002
QE 1 $(t{+}1)$	−1.922***	−2.384	−0.980*	−3.594***	−5.819***	−4.573***	0.955	2.036	6.953***	0.368	0.664**
QE 1 $(t{+}2)$	−2.735	−6.237**	−5.806**	−5.947***	−6.270***	−5.788***	−10.646**	−3.975***	2.386	−5.338***	−2.312**
QE 2 $(t{+}1)$	0.416	−3.968***	−0.446*	0.836***	−1.877***	0.281	29.577***	5.639***	37.880	16.405***	6.836***
QE 2 $(t{+}2)$	0.564*	−4.949***	2.699	0.588***	0.224	−1.454***	10.409***	−4.995***	31.156	−11.160***	−6.412***
QE 3 $(t{+}1)$	−1.879***	4.500	−0.824***	−0.592*	−2.780***	−0.869***	−4.096	1.714***	−2.853***	18.521***	5.436***
QE 3 $(t{+}2)$	−1.808***	−6.222***	−2.035***	−1.812***	−1.377***	−1.860***	27.172***	−15.355***	2.741***	1.087	−12.519***
FG $(t{+}1)$	−0.523	−1.652	2.369***	3.944***	3.341***	0.895**	6.961***	−11.166***	−5.810***	1.828	−10.118***
FG $(t{+}2)$	−8.432***	−11.418***	0.814***	−11.005***	4.030***	0.420*	14.614***	−9.898***	−2.669**	−23.900***	−3.551***
OT $(t{+}1)$	−1.013**	−1.886	−1.354***	−6.783***	−0.504	−0.568	−32.726**	−12.219***	10.630***	−16.392***	−19.544***
OT $(t{+}2)$	−2.136	−8.546***	−1.142***	1.422***	−0.849*	−1.486***	22.367	12.794***	8.039***	14.965***	4.908
Taper $(t{+}1)$	4.497	1.301	7.439	1.003	0.274	3.649***	44.050***	3.378***	11.761***	13.592*	5.223***
Taper $(t{+}2)$	3.729	3.693	−11.420	6.027**	1.545***	−0.856	18.147	4.352***	−8.380***	9.362	3.131***
$\Delta\, VSTOXX$	0.438	3.923***	−1.594*	1.333*	−6.489***	−1.487***	16.136***	14.370***	14.587***	21.440***	15.742***
$\Delta\, CDS$	0.221***	0.230***	−0.105	0.167***	−0.162***	0.098***	0.149**	0.515***	0.351**	0.545***	0.540***
$\Delta\, Redom$	−0.010	0.267***	0.051	0.126***		0.033	0.162	0.097***	0.097**	0.219***	0.246***
$CESI_{\mathrm{eu}}$	−0.001	−0.000	−0.001	−0.001	−0.002**	−0.001	−0.001	−0.000	0.001	−0.001	0.000
ECB	−0.802	−1.951***	−1.377**	−1.517***	−0.619*	−1.479**	−3.517***	−1.328*	−1.795**	−1.989*	−2.130*
Δy_{t-1}	−0.127**	−0.112	−0.196***	−0.138*	−0.179**	−0.154***	0.096*	−0.059*	0.062*	0.076*	−0.049
$\Delta y_{t-1,\mathrm{Italy}}$	0.013	0.076*	0.022	0.014	−0.055**	−0.009	0.175**		0.104*	0.045	0.025
$\Delta y_{t-1,\mathrm{Spain}}$	−0.033	−0.039*	−0.036	−0.010	0.012	−0.014	−0.134	−0.003	−0.052	−0.134*	
$\Delta y_{t-1,\mathrm{Portugal}}$	−0.010	−0.007	−0.002	−0.010	0.002	−0.005	0.069	−0.006	0.003		−0.029*
$\Delta y_{t-1,\mathrm{Ireland}}$	0.034	0.020*	0.023*	0.035*	0.015	0.014	−0.032	0.024		0.008	0.031
$\Delta y_{t-1,\mathrm{Greece}}$	−0.000	−0.002	−0.001	−0.002	0.001	0.000		−0.006*	−0.004	−0.006	−0.005**
ARCH											
Constant	0.379**	0.417***	0.417**	0.378***	0.318***	0.037***	0.060***	0.290***	0.265***	0.155***	0.427***
L.arch	0.360***	0.204***	0.204***	0.132***	0.145***	0.132***	0.177***	0.068***	0.103***	0.074***	0.078***
L(2).arch	−0.236**					−0.085***					
L.garch	0.851***	0.769***	0.769***	0.832***	0.808***	0.949***	0.874***	0.924***	0.896***	0.931***	0.914***
Obs.	2088	2088	1980	2039	2088	1980	2088	2088	1982	1965	2039
AIC	5.034	5.295	4.706	4.923	4.386	4.482	8.750	5.985	6.553	7.159	6.347
BIC	5.112	5.367	4.781	5.001	4.456	4.560	8.820	6.055	6.630	7.236	6.419

Notes: The table present the estimation results of Eq. (9) for all the eurozone countries in the sample. $t+1$ $(t+2)$ implies that the announcements in the specific QE programme dummy equal 1 on the first (*second*) day after the official announcement date t described in Table 2 and 0 otherwise. The dependent variables are in first differences, and the results are shown in basis points. Bollerslev-Woolridge standard errors have been used to compute the coefficient covariance matrix. *,**,*** denote the 10 percent, 5 percent and 1 percent significance levels, respectively.

An explanation for these unexpected results may be the exceptional credit market stress Greece encountered during the sample period.[32]

A particularly interesting result is that tapering announcements by the Fed increased term premia of nearly all eurozone government bonds. For virtually all countries, the rise in term premia after these announcements is smaller in magnitude than the overall shrink in term premia after non-tapering announcements. This incongruity may have emerged because financial markets interpreted tapering announcements differently from monetary easing announcements. While the latter announcements may have signalled that the Fed did whatever it took to ease financial conditions, tapering did not signal a proportional pace of tightening of financial conditions (Rogers et al., 2014). On average, the magnitude of tapering effects is larger for the peripheral countries, compared to the core countries of the eurozone. This may reflect the peripheral status of these countries, leading to a stronger reaction of investors towards peripheral government bonds after the Fed announced to taper off securities.

7 Conclusions, limitations and further research

This thesis contributes to the existing literature by examining the effects of UMP announcements by the Fed on eurozone government bond markets. I find that these announcements found their way to European bond markets through both a signalling channel and a portfolio balance channel. The signalling channel had the same effect in government bond markets of the eurozone by altering investors' expectations of future policy rates. The portfolio balance channel is found to be the most important for government bond markets in the core of the eurozone. This effect appears to be minor for markets of government bonds in the periphery of the eurozone. These findings indicate that announcements by the Fed on its UMP mainly triggered a flight to eurozone government bonds with a safe-haven status.

The results of this thesis may be of interest to monetary policy makers. The eurozone may have experienced positive or negative spillover effects of UMP announcements by the Fed. The reduction in bond yields after these announcements may have been beneficial for the ECB in times where its policy rate nearly hit the lower bound. On the other hand, these spillover effects are less advantageous if these announcements also triggered a flight out of peripheral government bonds towards safe eurozone government bonds. This may have led to an increase in the yield spread between core and peripheral eurozone government bonds while the ECB aimed to narrow this spread with its UMP. These changes in interest rates potentially also altered the EUR/USD exchange rate, which may have spurred or deterred eurozone exports. All these effects could, therefore, have contradictory or stimulative effects on the UMP pursued by the ECB. More research into this topic would be a fruitful area of future work.

An issue not addressed in this study is how UMP announcements by the Fed influenced

[32]This is for instance reflected by the relatively large values of the information criteria and unexpected result of the quanto CDS rate.

the EUR/USD exchange rate. To the extent that U.S. yields decline more than eurozone yields, the Uncovered Interest Rate Parity (UIRP) condition predicts that the USD has to appreciate vis-a-vis the Euro. This expected exchange rate change would make US investors indifferent between investing in US government bonds or eurozone government bonds. In this way, investors would not be inclined to rebalance their portfolio towards eurozone government bonds in response to UMP announcements by the Fed. However, a great deal of previous literature empirically rejects the UIRP condition and finds that lower interest rate currencies depreciate relative to higher interest rate currencies. The results of Neely (2015) also confirm these findings and show that the dollar depreciates (appreciates) after monetary easing (tapering) announcements by the Fed. The identified portfolio balance effects in this thesis are therefore consistent with this path of EUR/USD exchange rate changes in response to announcements by the Fed on its UMP.

A Appendix

A.1 Unit root tests

Table A.1: P-values of Augmented Dickey-Fuller Test

Variable	Austria	Belgium	Finland	France	Germany	Netherl.	Greece	Italy	Ireland	Portugal	Spain	All eurozone	US
Yield-OIS (10y)	0.1807	0.1912	0.1255	0.3142	0.1641	0.1995	0.4182	0.4180	0.5964	0.6333	0.4743		**0.0437**
CDS	0.0779	0.2706	0.3143	0.2230	0.0938	0.2775	0.7790	0.1399	0.2852	0.3403	0.2272		
Redom	**0.0005**	0.1273	**0.0001**	**0.0287**		0.0718	0.6975	0.2210	0.6008	0.5033	0.4064		
OIS rate (10y)												0.8880	0.0907
VSTOXX												**0.0009**	
CESI												**0.0246**	**0.0146**

Notes: This table shows the p-values of the Augmented Dickey-Fuller (ADF) test. The null hypothesis is that the variable has a unit root. This hypothesis is rejected if the p-value < 0.05 (highlighted in bold). The ADF with trend and intercept has been performed if variables have a clear trend. The column "All eurozone" shows the p-values for the time series observations. All variables in this test are measured in level values.

A.2 ECB announcements

Table A.2: ECB announcements incorporated in the dummy variable ECB_t

Date	Program	Policy Measure
28-03-2008	LTRO	GC decides to conduct supplementary longer-term refinancing operations with a maturity of 6 months
15-10-2008	LTRO	GC decides to conduct all refinancing operations with a fixed-rate tender procedure and full allotment. The list of assets eligible as collateral is expanded
07-05-2009	LTRO/CBPP	GC decides to conduct longer-term refinancing operations with a maturity of 12 months, and to purchase euro-denominated covered bonds issued in the euro area
04-06-2009	CBPP	GC releases the technical modalities of the €60 billion covered bonds purchase programmes
10-05-2010	SMP	GC decides to conduct interventions in the euro area public and private debt securities markets
30-06-2010	SMP	The purchases of €60 billion in covered bonds are fully implemented. The Eurosystem central banks intend to keep the purchased covered bonds until maturity
06-10-2011	CBPP	GC decides to launch a new covered bonds purchase programmes with an intended amount of €40 billion
07-08-2011	SMP	Draghi announces the reactivation of the SMP especially targeting Italian and Spanish Bonds.
03-11-2011	CBPP	GC releases details of the new covered bonds purchase programmes. Covered bonds to be purchased under the new programme must have a maximum residual of 10.5 years
08-12-2011	LTRO	GC decides to conduct LTROs with a maturity of 36 months, and further expands eligible collectoral
28-07-2012	OMT	Draghi speech: ”ready to do whatever it takes to preserve the Euro”
02-08-2012	OMT	Draghi indicates the expansion of sovereign debt purchases
06-09-2012	OMT	GC introduces outright monetary transactions with no ex-ante time or size limit
04-09-2014	ABSPP/CBPP3	The GC announces the ABSPP and CBPP3 programmes
02-10-2014	ABSPP/CBPP3	The ECB publishes the detailed modalities of the ABSPP and CBPP3 programmes
22-01-2015	PSPP	The GC announces an expanded asset purchase programme, which encompasses the new PSPP, the ABSPP and CBPP3
09-03-2015	PSPP	The Pspp is implemented

Notes: GC indicates the Governing Council of the ECB, LTRO indicates Long-term Refinancing Operations, CBPP indicates Covered Bond Purchase Programme, SMP indicates Securities Markets Programme, ABSPP indicates Asset-Backed Securities Purchase Programme, OMT indicates Outright Monetary Transactions,PSPP indicates Public Sector Purchase Programme. The information in this table is taken from the ECB website.

A.3 Inequality constraints GARCH(1,2) and GARCH(2,1) models

Equation (10) shows that in the GARCH(p,q) model the variance of the error term is modelled as:

$$\sigma_t^2 = \omega + \sum_{i=1}^{q} \delta_i \epsilon_{t-i}^2 + \sum_{j=1}^{p} \eta_j \sigma_{t-j}^2$$

where p refers to the number of GARCH terms (σ^2) and q to the number of ARCH terms (ϵ^2). Bollerslev (1987) imposed non-negativety constraints on the parameters of Eq. (10), to guarantee that the variance is non-negative ($\sigma_t^2 \geq 0$) . This implies, as shown in sub-section 4.2.3, that:

$$\omega, \delta_i, \eta_j \geq 0$$

Nelson and Cao (1992) argue that these conditions are valid for the GARCH (1,1) model, but that these are too stringent for higher order GARCH models. They show that in case of the GARCH (1,2) model, the necessary and sufficient non-negativity constraints become:

$$\begin{aligned} \omega &\geq 0 \\ 0 \leq \eta_1 &< 1 \\ \delta_1 &\geq 0 \\ \eta_1 \delta_1 + \delta_2 &\geq 0 \end{aligned}$$

while for the GARCH (2,1) model these conditions reduce to:

$$\begin{aligned} \omega &\geq 0 \\ \eta_1 &\geq 0 \\ \delta_1 &\geq 0 \\ \eta_1 + \eta_2 &< 1 \\ \eta_1^2 + 4\eta_2 &\geq 0 \end{aligned}$$

Nelson and Cao (1992) argue that the stationarity conditions of the GARCH (1,1) model presented in sub-section 4.2.3, also apply to the GARCH (1,2) and GARCH (2,1) models.

I follow the non-negativity and stationarity restrictions imposed by Nelson and Cao (1992) for the GARCH (1,2) and GARCH(2,1) models presented in Table 6. It appears that none of the models violates these restrictions.

A.4 Descriptive statistics

Table A.3: Descriptive statistics

Variable	Union (part)	Mean	Std. Dev	Obs.
Zero coupon bond yield (10y)	eurozone core	2.790	1.282	1965
	eurozone periphery	5.704	2.382	1965
	US	2.835	0.806	1937
OIS rate (10y)	eurozone	2.364	1.313	1965
	US	2.425	0.732	1937
Yield-OIS (10-year)	eurozone core	0.426	0.316	1965
	eurozone periphery	3.347	2.739	1965
	US	41.034	0.174	1937
VSTOXX	eurozone	25.412	9.202	1965
CDS	eurozone core	1032.203	834.481	1965
	eurozone periphery	1348.852	1032.803	1965
Redom	eurozone core	23.141	16.525	1572
	eurozone periphery	1318.258	1033.462	1965
CESI	eurozone	−1.771	56.400	1965
	US	−1.257	43.156	1937

Notes: For the eurozone, the statistics are measured over a (common) sample that coincides with the minimum number of observations in Table 6 (Portugal). The variables in the first three rows are measured in percentage points. The variables *CDS* and *Redom* are measured in basis points. The number of observations for the eurozone core *Redom* variable differs with the other variables because Germany is the baseline country in the measure of *Redom*.

A.5 LSAP's of the Fed

From late 2008 until 2013, the Fed mainly conducted UMP through LSAP's and by means of Forward Guidance. These measures aimed to support financial conditions, economic activity and job creation (Federal Reserve, 2016). LSAP's are usually named Quantitative Easing (QE) and consisted of mainly three rounds.

QE 1 The Fed announced the first round of QE late 2008. QE 1 was designed to primarily support the housing market since this market was the hardest hit by the sub-prime crisis of 2007. Therefore, the Fed mainly targeted the Mortgage Backed Securities (MBS) market in QE 1. The actual QE 1 purchases of the Fed were $ 1.75 Trillion, equivalent to 16 percent of GDP of the USA at that time (Ashworth, 2013).

QE 2 The second wave of QE started in late 2010, in response to a continuation of high employment and low inflation. QE 2 was specially designed to lower long-term interest rates and raise inflation in accordance with the dual mandate of the Fed. Therefore, the Fed mainly purchased longer-term Treasury securities in QE 2.

Operation Twist (OT) In mid-2011, the Fed experienced renewed fears of a recession in the US. In response to this, the Fed launched Operation Twist (OT). In contrast to earlier QE programmes, OT did not increase the monetary base of the Fed. This was because the Fed funded its purchases of $400 billion of longer-term Treasury securities, by selling $400 billion of short-term securities. Thereby, the Fed reduced longer-term interest rate relatively to short-term interest rates and hence altered the yield curve.

QE 3 To further support the weak economic conditions and slow employment growth, the FOMC announced the (widely expected) third round of QE on September 13th, 2012. The communication in QE 3 announcements was different from previous QE announcements. This was because the FOMC committed to a pace rather than a quantity of purchases, while there was no specific end date announced.

Tapering In early 2013, Chairman Ben Bernanke announced that the Fed would use a data-driven approach regarding tapering. This means that tapering would only take place when economic conditions improved. On May 22, 2013, Ben Bernanke talked for the first time about a possible tapering of QE. These so-called "tapering talks" surprised the market, as they occurred sooner than expected (Mishra et al., 2014). The actual implementation of tapering was announced on December 18, 2013.

A.6 Term premium component of Kim and Wright (2005)

Table A.4: Estimation Results Eq. (12) Kim and Wright (2005) measure

Variable	US TP K&W
Constant	0.008
Δy_{t-1}	0.002
QE 1	
25-11-2008	−16.772***
25-11-2008 $(t+1)$	−6.597
01-12-2008	−17.437***
01-12-2008 $(t+1)$	−2.915
16-12-2008	−11.899***
16-12-2008 $(t+1)$	−11.956***
28-01-2009	8.528***
28-01-2009 $(t+1)$	10.976
18-03-2009	3.157
18-03-2009 $(t+1)$	−39.968***
QE 2	
10-08-2010	−6.028
10-08-2010 $(t+1)$	−4.767
27-08-2010	12.008***
27-08-2010 $(t+1)$	−8.591**
21-09-2010	−8.682**
21-09-2010 $(t+1)$	−3.562
15-10-2010	5.273
15-10-2010 $(t+1)$	−7.208***
03-11-2010	−1.102
03-11-2010 $(t+1)$	−12.186***
FG & OT	
09-08-2011	−18.226***
09-08-2011 $(t+1)$	−0.586
21-09-2011	−4.037
21-09-2011 $(t+1)$	−11.411***
25-01-2012	−7.876*
25-01-2012 $(t+1)$	−4.723
20-06-2012	1.556
20-06-2012 $(t+1)$	−1.551
QE 3	
22-08-2012	−7.536*
22-08-2012 $(t+1)$	−2.444
31-08-2012	−5.444
31-08-2012 $(t+1)$	0.972
13-09-2012	−3.848
13-09-2012 $(t+1)$	9.589**
12-12-2012	3.015
12-12-2012 $(t+1)$	−0.184
Tapering	
22-05-2013	7.676*
22-05-2013 $(t+1)$	0.187
19-06-2013	14.471***
19-06-2013 $(t+1)$	6.165
18-12-2013	4.229
18-12-2013 $(t+1)$	5.954
ECB_t	1.313**
CESI_j	0.002
Observations	1937
R-squared (adj.)	0.073

Notes: Results of Eq. (12) if the term premium component of the 10-year US government bond, constructed by Kim and Wright (2005), is used as dependent variable. Results are shown in basis points. $t+1$ in brackets implies that the effect of this announcement is measured one day after the date that is specified before the bracket. The dates without brackets measure the effects on the exact date that is specified. *, **, *** denote the 10 percent, 5 percent and 1 percent significance levels, respectively.

References

Arghyrou, M. G., & Kontonikas, A. (2012). The EMU sovereign-debt crisis: Fundamentals, expectations and contagion. Journal of International Financial Markets, Institutions and Money, 22(4), 658-677.

Ashworth, J. (2013) 'Quantitative Easing by the Major Western Central Banks during the Global Financial Crisis', in S. Durlauf and L.E. Blume (eds) The New Palgrave Dictionary of Economics,(Online Edition, 2013 edn).

Bauer, M. D., & 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., & Rudebusch, G. D. (2013). The signaling channel for Federal Reserve bond purchases. International Journal of Central Banking, forthcoming.

Beber, A., Brandt, M., & Kavajecz, K. 2009. "Flight-to-Quality or Flight-to-Liquidity? Evidence from the Euro-Area Bond Market." Review of Financial Studies 22 (3): 925–57

Blot, C., Creel, J., Hubert, P., & Labondance, F. (2015). The QE experience: Worth a try?. European Parliament's Committee on Economic and Monetary Affairs, In-depth analysis, Directorate General For Internal Policies Policy Department A: Economic And Scientific Policy.

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. Journal of econometrics, 31(3), 307-327.

Bollerslev, T., & Wooldridge, J. M. (1992). Quasi-maximum likelihood estimation and inference in dynamic models with time-varying covariances. Econometric reviews, 11(2), 143-172.

Bowman, D., Londono, J. M., & Sapriza, H. (2015). US unconventional monetary policy and transmission to emerging market economies. Journal of International Money and Finance, 55, 27-59.

Caceres, C., Guzzo, V., & Segoviano Basurto, M. (2010). Sovereign spreads: Global risk aversion, contagion or fundamentals?. IMF working papers, 1-29.

Christensen, J. H. E., & Rudebusch, G. D., November 2012. The response of interest rates to us and uk quantitative easing. Economic Journal 122 (564), F385–F414.

Codogno, L., Favero, C., & Missale, A. (2003). Yield spreads on EMU government bonds. Economic Policy, 18(37), 503-532.

D'Amico, S., & King, T. B. (2013). Flow and stock effects of large-scale treasury purchases:

Evidence on the importance of local supply. Journal of Financial Economics, 108(2), 425-448.

De Santis, R. A. (2012). The Euro area sovereign debt crisis: safe haven, credit rating agencies and the spread of the fever from Greece, Ireland and Portugal.

De Santis, R. A. (2015). A measure of redenomination risk (No. 1785). ISO 690.

Doornik, J. A., & Ooms, M. (2003). Multimodality in the GARCH regression model. Nuffield College.

ECB. (2007). Demand For Bonds by Institutional Investors and Bond Yield Developments in The Euro Area. ECB Monthly bulletin May, 5, 30-32.

Ejsing, J., Grothe, M., & Grothe, O. (2012). Liquidity and credit risk premia in government bond yields.

Falagiarda, M., & Reitz, S. (2013). Announcements of ECB unconventional programmes: Implications for the sovereign risk of Italy (No. 1866). Kiel Working Paper. ISO 690.

Fawley, B., & Neely, C. J., January/February 2013. Four stories of quantitative easing. Federal Reserve Bank of St. Louis Review 95 (1), 51–88.

Federal Reserve System (Last update December 2015), ”Money, Interest Rates, and Monetary Policy”, Accessed August 11 2016, https://www.federalreserve.gov/faqs/money-rates-policy.html.

Fratzscher, M., Lo Duca, M., & Straub, R. (2013). On the international spillovers of US quantitative easing.

Gagnon, J., Raskin, M., Remache, J., & Sack, B., March 2011. The financial market effects of the federal reserve’s large-scale asset purchases. International Journal of Central Banking 7 (1), 3–43.

Hamilton, J. D., & Wu, J. C. (2012). The effectiveness of alternative monetary policy tools in a zero lower bound environment. Journal of Money, Credit and Banking, 44(s1), 3-46.

Hausken, K., & Ncube, M. (2013). Quantitative easing and its impact in the US, Japan, the UK and Europe. Springer.

Hausman, J., & Wongswan, J., April 2011. Global asset prices and fomc announcements. Journal of International Money and Finance 30 (3), 547–571.

Joyce, M., Lasaosa, A., Stevens, I., & Tong, M., September 2011. The financial market impact of quantitative easing in the united kingdom. International Journal of Central Banking 7 (3), 113–161.

Joyce, M. A., & Tong, M. (2012). QE and the gilt market: a disaggregated analysis. The Economic Journal, 122(564), F348-F384.

Kilponen, J., Laakkonen, H., & Vilmunen, J. (2015). Sovereign Risk, European Crisis-Resolution Policies, and Bond Spreads. International Journal of Central Banking, 11(2), 285-323.

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.

Krishnamurthy, A., & Vissing-Jorgensen, A. (2011). The effects of quantitative easing on interest rates: channels and implications for policy (No. w17555). National Bureau of Economic Research.

MacKinlay, A. C. (1997). Event studies in economics and finance. Journal of economic literature, 35(1), 13-39.

Mercurio, F. (2009). Interest rates and the credit crunch: new formulas and market models. Bloomberg portfolio research paper, (2010-01).

Mishra, P., Moriyama, K., & N'Diaye, P. (2014). Impact of Fed tapering announcements on emerging markets.

Moore, J., Nam, S., Suh, M., & Tepper, A. (2013). Estimating the impacts of US LSAPs on emerging market economies' local currency bond markets. Federal Reserve Bank of New York Staff Report, 595.

Morini, M. (2009). Solving the puzzle in the interest rate market. Available at SSRN 1506046.

Neely, Christopher J. "Unconventional monetary policy had large international effects." Journal of Banking & Finance 52 (2015): 101-111.

Nelson, D. B., & Cao, C. Q. (1992). Inequality constraints in the univariate GARCH model. Journal of Business & Economic Statistics, 10(2), 229-235.

Park, K. Y., & Um, J. Y. (2016). Spillover Effects of United States' Unconventional Monetary Policy on Korean Bond Markets: Evidence from HighFrequency Data. The Developing Economies, 54(1), 27-58.

Pericoli, M., & Taboga, M. (2015). Decomposing euro area sovereign spreads: credit, liquidity and convenience. Bank of Italy Temi di Discussione (Working Paper) No, 1021.

Rivolta, G. (2012). An event study analysis of ECB unconventional monetary policy. mimeo.

Rogers, J. H., Scotti, C., & Wright, J. H. (2014). Evaluating asset-market effects of unconventional monetary policy: a multi-country review. Economic Policy, 29(80), 749-799.

Taboga, M. (2014). What is a prime bank? A Euribor–OIS spread perspective. International Finance, 17(1), 51-75.

Watfe, G. (2015). The Impact of the ECB's Asset Purchase Programmes on Sovereign Bond Spreads in the Euro Are (No. 35). European Economic Studies Department, College of Europe.

Weiss, A. A. (1986). Asymptotic theory for ARCH models: estimation and testing. Econometric theory, 2(01), 107-131.