A Theoretical and Empirical Assessment of Quantitative Easing in the Eurozone

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Abstract

The ECB's launch of unconventional monetary policy in response to the financial crisis of 2008 and the sovereign debt crisis starting in 2010 was a true experiment without a theoretical foundation. In order to improve our understanding of the effect of Quantitative Easing on the financial system, we present a coherent model consisting of the provision of credit by the banking and the non-banking sector. Our model suggests that by acting as an additional supplier of credit in the bond market, the ECB brought about a decrease in long-term bond yields. Our model further implies that the ECB's various Quantitative Easing programs influenced the interest rate in the bond market via credit risk and term premium channel. By applying an error correction model and an event based regression, we test these hypotheses empirically and find significant effects for the majority of Quantitative Easing programs.

Keywords: Government Bonds, Monetary Policy, Quantitative Easing.

JEL Codes: E43, E44, E52, E58.

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1 Introduction

"The problem with QE is it works in practice, but it doesn't work in theory", Bernanke answered when asked about the effectiveness of Quantitative Easing (QE) in 2012.

So far, several empirical studies, mainly dealing with the programs by the Fed and the BoE, have shown that QE does indeed have the desired effects, especially in terms of lowering sovereign bond yields. These studies to a large extent identify and disentangle various channels of transmission of QE on sovereign bond yields.[1]

In the Euro area, where the European Central Bank's (ECB) unconventional measures were mainly aimed at reducing inter-country sovereign bond spreads in response to the financial crisis, the sovereign-banking nexus, and the sovereign debt crisis, the focus of literature lies on bond spread reduction. A significant impact of QE, in terms of decreasing bond spreads relative to the German Bund, has been found for the Eurozone by Falagiarda and Reitz (2015), Szczerbowicz (2015), Gerlach-Kristen (2015), and Eser and Schwaab (2016) in the context of programs prior to 2015.

In analyzing sovereign bond yields instead of spreads and therefore capturing the effects of QE for German Bunds as well, our paper best aligns to the papers by Altavilla, Carboni and Motto (2015) and De Santis (2016), who identified an overall negative reaction of sovereign bond yields resulting specifically from the announcement of the ECB's Asset Purchase Programme (APP) in January 2015 and additionally analyzed several transmission channels for the negative effect on long-term yields in the Euro area. To the best of our knowledge, thus far no paper has evaluated the entire range of QE programs conducted by the ECB both in a coherent theoretical model and empirically.

First, we aim to add to the existing literature by developing a coherent theoretical model that is capable of depicting the effects of QE on the financial system and its mere announcement by considering two transmission channels (the term premium channel and credit risk channel). For this purpose, we distinguish two markets with the financial system. One is the bank credit market, where banks supply credit and in this way create money.[2] The other is the bond market, where non-banks redistribute the money created by the banking sector by purchasing bonds, and in doing so implicitly grant loans to banks and non-banks. We further identify non-bank suppliers of credit as the counterparty for the ECB's large scale asset purchases. Therefore, in our model, we establish the bond

[1] For a comprehensive overview see Krishnamurthy and Vissing-Jorgensen (2011).

[2] In terms of the banking sector, our model is similar to the model in Disyatat (2011).

market as the effective area of QE, before coming to the main upshot of our theoretical model: By acting as an additional supplier of money in the bond market, the central bank is able to lower the bond yields. This effect can be observed upon the mere announcement of QE and leads to decreasing credit risk and interest rate expectations, because agents on the bond market tend to price in actions of monetary policy as soon as they can be anticipated.

Second, we seek support for our theoretical model by empirically testing the hypotheses derived from our model, regarding the effect of QE on 5-year sovereign bond yields for Germany, France, Portugal, Spain, Italy and Ireland and the European benchmark bond. For this purpose, we apply an error correction model in order to distinguish between long and short run effects on the credit market equilibrium of our model and test the hypotheses on credit risk and interest rate expectations via an event based regression. Our results are in line with our expectations based on the model. We find a negative yield effect on sovereign bond yields for most countries, but also determine a yield increasing effect on German and French bond yields, which seems sensible, as Germany and France were not as severely affected by the Euro area crisis as the European periphery countries. Moreover, the clear-cut effect we find on credit risk provides support for our suggestion that by conducting QE programs, the ECB rebuilt trust between financial actors and can therefore be seen as a *lender of confidence* causing the credit risk to decrease. Lastly, our findings regarding the effect of QE on interest rate expectations, which we acquired via the measurement of the effect on term premia, paint a diverse picture, which speaks in favor of a portfolio rebalancing effect.

The remainder of the paper is organized as follows: In Section 2 we give an overview on the existing monetary policy tools of the ECB as of 2017, before we analyze the literature on the unconventional programs of the ECB in line with the most-cited papers on US and UK monetary policy in Section 3. In Section 4, we derive our model for the banking and non-banking sector step by step. We conclude this section with three hypotheses on the effects and transmission of QE that can be derived from the model. We then put these hypotheses to an empirical test and provide both our method and results in in Section 5. Section 6 ultimately concludes condensing the main results.

2 ECB monetary policy instruments

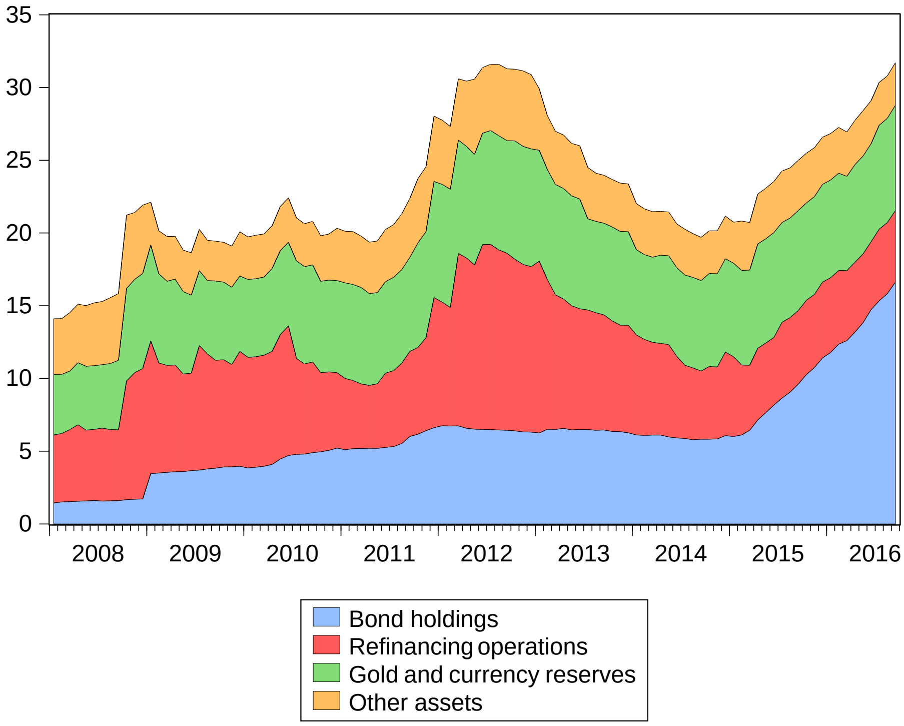
The four major central banks—Federal Reserve Bank (Fed), Bank of England (BoE), Bank of Japan (BoJ) and ECB—draw on a set of monetary policy tools to influence the economy. Under normal conditions they provide liquidity to the banking system by using standard instruments. Since the financial crisis, however, unconventional measures have been added to their toolboxes, to address the increased demand for liquidity in banking and bond market. When focusing on the ECB's instruments, we first categorize them by conventionality and targeted market before placing them in temporal context:[3]

1. Conventional Instruments
   (a) Banking Market
      i. Main Refinancing Operations
      ii. Fine Tuning Reverse Operations
      iii. Structural Reverse Operations
      iv. Longer-Term Refinancing Operations
2. Unconventional Instruments
   (a) Banking Market
      Liquidity Support Measures
         i. Longer-Term Refinancing Operations with a maturity > 3 months (LTRO)
         ii. Targeted Longer-Term Refinancing Operations (TLTRO)
   (b) Bond market
      Quantitative Easing (QE)
         i. Covered Bonds Purchase Program (CBPP)
         ii. Securities Market Program (SMP)
         iii. Outright Monetary Transactions (OMT)
         iv. Public Sector Purchase Program (PSPP)
         v. Corporate Sector Purchase Program (CSPP)

[3] The conventional instruments listed under item 1a comprise the operational framework of the Eurosystem, whereby the interaction of the ECB with the banking sector is limited to setting the price for short and longer-term refinancing of banks at the Central Bank. The unconventional measures taken by the ECB can be differentiated into Liquidity Support Measures and Quantitative Easing, depending on the market in which the Central Bank takes action.

Within a narrow time frame to the financial crisis spillover to Europe, shortly after the collapse of Lehman Brothers, the ECB attempted to counteract the loss of confidence among banks and the resulting dry up of interbank funding by employing conventional instruments, such as lowering the refinancing rate. In order to satisfy the increased demand for central bank refinancing, moreover, the ECB engaged in unconventional measures that extended its balance sheet significantly (see Figure 1). The composition of the Central

Figure 1: Composition of the ECB's assets in percent of GDP



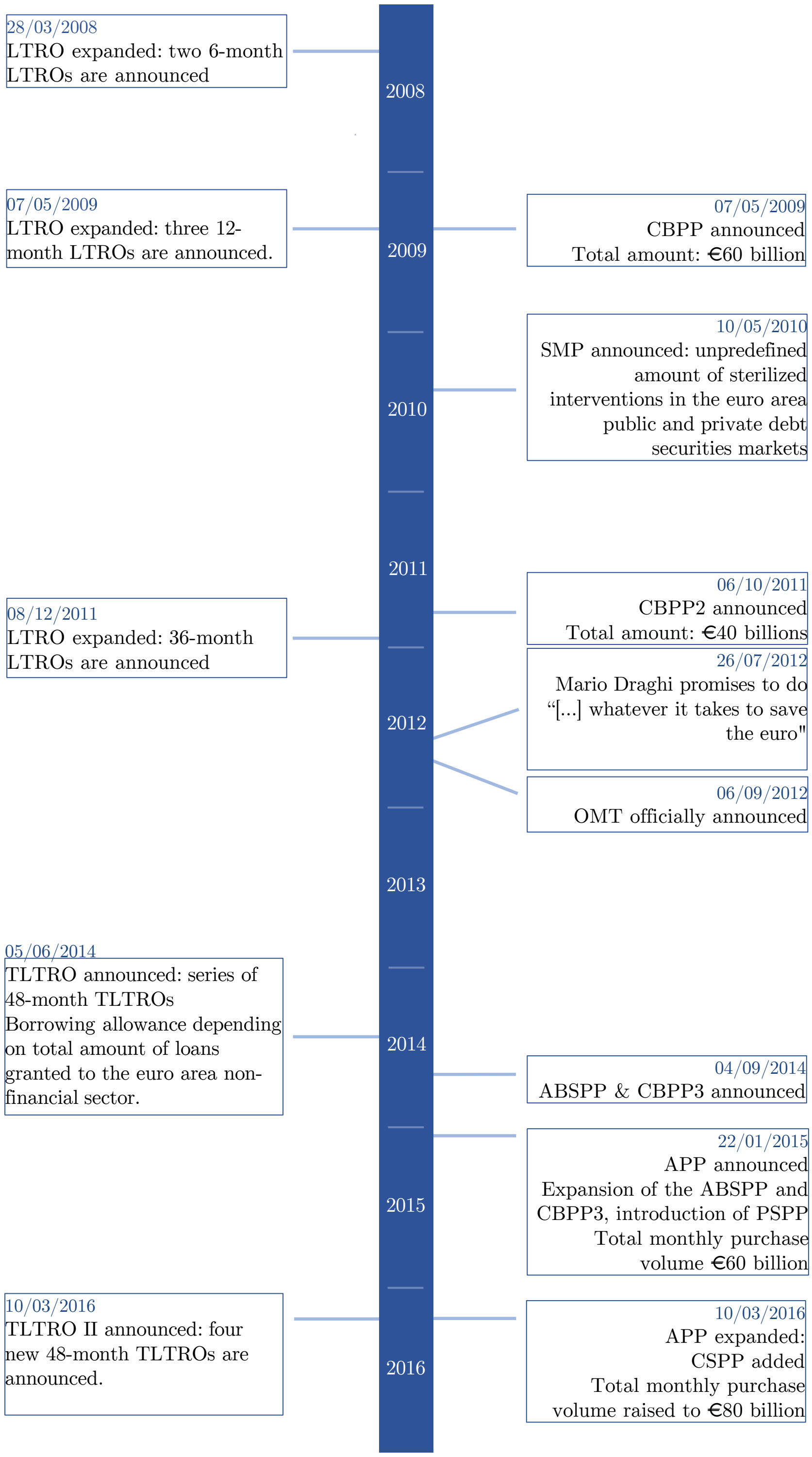
Source: ECB and own calculations.

Bank's assets shows that the balance sheet expansion in the early years after the crisis is mainly accounted for by the implementation of liquidity support measures. In particular, the ECB granted full allotment and extended the maturity of LTROs gradually from three months up to three years until the end of 2011, in order to close the funding gap in the banking sector, which had arisen as a result of the dysfunctioning interbank market. As these measures were insufficient by themselves to sustainably stabilize the interbank market, the ECB additionally introduced asset purchase programs. Especially, the employment of the so called Expanded Asset Purchase Programme, including a third CBPP, the PSPP and later the CSPP, caused another major expansion of central bank assets in 2015, right after the ECB's balance sheet had shrunk due to the repayment of excess liquidity between 2013 and 2014.

The set of measures of the ECB started with the prolongation of two LTROs to a duration six month on March 28, 2008, Jean-Claude Trichet offered three 12-month LTROs to provide even longer-term liquidity to banks and announced the ECB's first asset purchase program, the CBPP, on May 7, 2009. Backed by a dedicated pool of loans, Covered Bonds represent an important funding instrument of banks in the medium and long term. Accordingly, the ECB's motivation in purchasing Covered Bonds was firstly to ease the funding conditions of banks, and secondly to exert positive effects on funding conditions of non-financial corporations and households. Beyond the problems in the interbank market, the emergence of the sovereign debt crisis in Greece in 2010 induced an increase in default risk and fire sales of Eurozone government bonds. With the objective of preventing this development from getting out of hand and in order to "ensure the sustainability of [their] public finances" (see ECB, 2010), the ECB announced the SMP on May 10, 2010. Over the course of the SMP, the ECB conducted sterilized interventions in the public and private debt securities markets and purchased a total of €219.5 billion in Irish, Greek, Portuguese, Italian, and Spanish sovereign bonds despite recurring criticism that it was overstepping its mandate. After the Greek debt crisis had somewhat stabilized in the beginning of 2011, concerns were raised about spillovers to Italy and Spain. This led Mario Draghi to affirm the ECB's subsequent willingness to continue the SMP in August 2011. Furthermore, the ECB reintroduced the CBPP on October 6, 2011, in response to the persistently stressed banking sector and the negative feedback loop of government bond yields on banks in the European periphery countries. To counteract the banks' ongoing fire sales of government bonds and continual deleveraging, and to further stabilize the the banking sector's lending activity, on December 8, 2011, LTROs were extended to an exceptionally long period of 36 months, which enabled the banks to obtain cheap long-term funding. As concerns about the stability of the Eurozone increased due to the sovereign-banking nexus and the continuous accumulation of sovereign debt, Mario Draghi promised to do 'whatever it takes to save the euro' on July 26, 2012. This vague statement was interpreted by the markets as an unofficial announcement of another asset purchase program. His words were substantiated when the Governing Council revealed the takeover of the SMP by the OMT on September 6, 2012, in order to smooth the monetary transmission and to harmonize credit conditions in the Eurozone. In contrast to the SMP, the OMT required governments to comply with the adjustment programs of the European Financial Stability Facility (EFSF) or the European Stability Mechanism (ESM), as a precondition to qualify for central bank purchases of sovereign bonds with a shorter maturity of between 1 and 3 years. A period of regeneration followed in 2013 and early 2014, before stress tests of the European Banking Authority again put pressure on European banks. In order to support the banking sector while encouraging its provision of credit to the private sector, in June 2014, the ECB extended the LTROs once more to a maturity of 48 months and set the borrowing allowance for banks contingent upon the total amount of loans granted to the Euro area non-financial sector (TLTROs). This recurrent easing of funding for banks was followed by the introduction of additional asset purchase programs. On September 4, 2014, the ECB announced purchases of asset backed securities (ABSPP). As the underlying assets consist of claims against the non-financial private sector, the ABSPP was aimed at facilitating new credit flows to the non-financial sector. At the same time, the ECB announced another CBPP. Both the ABSPP and the CBPP3 were introduced without a predefined end date and are still ongoing with current holding volumes of €24 and €219 billion, respectively, as of May, 2017.

When the weak economy in the Eurozone was exacerbated further by low inflation rates and restrained inflation expectations, the ECB announced the addition of the PSPP to its current purchase programs in January 2015. Amounting to €60 billion, the monthly purchases of combined assets under the CBPP3, ABSPP, and PSPP were designed to counteract deflationary pressure and second-round deflationary effects on wages and prices. Soon after the first purchases were made under the PSPP, the ECB expanded the total monthly purchase volumes and added investment-grade bonds of non-financial corporations to its purchase-portfolio on March, 10th 2016. Being the first ECB program to directly purchase corporate bonds, the aim of the CSPP is to bypass the weak banking sector and to strengthen the credit conditions for business financing in the light of poor credit transmission. Ultimately, the ECB hopes to ease credit supply and exert an inflationary stimulus on the economy in the Eurozone via the asset purchase program as well as further conditional long-term liquidity provision to European banks (TLRTO II).

Figure 2: Timeline ECB unconventional policy



Note: The liquidity support measures taken by the ECB are listed in temporary order on the lefthand side and the ECB's asset purchase programs are listed sequentially on the righthand side.

3 Literature Overview

In order to fully understand the empirical literature to which our paper belongs, the existing empirical literature on unconventional monetary policy must be considered in its entirety. The wealth of scientific research on unconventional monetary policy can be organized according to two main factors, namely the type of the program, i.e. either Quantitative Easing or Liquidity Support Measures, and the central bank which implements the programs referred to in a paper. However, there are also a few papers which deal with the programs of two or more of the four major central banks.

Specifically, our paper belongs to the strand of literature focusing on the QE policy of the ECB, but is special in that it analyzes the macroeconomic effects on financial markets both theoretically and empirically. The empirical approach we employ to investigate the ECB's unconventional measures is related to those of Falagiarda and Reitz (2015), Szczerbowicz (2015), Gerlach-Kristen (2015), and Eser and Schwaab (2016), who analyzed the effects of QE on inter-country sovereign yield spreads in the Eurozone via event study. Moreover, our empirical study is closely related to those of Altavilla, Carboni and Motto (2015) and De Santis (2016), who performed event based regressions on sovereign bond yields, we however complement these works by evaluating the full range of unconventional instruments applied by the ECB up until late 2016.

3.1 Literature on Quantitative Easing

Due to a previous lack of data on and experience with QE as a form of unconventional monetary policy, the majority of the empirical literature on this topic has only evolved over the course of the last decade.[4] The announcement of the QE1 program by the Fed and the QE1 by the BoE, when both were in need of a monetary policy tool at the Zero Lower Bound during the post-crisis period, sparked the release of numerous papers on unconventional monetary policy instruments. Due to the lagged implementation of QE in the Eurozone, empirical studies on similar measures employed by the ECB were first conducted with some delay, and often follow highly-cited papers on Fed and BoE policies with regard to their structure and methodology. The empirical literature on QE can be

[4] One of the few acknowleged empirical papers on QE in the 20th century is a time series analysis by Modigliani and Sutch (1967) referring to the FED's "Operation Twist" in 1961. With the implementation of large scale asset purchases termed "Quantitative Easing" by the Bank of Japan shortly after the turn of the millennium, the number of empirical studies on QE started to grow, comprising papers by Bernanke, Reinhart and Sack (2004), Okina and Shiratsuka (2004) and Ugai (2007).

classified by the observed part of the transmission mechanism. While one area of the empirical literature analyzes the effect of QE on macroeconomic aggregates, another area, that to which our paper belongs, focuses on the transmission of QE to financial markets.

Literature on Macroeconomic Transmission

In terms of measuring the effects of QE on the real economy, the most common methods applied are VAR models. Using a structural VAR model, Baumeister and Benati (2013) find that the interest rate spread shock implied by unconventional measures has a positive effect on output growth and that these measures were successful in preventing the danger of deflation in the US and the UK. Applying a Bayesian VAR model developed by Bańbura, Giannone and Lenza (2009), Lenza, Pill and Reichlin (2010) get similar results for the Eurosystem and also identify a lag of several months in the positive real effects of QE. By implementing a panel VAR model, Gambacorta, Hofmann and Peersman (2014) find that for the US, the UK, and the Eurosystem an exogenous increase in the central bank's balance sheet effects output growth and inflation temporarily and non-persistantly at the Zero Lower Bound.

Empirical Literature on Financial Market Transmission

Event Studies For the analysis of effects on financial markets triggered by QE announcements, the most commonly chosen empirical approach is that of an event study aka. event based regression. This approach is based on the assumption that markets are forward looking and tend to price monetary policy actions in as soon as they can be anticipated. Therefore, event studies observe yield changes which occur around the time of an unconventional monetary policy announcement, integrated into the model as a dummy variable.

Beyond proving the existence and identifying the magnitude of a decreasing effect on long-term yields, many event studies additionally try to disentangle and examine the distinct channels through which QE affects long-term yields and financial conditions. In accordance with term structure theory, the majority of these event studies identify the signaling and portfolio rebalancing channels.[5] Specifically, Joyce et al. (2011) and Bauer and Rudebusch (2014) attribute changes in the Overnight Index Swap (OIS) rate to the signalling channel and changes in the UK gilt or the US treasury to OIS spreads to the portfolio rebalancing channel. In contrast, papers such as Krishnamurthy and Vissing-Jorgensen (2011) and D‘Amico et al. (2012) uncover additional (sub-)channels through which QE affects financial markets, among others duration risk and safety premium channels.

Considering the respective central bank addressed by each event study, the most commonly cited event studies are conducted on the data of unconventional programs in the US, such as Gagnon et al. (2010), D‘Amico et al. (2012), and Bauer and Rudebusch (2014). Other highly-cited papers comprise studies on the effects of the unconventional programs employed by the BoE, such as Joyce et al. (2011), and combined studies for both Fed and BoE programmes, as performed by Meaning and Zhu (2011). Less well-known event studies were performed on the QE programs of the BoJ by Bernanke, Reinhart and Sack (2004) and Ueda (2012), and on those of the ECB. For the Eurozone, event studies identifying the impact of QE on long-term yields of asset classes purchased in the course of QE programs in the Eurozone were performed by Altavilla, Carboni and Motto (2015) and De Santis (2016), who both found a negative yield effect on asset classes purchased in the course of the APP. Additional to standard yield analyses, event based regressions may also measure the effectiveness of QE programs by observing inter-country yield spreads, taking German bonds as the risk free basis, are unique for the Eurozone. Such analyses include Falagiarda and Reitz (2015), Szczerbowicz (2015), and Eser and Schwaab (2016). While Eser and Schwaab (2016) found that the yield spread of periphery countries decreased significantly for the SMP, the former two proved this effect for both SMP and OMT.

While the main focus of most contributions to this area of research lies on the price and yield of a purchased domestic asset, there are papers which additionally analyze the spillover effect on other domestic asset classes as well. With regard to the ECB’s programs, Szczerbowicz (2015) finds that the CBPP caused a spillover effect on sovereign

[5] Disregarding second-round effects of QE the signaling channel and portfolio balance channel explain the upward sloping yield curve. QE underpins future expectations of low short-term yields and thus lowers long-term yields via the signaling channel. In combination with the assumption of market segmentation, QE decreases the risk premium on the purchased assets, which again can be explained by a signaling effect imposed by the central bank’s willingness to purchase an asset or by the lower market supply of bonds with a certain maturity resulting from the actual purchases. The latter explanation refers to the portfolio balance channel and also holds plausible for the spillover effects on substitute asset classes. In particular, investors tend to substitute bonds that are purchased by the central bank with bonds of a similar maturity and risk profile, e.g. corporate bonds or sovereign bonds issued by other countries, due to the existence of ”preferred habitats” for investors (cf. Modigliani and Sutch, 1967; Vayanos and Vila, 2009).

bond spreads, and converseley, SMP and OMT produced a similar effect on covered bond yields. Furthermore, international spillovers to long-term sovereign bond yields are found for US and UK programs by Glick and Leduc (2012) and Neely (2015). However, the identified spillover effects are relatively small compared to the intended effects on targeted assets, when applying an event study approach, because of a weaker signaling channel for non-targeted assets.

Further econometric studies As event studies are primarily suited for identifying the significance of an initial yield drop around the announcement date of an asset purchase program, further econometric studies are often applied in some of the aforementioned papers, in order to measure the long run impact of QE on bond rates. Generally, most econometric studies on QE find smaller yield effects than event studies, a result attributed to a strong initial announcement effect of purchase programs which then subsides over time, according to Martin and Milas (2012).
When used as an independent variable to explain changes in yields, QE can be included in the regression as either a stock or a flow variable. While Gagnon et al. (2010) and Joyce et al. (2011) base their estimates for yield changes on a stock variable, namely the volume of publicly held bonds, Meaning and Zhu (2011) regress the yield curve effects caused by QE on a flow variable, specifically the size of the regular asset purchases. As another distinctive feature to further structure econometric studies into two approaches, Martin and Milas (2012) refer to the periods of data used: Econometric models using the "historical data approach", as employed by Joyce et al. (2011) and Gagnon et al. (2010), assess the yield effect based on data from periods prior to the implementation of QE and additionally control for inflation and output movements, but only show the overall effect of various QE measures. In contrast to this, estimates using the "contemporary data approach", such as those conducted in this paper as well as that of Meaning and Zhu (2011), Glick and Leduc (2012), and D'Amico and King (2013) estimate the yield curve using daily or high-frequency data from the period in which QE programs took place. This practice allows the assessment of the effect of individual QE programs and considers the changed relationship between monetary policy and bond rates in times of financial distress.

3.2 Literature on Liquidity Support Measures

Literature on Liquidity Support Measures almost exclusively analyzes financial market effects, due to these measures being targeted at restoring the function of monetary transmission rather than at effecting inflation and growth directly (cf. Rieth and Gehrt, 2016). The estimation methods used to find evidence for the effectiveness of Liquidity Support Measures depend on the type and aims of the analyzed program, according to a survey by Borio and Zabai (2016). With regard to the central banks considered, the literature is limited to examination of programs by the ECB and the Fed, as the BoE did not introduce a special liquidity provision program for banks and the Stimulating Bank Lending Facility introduced by the BoJ in 2012 did not receive considerable attention. While the Fed eased refinancing conditions with the Term Auction Facility and the Term Securities Lending Facility, the programs of the ECB additionally extended the duration of long-term refinancing operations for the banking sector via LTROs and TLTROs. For the ECB's Liquidity Support Measures the literature consistently shows that additional liquidity provision achieved its goal. Using a time series regression on the implementation of LTROs at fixed rate tender with full allotment, Abbassi and Linzert (2012) find a sizeable reduction in Euribor rates of more than 100 bp, which can be explained by the increase in the aggregate amount of outstanding open market operations. Using a panel regression, Angelini, Nobili and Picillo (2011) detect a significant spread reduction of 10 to 15 basis points between secured and unsecured interbank loans for the announcement of LTROs after the Lehman shock. In line with these results, the event based regression Szczerbowicz (2015) states that the announcement and implementation of 3-year LTROs reduced Euribor-OIS spreads and consequently eased interbank lending significantly.

4 The Model

Recently, central banks have influenced the long-term interest rate on bonds by purchasing them in the bond market. In order to capture and depict the effects of QE theoretically, we therefore need a model which is capable of distinguishing the banking market from the bond market within the financial system.

In the banking market, banks are the suppliers of credit, while the borrowers represent the demand side. After credit provision, banks can choose between a mixture of central bank credit, deposits, equity and bonds to refinance their businesses. In this environment, the central bank is able to influence the banking sector's business by controlling the refinancing rate, making it a key determinant of banks' credit supply.

In the process of credit creation, banks create money, defined as the sum of cash and deposits, by making additional deposits. Money is differentiated from credit on its maturity. Money is a short-term concept on the liability side of the banking sector, whereas credit is recorded on the asset side of bank's balance sheet and refinanced with deposits, high-powered money, and longer-term refinancing instruments, such as bonds and equity. Money holders have the option of holding money either in liquid (cash and deposits) or illiquid (bonds) form. In buying bonds they implicitly provide money to counterparts who have a liquidity shortage.[6] Thus, when credit is granted in the bond market, money is merely changing hands.

In a financial system consisting of these two markets, borrowers have the option of demanding bank credit or demanding credit on the bond market. Beyond the interconnection of the two demand sides, the supply side of the banking market is linked to the bond market as well. Banks are able to refinance their businesses by issuing bonds in the bond market. Thus the cost of the banking sector depends on the interest rate for bonds.

The two most important insights of the model are the illustration of endogenous credit creation in the banking market (Palley, 1996; Disyatat, 2011; McLeay, Radia and Thomas, 2014; Werner, 2014) and the development of the bond market where the created money is redistributed.

The model is described as follows: We first derive the equilibrium interest rate and credit amount of the banking market. For refinancing purposes after granting credit, banks demand a fixed proportion of credit, determined by the credit multiplier relation, in high-powered money. In line with the equilibrium amount of credit, we derive the demand for high-powered money, which is abundantly met by the central bank. The equilibrium in the bond market is then derived similarly to the banking market equilibrium.

4.1 Banking Market

In order to derive the equilibrium for the banking market, we need to set up the respective supply and demand function. The market is in equilibrium when the supply of loans is equal to their demand.

[6] In the general literature, what we refer to as credit supply in the bond market is called bond demand.

Supply side Banks seek to maximize their profit. While for the banking and bond markets the revenue generated by granting credit depends on the interest rate spread between the interest rate for lending and that for borrowing (see for banks Spahn (2013); Friedman (2013, 2015)), the cost structure differs for the two markets, with the banking sector facing higher costs. The reasons for the higher costs of the banking sector are that banks face higher credit risk due to the higher risk profile of its borrowers, and lastly, specified capital requirements due to banks' higher risk profile. Keeping in mind that the profit function for one representative bank j is

$$\pi_B^j = i_B Cr_{B/NB}^j - i_D D^j - i_R(Cr_{CB/B}^j - R^j) - i_E E^j - i_{NB} B^j - O^j - V_B^j$$
$$\text{with } V_B^j = c_B (Cr_{B/NB}^j)^2,$$

the revenue is determined by credit granted to non-banks $Cr_{B/NB}$ at the price of credit i_B. The costs for the banking sector consist of the interest paid on deposits $i_D D$, on the net refinancing costs arising from central bank refinancing $i_R(Cr_{CB/B} - R)$, on equity refinancing $i_E E$, and on the funds borrowed from the bond market $i_{NB} B$, plus operational costs O and credit risk costs V_B, whereby it is assumed that the latter one will increase disproportionately with an increase in the credit volume (Fuhrmann, 1987).
Using the balance sheet identity according to the following balance sheet of a bank j (see Table 1), we can further derive $Cr_{CB/B}^j - R^j = Cr_{B/NB}^j - D^j - E^j - B^j$.

Table 1: Bank's balance sheet

Assets	Liabilities
Credit from Banks to Non-Banks $Cr_{B/NB}$	Equity E
	Bonds B
Reserves R	Deposits D
	Credit from Central Bank to Banks $Cr_{CB/B}$

In addition, we assume that a fixed proportion of credit granted to the non-banking sector $\eta^E = \frac{E^j}{Cr_{B/NB}^j}$ is held as equity according to the Basel Regulatory framework, and another proportion $\eta^B = \frac{B^j}{Cr_{B/NB}^j}$ is held as bonds to reduce interest rate risk (according to the Liquidity Coverage Ratio and Net Stable Funding Ratio declared in Basel III). This leads us to the following profit function (1). By maximizing (1) with respect to credit volume and solving for $Cr_{B/NB}^j$, we receive the credit supply for a single bank j, which leads us to the credit supply for the banking sector (2) by summing up for n homogeneous banks

$$\pi_B^j = (i_B - i_R) - \eta^E(i_E - i_R) - \eta^B(i_{NB} - i_R))Cr^j_{B/NB} - (i_D - i_R)D^j - O^j - c_B(Cr^j_{B/NB})^2 \quad (1)$$

$$Cr^S_{B/NB} = n\sum_{j=1}^{n} Cr^j_{B/NB} = n\left(\frac{(i_B - i_R) - \eta^E(i_E - i_R) - \eta^B(i_{NB} - i_R)}{2c_B}\right) \quad (2)$$

Demand Side The demand for credit stems from borrowers (sovereigns, non-financial corporations, and households) that are usually driven by the desire to invest and/or consume (Minsky et al., 1993). Because of high entrance costs and the lack of opportunity to trade small volumes of credit on the bond market, the two types of credit (bank credit and bonds) represent imperfect substitutes and the cost of credit is different for each market. Consequently, apart from the economy's income, the determinants of credit demand are the spread between the interest rate for credit in the respective market and the credit interest rate in the substitution market.

The amount of credit demanded depends negatively on the respective price, where the saturation amount a is dependent on income. Furthermore, the demand for bank loans depends positively on the price for the substitute loan type, with the effect, dependent on the substitution elasticity d, ranging from values of 0 (fully independent loans) to ∞ (perfect substitutes).[7] This yields the following demand function for bank loans:

$$Cr^D_B = a - bi_B + d(i_{NB} - i_B),$$
$$\text{with } a = \mu + \gamma Y.$$

Equilibrium Assuming $n = 1$ and solving the equilibrium condition for the banking market, we get

$$Cr^*_{B/NB} = \frac{a - (b+d)(i_R + \eta^E(i_E - i_R) + \eta^B(i_{NB} - i_R)}{1 + 2c_B(b+d)}$$

$$i^*_B = \frac{2c_B(a + di_{NB}) + (i_R + \eta^E(i_E - i_R) + \eta^B(i_{NB} - i_R))}{1 + 2c_B(b+d)}.$$

[7] The demand function with respect to the substitutability is derived by Singh and Vives (1984), Wied-Nebbeling (1997), and Ledvina and Sircar (2010).

Bank credit multiplier

In granting credit, banks simultaneously demand high-powered money in accordance with their liability structure. In order to derive the fraction of credit refinanced by high-powered money, we first need to define a bank credit multiplier m_B, which is the ratio of credit from banks to non-banks $Cr_{B/NB}$ to high-powered money H. As money consists of cash and deposits, high-powered money consists of cash and reserves, and $Cr_{B/NB}$ can be rewritten as $\frac{M}{1-\eta^E-\eta^B}$, thus the money multiplier can be redefined as follows:

$$m_B = \frac{Cr_{B/NB}}{H} = \left(\frac{1+h}{h+r}\right)\left(\frac{1}{1-\eta^E-\eta^B}\right),$$

where h represents the cash holding coefficients of the public and r the minimum reserve requirements , both of which are calculated as fractions of deposits.
Assuming $\eta^E+\eta^B<1$, $h>1$ and $r>1$, the bank credit multiplier is always greater than one.

Market for High-powered Money

The demand for high-powered money is determined by the volume of bank credit at a given refinancing rate. For the derivation of the linear high-powered money demand function, we need to obtain two points on the line. First, we use the equilibrium amount of credit granted ($Cr^*_{B/NB}$) to obtain the demanded volume of high-powered money (H^*) over the multiplier relation at the respective refinancing rate (i_{R_0}). Second, we determine the refinancing rate, at which the demand for high-powered money equals zero. By subtracting the spread for equity and bond refinancing from the prohibitive price of credit demand, we obtain this refinancing rate at which the volume of granted credit is equal to zero and consequently the demand for high-powered money is equal to zero as well. Analytically, the demand function for high-powered money is defined as:

$$H^D = e\frac{m_B}{Cr^*_{B/NB}}(e-1) - \frac{m_B}{Cr^*_{B/NB}}(e-i_{R_0})i_R$$
$$\text{with } e = (\frac{a+di_{NB}}{b+d}) - \eta^E(i_E-i_R) - \eta^B(i_{NB}-i_R).$$

As the central bank serves as a monopolistic supplier of high-powered money, it meets the full demand for high-powered money at the fixed price of the refinancing interest rate.

4.2 Bond Market

Once money is created in the process of bank lending, it can be used for buying bonds in the bond market.[8] The bond market functions similarly to the banking market. But in contrast to the banking market's role as the platform for money creation, the bond market is the platform for money circulation, where money is reused multiple times in order to create credit.

Supply side The revenues of the bond market suppliers are determined by the spread between the interest rate for long-term lending and the deposit rate because investors can only choose between either holding money as deposits or lending it. In contrast to the banking sector, non-banks do not face any cost due to capital requirements and their cost due to interest rate risk arise from opportunity costs of holding money as deposits. Consequently, the profit function of a non-bank k appears as follows:

$$\pi_{NB}^{k} = i_{NB}Cr_{NB}^{k} - i_{D}Cr_{NB}^{k} + (\frac{i_{NB}}{i_{t+1}^{e}} - \frac{i_{NB}}{i_{t}})Cr_{NB}^{k} - I^{k} - V_{NB}^{k},$$
$$\text{with } V_{NB}^{k} = c_{NB}(Cr_{NB}^{k})^{2}.$$

The revenue is determined by the revenues of the credit business $i_{NB}Cr_{NB}^{k}$. The costs stemming from granting credit are opportunity costs $i_{D}Cr_{NB}^{k}$, and those from the possibility of bond price losses, the so called *term premium*, are depicted in the term $(\frac{i_{NB}}{i_{t+1}^{e}} - \frac{i_{NB}}{i_{t}})Cr_{NB}^{k}$, according to which an increase in the expected interest rate i_{t+1}^{e} results in losses on bonds. Furthermore, information cost I^{k} and credit risk costs V_{NB}^{k} add to the costs faced by non-banks.

For the purpose of simplicity, we assume that $i_{D} = i_{R}$ and bonds are priced at par, yielding to $i_{NB} = i_{t}$. After maximizing the resulting profit function (3) with respect to credit volume and solving for Cr_{NB}^{k}, we receive the credit supply for a single non-bank k, which we convert to the credit supply for the non-banking sector by summing it up for m homogeneous non-banks (4):

$$\pi_{NB}^{k} = (i_{NB} - i_{D})Cr_{NB}^{k} + (\frac{i_{NB}}{i_{t+1}^{e}} - 1)Cr_{NB}^{k} - I^{k} - c_{NB}(Cr_{NB}^{k})^{2} \tag{3}$$

$$Cr_{NB}^{S} = m\sum_{k=1}^{m} Cr_{NB}^{k} = m\left(\frac{(i_{NB} - i_{R}) + (\frac{i_{NB}}{i_{t+1}^{e}} - 1)}{2c_{NB}}\right). \tag{4}$$

[8]We assume that for the derivation of the bond market no additional funds from the banking market flow into the bond market.

Demand Side Alongside sovereigns and non-financial corporations, banks are a major borrower in the bond market. Banks demand credit from the bond market in order to reduce the maturity mismatch in the balance sheet which results from their business model of lending long and borrowing short.

The determinants of credit demand in the bond market are the given economy's income, the cost of credit, and cost of credit of the substitute loan type, similar to those in the banking market. This yields the following demand function:

$$
\begin{aligned}
&Cr_{NB}^D = a - b i_{NB} + d(i_B - i_{NB}),\\
&\text{with } a = \mu + \gamma Y.
\end{aligned}
$$

Equilibrium After equating credit demand with supply, we obtain the equilibrium amount of credit and interest rate in the bond market:

$$
Cr_{NB}^* = \frac{(a + d i_B)\left(\frac{i_{t+1}^e + 1}{i_{t+1}^e}\right) - (b+d)(i_R + 1)}{\frac{i_{t+1}^e + 1}{i_{t+1}^e} + 2c_{NB}(b+d)}, \tag{5}
$$

$$
i_{NB}^* = \frac{2c_{NB}(a + d i_B) + i_R + 1}{\frac{i_{t+1}^e + 1}{i_{t+1}^e} + 2c_{NB}(b+d)}. \tag{6}
$$

Comparing the equilibria in the banking and the bond market, we detect asymmetry with regard to interest rates and credit volumes, which is a result of differing costs on the supply sides. However, bank loans and bonds coexist in equilibrium due to institutional factors.[9]

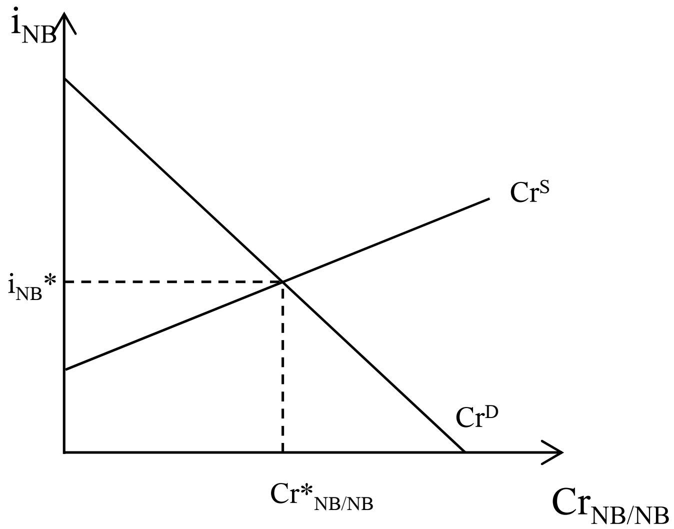
4.3 Graphical illustration

We graphically derive the bond market (see Figure 3). In contrast to the intercept of the loan supply in the banking market, which is determined by the refinancing rate, the cost of equity, and the cost of bonds, here the intercept is set by the refinancing rate and the interest rate expectations in the bond market. At the intersection of the - in comparison with the banking market - similarly shaped demand curve and the flatter supply curve[10] lie the equilibrium amount of non-bank credit $Cr_{NB/NB}^*$ and the interest rate i_{NB}^* in the bond market.

[9] Banks' money creation is a prerequisite for the functioning of the bond market.

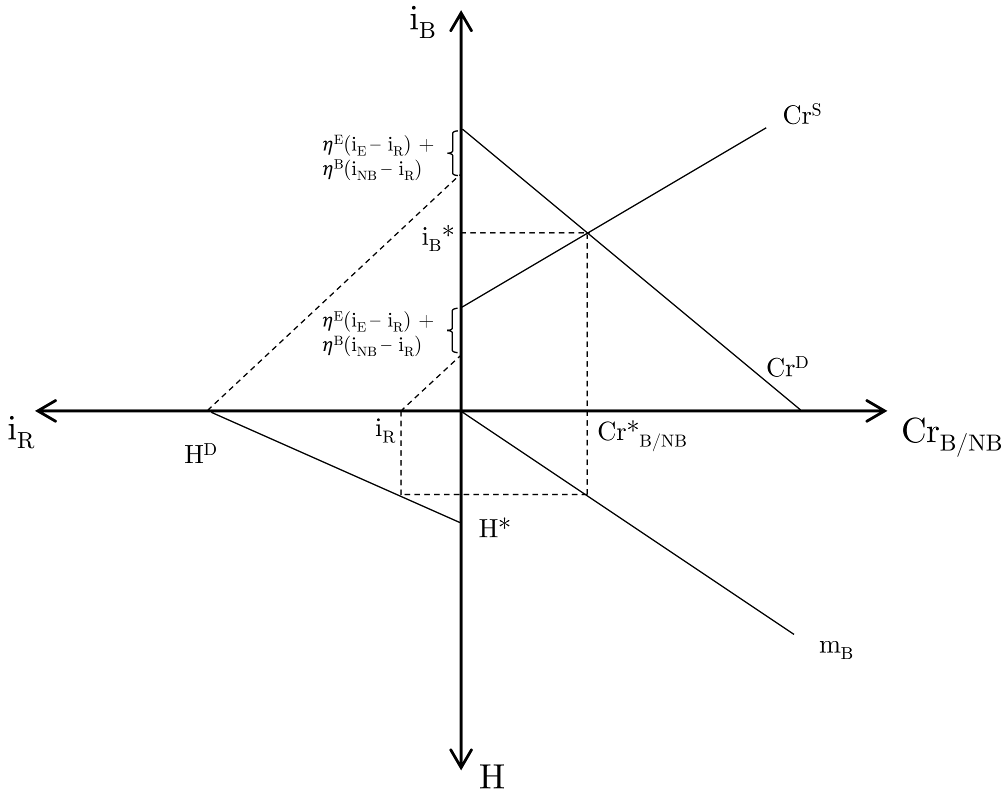
[10] Non-bank suppliers face lower costs than the banking sector.

Figure 3: Bond market



Regarding the market for bank credit (see Figure 4), the equilibrium amount of credit $Cr^*_{B/NB}$ and the interest rate i^*_B lie at the intersection of the negatively sloped loan demand curve and the positively sloped loan supply curve. By inserting the equilibrium amount of bank credit into the bank credit multiplier relation m_B with a slope of > 1, we obtain the demanded amount of high-powered money H (second quadrant). This demand for high-powered money H can be displayed on the negatively sloped demand function for high-powered money at the price of i_R (third quadrant).

Figure 4: Bank credit market



4.4 Unconventional monetary policy

In the following, we apply the unconventional monetary policy instruments (Liquidity Support Measures and QE) described in Chapter 3 to our model.

Liquidity Support Measures target the liability side of the banking sector's balance sheet. The introduction of several unconventional long-term refinancing operations by the ECB is meant to address refinancing problems that have repeatedly emerged in the interbank market and the bond market since the financial crisis. In the context of our model, these measures offer the banking system an opportunity to ameliorate the maturity mismatch by refinancing with lower-yield central bank loans instead of high-yield bonds. As a result, the proportion of borrowing conducted by the banking sector in the bond market, η^B , declines. This inference regarding the composition of the aggregated balance sheet of the banking sector in the Euro area is taken into account.

In contrast to this, the ECB's **QE** targets the asset side of the balance sheets of bank and non-bank suppliers of financing. In our theoretical model, QE exhibits three effects, which we identify in the following hypotheses:

Hypothesis 1: Decline in bond yields

First, we expect a decline in bond yields due to the intervention of the ECB on the bond market. The ECB acts as additional supplier of liquidity who is able to shift the supply curve to the right which ceteris paribus leads to a decrease in bond yields. However, assuming forward looking agents on the bond market, these agents already take the announcements of QE into account. Therefore, the announcements of QE by the ECB influence the behavior of the supply side in our model, which leads to the second and third hypothesis.

Hypothesis 2 : Decrease in credit risk

Since the quality of outstanding credit deteriorates in times of financial turmoil, the credit risk of these assets has increased. By acting as a lender of confidence, the ECB helps to *decrease the credit risk* of bonds issued by sovereigns (SMP,OMT and PSPP), banks (CBPP), and non-financial corporations (CSPP). This results in a decline in credit risk costs c_{NB}, which ceteris paribus implies a declining interest rate in the bond market i_{NB}. This effect is already obtained by the announcement of the ECB, because the agents on the bond market are forward looking such that they price this effect at the announcement day in.

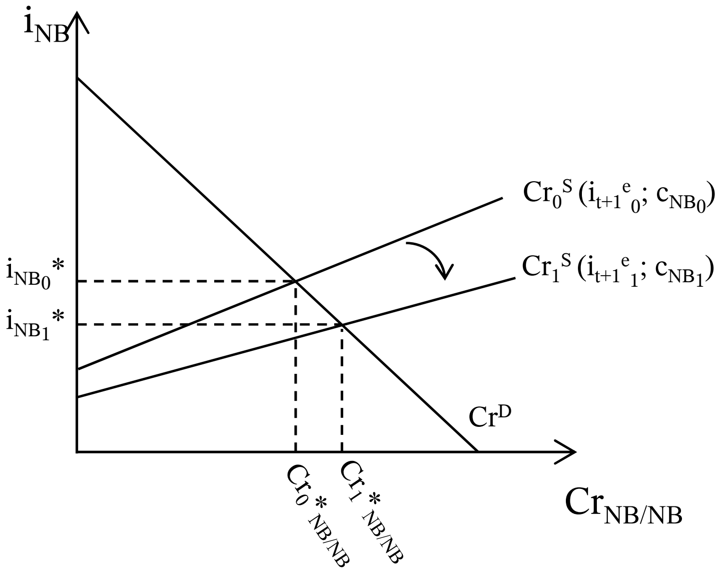
Hypothesis 3: Decrease in interest rate expectations

Additionally, the central bank's interventions influence the *expectations on long-term interest rates*, but the overall effect on interest rate expectations is ambiguous. If bond market participants expect an ongoing decline in long-term interest rates due to further QE programs, expected interest rates will decline as well. Alternatively, bondholders may expect a rise in long-term bond rates due to the fact that the central bank is not able to lower the bond rates further, as the interest rate has reached the zero lower bound. Hence, we conclude that QE programs lower expected interest rates in the short run, but increase the expected interest rate in the long run, thus diminishing the initial effect of QE.

Graphically, the latter two effects of QE depict that the credit supply curve of the non-banking sector rotates clockwise due to reduced credit risk costs ($c_{NB_0} \rightarrow c_{NB_1}$), and shifts parallel downward due to lower interest rate expectations in the short run ($i^e_{t+1_0} \rightarrow i^e_{t+1_1}$), leading to a decrease in the equilibrium interest rate in the bond market ($i^*_{NB_0} \rightarrow i^*_{NB_1}$).[11]

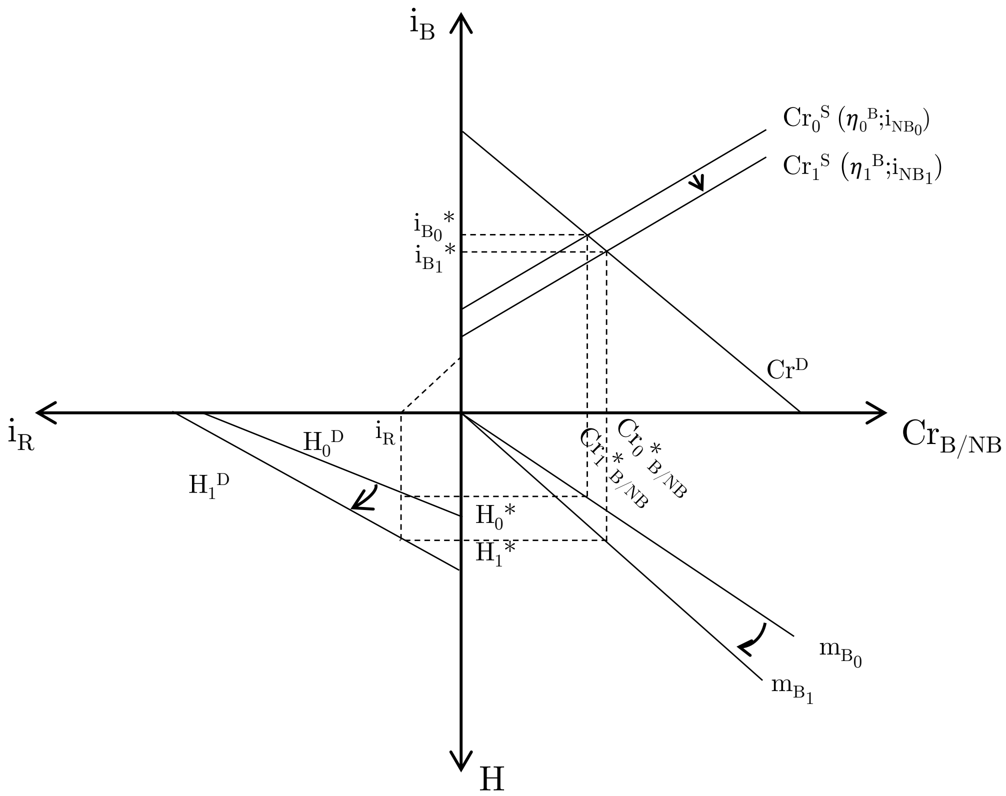
[11] We assume that at the new equilibrium $d(i_{B_0} - i_{NB_0}) = d(i_{B_1} - i_{NB_1})$ in order to abstract from demand side effects.

Figure 5: Unconventional monetary policy in the bond market



In the banking market, the lower interest rate on bonds (lower i_{NB}) and the reduction in the proportion of lending in the bond market (smaller η^B) lead to a parallel downward shift in the credit supply curve of the banking sector. This results in a lower interest rate and an increase in credit volume in the banking market. Due to the shift in bank's financing structure away from refinancing in the bond market and towards refinancing through the central bank, the bank credit multiplier declines. In particular, the demand for high-powered money increases because the banking system demands the long-term refinancing operations, which substitute for funds from the bond market.

Figure 6: Unconventional monetary policy in the bank credit market



5 Empirical Evidence

In the empirical section, we test the hypotheses derived in section 4.4 regarding the effects of QE on the bond market, and on the sovereign bond market in particular.[12] First, we test the hypothesis that the announcements of QE lead to a decline in bond yields (hypothesis 1), and second, we show that the yield-depressing effect of QE operates via two transmission channels, reducing both credit risk (hypothesis 2) and interest rate expectations (hypothesis 3). To test the hypothesis regarding bond yields, we use an error correction model, which provides the advantage of addressing both the long and the short run effects of our theoretical model. In a second step, we apply an event-based regression to isolate the effects of QE on credit risk and interest rate expectations.

A possible issue of empirical evaluations in the context of Quantitative Easing is that announcements of QE become endogenous as soon as the ECB reacts to market developments such as e.g. a rise in credit spreads. We deal with this issue by following Fratzscher, Lo Duca and Straub (2012) in assuming that the QE announcements were of the 'leaning-against-the-wind' variety.

[12]We do not consider the effects in the banking market which arose via liquidity support measures due to the non-availability of daily banking data.

5.1 Error Correction Model

The methodology of an error correction model was first applied by Sargan (1964) in the context of wage and price adjustments in the UK. Particularly within the framework of financial markets, many authors have estimated the long run money demand equation or interest rate adjustments using an error correction model (Mehra, 1993; Heffernan, 1997; Winker, 1999; Dreger and Wolters, 2015).

In the previous chapter, we derived the long run equilibrium for the bond market (see Equations 5 and 6). When estimating this equilibrium in levels, we face the problem of spurious regression results due to non-stationary time series (see Appendix, Tables 2-6). In order to solve this problem, we apply an error correction model. The error correction model assumes that a long run equilibrium relationship exists, but that in the short run we observe disturbances which lead to a divergence from the equilibrium.

Based on this distinction between long and short run effects, we now present the two parts of the error correction model (Sargan, 1964; Davidson, 1978).

First, we identify the long run relationship which is explained by our theoretical model. Using daily data for our estimation and excluding bank interest rates, due to their non-availability on a daily basis, we define

$$i_{NB_t} = \alpha_0 + \alpha_1 i_{R_t} + \alpha_2 log(Y_t) + \alpha_3 c_{NB_t} + \alpha_4 i_t^e + u_t, \tag{7}$$

consisting of the sovereign bond yield i_{NB_t}; the refinancing rate of banks i_{R_t}; the log of income in the current period $log(Y_t)$; the credit risk costs c_{NB_t}; the interest rate expectations for bonds of the same maturity as the respective government bond i_t^e; and the error term of the long run model u_t. All variables are specified as levels at time t except for income, which is indicated in log-levels.

Second, the short run relationship consists of all variables of the long run model in first differences. Accordingly, we obtain the following equation:

$$\begin{aligned} \Delta i_{NB_t} = \beta_0 + \beta_1 \sum_{n=0}^{N_1} \Delta i_{R_{t-n}} + \beta_2 \sum_{n=0}^{N_2} \Delta log(Y_{t-n}) + \beta_3 \sum_{n=0}^{N_3} \Delta c_{NB_{t-n}} \\ + \beta_4 \sum_{n=0}^{N_4} \Delta i_{t-n}^e + \beta_5 \sum_{n=0}^{N_5} \Delta i_{NB_{t-n}} + \beta_6 u_{t-1} + \epsilon_t. \end{aligned} \tag{8}$$

For the short run equation the variables are similar to those of the long run equation, but are defined in first differences with current and past lags for $N_i = \{1, 2, 3, ...\}$. u_{t-1} is the lagged disturbance term of the long run equation and ϵ_t is the short run error term. The coefficient of u_{t-1}, β_6 is the adjustment term of the short run equation. It states that the interest rate of government bonds deviating from the equilibrium converges towards it. For the validity of the error correction model to be maintained, the interest rate of government bonds must not diverge from the long run equilibrium, requiring u_t in the long run equation to be stationary and the coefficient of u_{t-1} in the short run equation to be negatively significant.

There are two possible ways to estimate the error correction model. The first is to estimate Equation 7 and plug the obtained error term into Equation 8, while the second procedure is to substitute the long run equation for u_{t-1} in the short run equation (Stock, 1987). Using the latter method, we obtain

$$\begin{aligned} \Delta i_{NB_t} = \theta_0 + \beta_1 \sum_{n=0}^{N_1} \Delta i_{R_t - n} + \beta_2 \sum_{n=0}^{N_2} \Delta log(Y_{t-n}) \\ + \beta_3 \sum_{n=0}^{N_3} \Delta c_{NB_{t-n}} + \beta_4 \sum_{n=0}^{N_4} \Delta i^e_{t-n} + \beta_5 \sum_{n=0}^{N_5} \Delta i_{NB_{t-n}} \\ + \theta_1 i_{NB_{t-1}} + \theta_2 i_{R_{t-1}} + \theta_3 log(Y_{t-1}) + \theta_4 c_{NB_{t-1}} + \theta_5 i^e_{t-1} + \epsilon_t, \end{aligned} \tag{9}$$

where the coefficients are defined as follows:

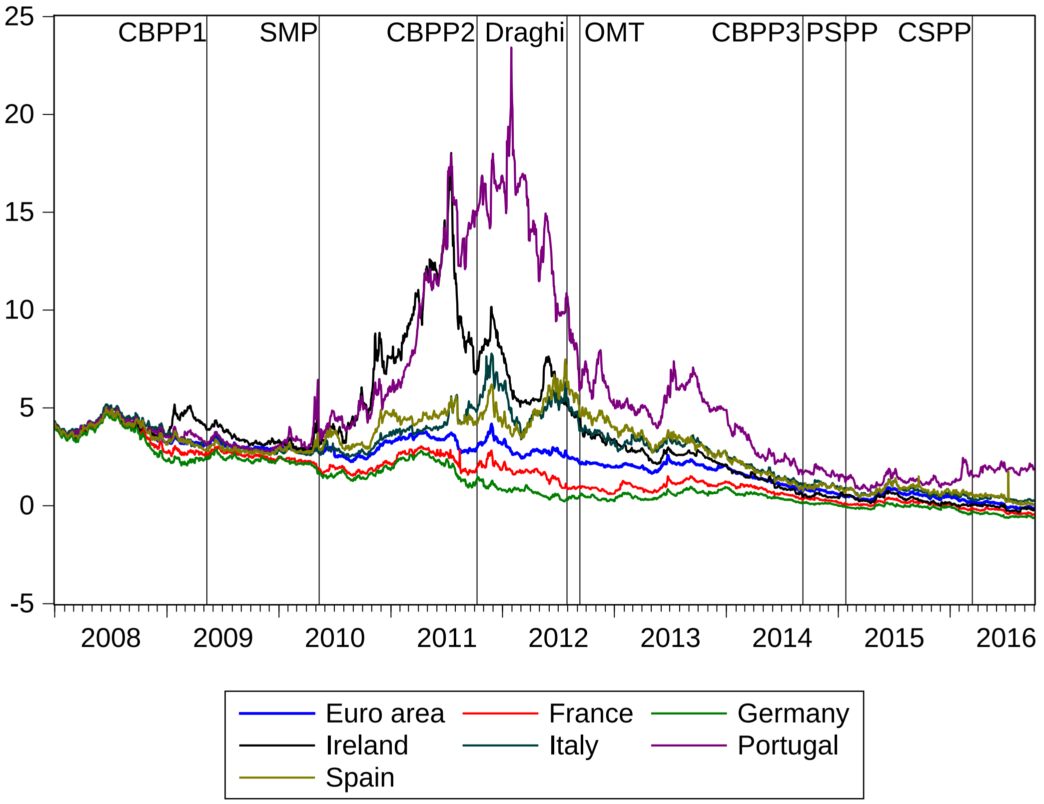
$$\begin{aligned} \theta_0 &= \beta_0 - \beta_6 \alpha_0; \\ \theta_1 &= \beta_6; \\ \theta_2 &= -\beta_6 \alpha_1; \\ \theta_3 &= -\beta_6 \alpha_2; \\ \theta_4 &= -\beta_6 \alpha_3; \\ \theta_5 &= -\beta_6 \alpha_4. \end{aligned}$$

The short run coefficients (β_1 to β_5) can be drawn directly from Equation 9. To obtain the long run effects (θ_1 to θ_5), in Equation 7 we recalculate the short run effects from Equation 9. For instance, to obtain the coefficient of the refinancing rate i_{R_t}, we divide θ_2 by $-\theta_1$, which is equal to $-\beta_6$.

Data

We use daily data from January 1st, 2008 through September 30th, 2016 in order to evaluate the effect of QE on 5-year sovereign bond yields of France, Germany, Ireland, Italy, Portugal, Spain, and the Euro area. We choose a maturity of five years due to the focus of the ECB's purchases on bonds of this maturity. Our dependent variable is the **sovereign bond yield** with a maturity of 5 years. The sovereign bond rates for each country are shown in Figure 7. Over the entire time horizon, the sovereign bond yields for Germany and France stayed the lowest, which underlines their status as a safe haven for investors in the Euro area. Furthermore, the yield on the Euro area benchmark bond graphically separates the countries which suffered from the sovereign debt crisis (Italy, Ireland, Portugal, and Spain) from the safe haven countries (Germany and France). Prior to the financial crisis the sovereign bond yields for all euro area countries coincided, except for small deviations which occurred in early 2009. Since the start of the euro area crisis in 2010, however, the sovereign bond rates of Spain, Portugal, Ireland, and Italy have begun to increase and to diverge from the government bond rates of France and Germany. Particularly Ireland

Figure 7: Sovereign bond yields



and Portugal, which have been financially supported by the European rescue programs, experienced very high interest rates from 2010 until the end of 2012. Since the end of 2012 the interest rates have declined and have reached in 2014 lower levels than before the euro area crisis. Additionally, Figure 7 also displays the announcement days of the ECB's QE programs. Evidently, the programs tailored to the sovereign bond market, i.e. SMP, Draghi's speech[13], OMT and PSPP, effected a decline in sovereign bond yields. The PSPP in particular contributed to the convergence of sovereign bond yields, whereas programs for banks (CBPP1-3) and non-financial corporations (CSPP) seem to have had no direct effect on interest rates of sovereign bonds.

As previously implied by our estimating equation, a key determinant for sovereign bond yield is the short-term refinancing rate. We use the **EONIA** as the short-term refinancing rate in the Euro area (see Fig. 8 (a)). In reaction to the bankruptcy of Lehman Brothers and the triggered spillover effect on banks in the Euro area, the ECB soon began to cut refinancing rates. In 2011, however, it increased the refinancing rate, which in turn led to an increase in government bond yields. With the dawn of the euro area crisis, characterized by a highly indebted fiscal sector, the ECB started to lower the refinancing rate until it reached negative levels in 2016. This had a direct impact on German sovereign bond yields, which closely follow the short-term refinancing rate.

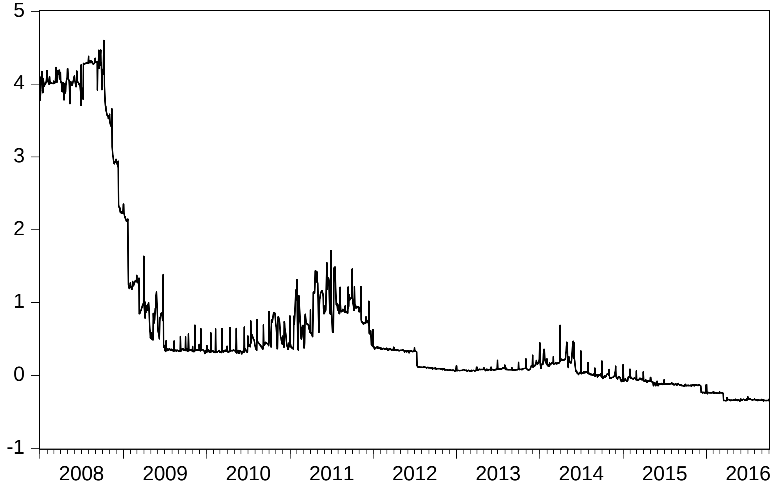
A quite similar development to that of sovereign bond yields can be observed for **credit risk spreads** (see Fig. 8 (b)). As measures of credit risk we use CDS spreads for each country and the bond spread for the Euro area benchmark bond [14] due to the non-availability of CDS spreads for the Euro area benchmark bond. CDS spreads are the price for credit insurance, and therefore show the perceived default risk for each borrower. The SMP, Draghi's speech and the OMT had a strong reducing effect on the CDS spreads of Ireland, Italy, Spain, and Portugal (see also Gerlach-Kristen, 2015). Since Draghi's speech, CDS spreads have decreased for all observed euro area countries.

[13]Draghi's speech can be seen as an implicit announcement of new QE programs initiated by the ECB.

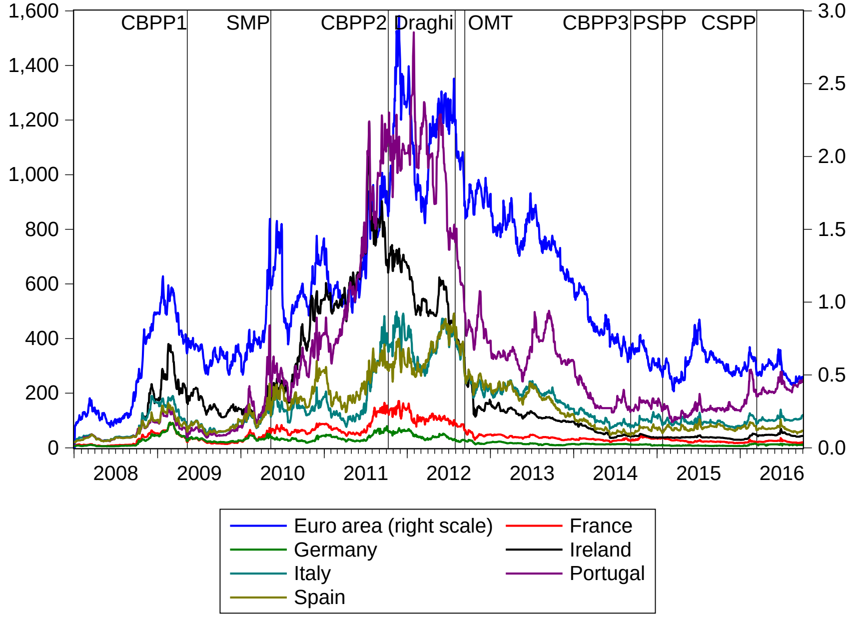
[14]Calculated as the difference between the yield on the Euro area benchmark bond and the German sovereign bond yield.

Figure 8: Independent variables

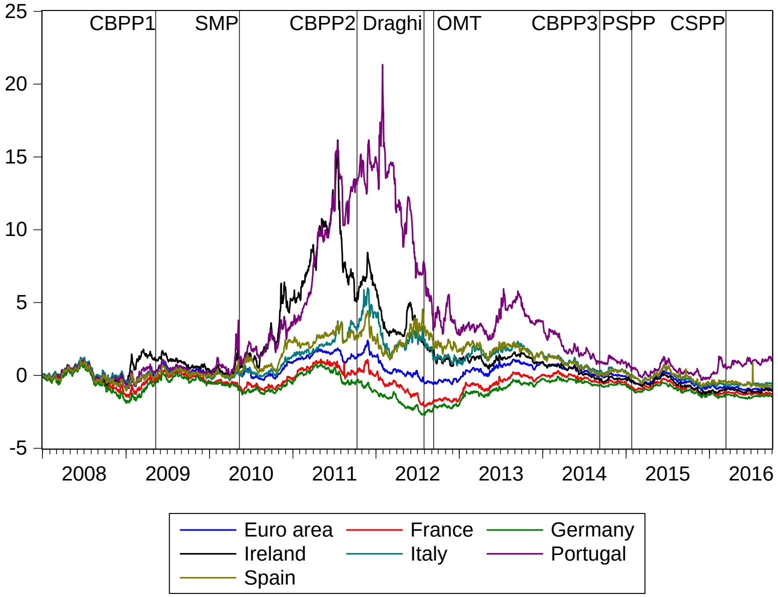
(a) EONIA in percent



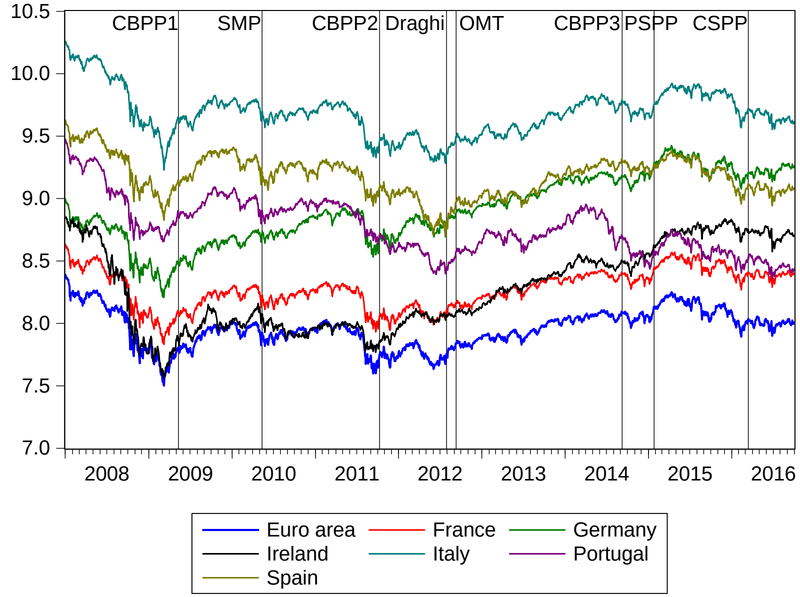
(b) Credit risk spread



(c) Term premium



(d) Equity indexes



In order to capture the effect of **interest rate expectations**, and thereby of expected capital losses on long-term bonds, we compute the risk/term premium for each country.[15] During the financial crisis investors have perceived the risk of capital losses as high (see Fig. 8 (c)). For Germany and France we even observe negative term premia. This indicates that investors prefer fixed interest over the entire investment horizon to fluctuating interest rates of shorter-term investments. As for the credit risk spreads, since Draghi's speech the term premium for each of the observed countries has converged to its pre-crisis level.
We use equity indexes as a proxy for income due to their availability on a daily basis. At the beginning of 2009, after the burst of the housing bubble, the **equity markets** were at their lowest levels during the observed period (see Fig. 8 (d)). In comparison with the other European equity markets depicted, the German and Portuguese equity indexes have exhibited better performance since 2009. Since the announcement of the PSPP, every observed index has increased.

Unit roots and Cointegration

In order to analyze each time series for the presence of unit roots, we use the augmented Dickey-Fuller test, the Phillips-Perron test, and the KPSS test.[16] For almost every time series the results indicate non-stationarity, with the exception of the equity indexes, for which the augmented Dickey-Fuller and the Phillips-Perron tests suggest stationarity but the KPSS test indicates non-stationarity. Consequently, we assume that each equity index has a unit root for our long run model.
When we regress a non-stationary variable on other non-stationary variables, cointegration of these variables should lead to stationary results. If this holds true, the linear combination of the variables is stationary as well. In order to test this assumption, we apply the Johansen cointegration method. For each country, the test results of the trace and maximum eigenvalue tests reveal at least one cointegrated equation at the 5 % significance level.

[15]Since risk averse lenders want to be compensated for the risk of capital losses throughout their holding period (Grkaynak and Wright, 2012), they demand term premia. These are calculated as the difference between the current bond rate with a maturity of 5 years and the mean of the EONIA forward rates of 1,2,3,4, and 5 years.

[16]for test results, see Appendix, Tables 2-6.

Regression setup

Building on the preliminary tests, we estimate Equation 9 by error correction model methodology.
To capture the effects of QE, we implement dummy variables for the announcement days of QE.
We assume that spillover effects on sovereign bond yields occur for the programs which are targeted toward banks and non-financial corporations as well. Thus we control for the announcements of CBPP 1-3 and the CSPP.
In accordance with Gerlach-Kristen (2015), we additionally control for the effects from bail-outs for Greece (May 5, 2010 and July 22, 2011), Portugal (May 16,2011), and Ireland (November 22, 2010) and from the default of Greece (February 21, 2012).
By including all relevant ECB purchase programs as dummy variables as well as the control variables in Equation 9, we receive the following equation:

$$\begin{aligned}\Delta i_{NB_t} &= \theta_0 + \theta_1 i_{NB_{t-1}} + \theta_2 i_{R_{t-1}} + \theta_3 log(Y_{t-1}) + \theta_4 c_{NB_{t-1}} + \theta_5 i^e_{t-1} \\ &+ \beta_1 \sum_{n=0}^{N_1} \Delta i_{R_t-n} + \beta_2 \sum_{n=0}^{N_2} \Delta log(Y_{t-n}) + \beta_3 \sum_{n=0}^{N_3} \Delta c_{NB_{t-n}} \\ &+ \beta_4 \sum_{n=0}^{N_4} \Delta i^e_{t-n} + \beta_5 \sum_{n=0}^{N_5} \Delta i_{NB_{t-n}} \\ &+ \beta_6 \text{CBPP} + \beta_7 \text{OMT} + \beta_8 \text{SMP} + \beta_9 \text{PSPP} + \beta_{10} \text{CSPP} + \beta_{11} \text{Draghi's speech} \\ &+ \beta_{12} \text{Greece} + \beta_{13} \text{GreeceDefault} + \beta_{14} \text{Portugal} + \beta_{15} \text{Ireland} + \epsilon_t.\end{aligned} \tag{10}$$

Regression results

We estimate our model for the full sample (see Table 8) and for three subsamples (see Tables 9, 10, and 11). The need for three subsamples, one sample each for before, during, and after the crisis, arises due to multiple breakpoint tests revealing that there are structural breakpoints in the time series around the days at the beginning (April 22, 2010) and end (August 1, 2012) of the crisis.
The results show that for the full sample the error correction model delivers significant results with a negative sign for the lagged independent variable, with the exception of Germany and the Euro area, where the results are non-significant. The error correction model is also appropriate for the subsamples of France, Ireland, Spain, and the Euro area.

For all other countries we observe at least one subsample that indicates that the error correction model is inappropriate.

For the full sample, the long run coefficients (lagged credit risk spread, lagged EONIA, lagged equity, and lagged term premium) for the euro area, France, Italy, Spain, and Portugal show the expected positive sign, but only some coefficients are significant. Interestingly, we find a significant negative effect of the EONIA on bond yields during the crisis, again with the exception of Germany and the Euro area. This effect indicates the fact that the control of the ECB were reduced due to the predominance of other factors (as e.g. uncertainty) during this period. The sign of the term premium indicates its significant positive influence on bond yields for most of the subsamples and for the full sample.

We are mainly interested in the effect of QE announcements on sovereign bond yields. When analyzing spillover effects on sovereign bond yields for the CBPP1 and CBPP2, we find an increase in bond rates for each country. This spillover effect on sovereign bonds, although they are not purchased directly, can be explained by portfolio substitution effects away from sovereign bonds towards bank bonds, or by increasing concerns about government rescue programs for banks. For the CBPP3 we detect the opposite effect, which can be attributed to a backward shift to sovereign bonds due to a healthier banking sector.

For the CSPP announcement, a significant negative sign can be observed for Germany, Spain, Portugal, Italy, Ireland, and the Euro area. As for the CBPP1, the CBPP2, and the CBPP3, the effect on sovereign bond yields stemming from the CSPP, which was designed to buy corporate bonds only, is merely an indirect effect occurring via asset substitution. The QE programs targeting the sovereign bond market present a different profile. The PSPP has a significant negative effect on the bond yields for each country. A surprising result is that bond yields for Germany and France increased on the announcement days of the SMP and the OMT. A plausible explanation for this result is that the ECB only acted as a lender of confidence for the countries most heavily affected by the euro area crisis. Another interpretation of the result is that lenders, who sold the bonds of periphery countries to the ECB, repurchased German and French bonds in the bond market. The equally surprising rise in the 5-year bond yields of Spain, Italy, and Ireland with the announcement of the OMT can in turn be explained by the fact that this program was designed to purchase bonds with a shorter maturity, ranging between 1 and 3 years. Furthermore, Draghi's speech had a negative significant effect on the bond yields of Germany, France, Italy, Portugal and the Euro area.

5.2 Event Based Regression

After capturing the total effect of QE on sovereign bond yields, we examine the two channels via which QE operates according to our theoretical model - credit risk and term premium channel.

As already stated in section 4.4, the credit risk of sovereign bond yields decreased with the ECB acting as a lender of confidence. Furthermore, the ECB's purchase programs affected the expectations of sovereign bond investors, reflected in a reduced term premium.

We perform an event based regression in order to capture the effect of these programs on the CDS spreads and the term premium (Szczerbowicz, 2015; Falagiarda and Reitz, 2015).

Regression setup

We apply a standard linear regression and estimate it using OLS with Newey-West standard errors, regressing the change in CDS spreads on its lagged change, the announcement day dummies for QE, and control variables:

$$\begin{aligned}\Delta \text{CDS}_t = {} & \alpha + \beta_1 \Delta \text{CDS}_{t-1} + \beta_2 \text{CBPP} + \beta_3 \text{OMT} + \beta_4 \text{SMP} + \beta_5 \text{PSPP} + \beta_6 \text{CSPP} \\ & + \beta_7 \text{Draghi's speech} + \beta_8 \text{EFSM/ESM} + \beta_9 \text{zero lower bound} \\ & + \beta_{10} \Delta \text{VStoxx}_t + \beta_{11} \Delta \text{TED}_t + \beta_{12} \Delta \text{EuroStoxx50}_t + \epsilon_t.\end{aligned}$$

We control for financial turmoil using the volatility stock index VStoxx and for market-wide business climate changes with a stock market index for the EU (Euro Stoxx 50) as well as with information on credit risk in the global economy drawn from the TED spread (see Falagiarda and Reitz, 2015). Additionally, we control for dates of news releases on the European rescue programs EFSM and ESM, and for the dates on which the ECB reached the zero lower bound (see Szczerbowicz, 2015).

Taking the same approach as that employed for CDS spreads, we estimate the effects of QE on the term premium (tp):

$$\begin{aligned}\Delta \text{tp}_t = {} & \alpha + \beta_1 \Delta \text{tp}_{t-1} + \beta_2 \text{CBPP} + \beta_3 \text{OMT} + \beta_4 \text{SMP} + \beta_5 \text{PSPP} + \beta_6 \text{CSPP} \\ & + \beta_7 \text{Draghi's speech} + \beta_8 \text{EFSM/ESM} + \beta_9 \text{zero lower bound} \\ & + \beta_{10} \Delta \text{VStoxx}_t + \beta_{11} \Delta \text{TED}_t + \beta_{12} \Delta \text{EuroStoxx50}_t + \epsilon_t.\end{aligned}$$

Regression results

With regard to CDS spreads (see Table 12), it is apparent that QE has lowered the CDS spreads of the entire sample via CBPP1 and CBPP3. The SMP, OMT, Draghi's speech and CSPP were especially effective in reducing the CDS spreads of the countries that were most severly hit by the euro crisis (Spain, Portugal, Italy, and Ireland). The results for the SMP and OMT correspond to the results of Szczerbowicz (2015), who analyzes the spread of Eurozone sovereign bonds compared to that of German sovereign bonds. Nevertheless, we find also a negative significant effect of Draghi's speech on CDS spreads of Germany and France. An increase in CDS spreads was triggered by the CBPP2 for Spain, Portugal, Italy, Ireland, and France, and by the PSPP for Ireland, Germany, and France.

Concerning the term premia, for the SMP we detect the expected decrease triggered by QE (see Table 13) for Spain, Portugal, Ireland, Germany, and the Euro area. For the OMT we observe a significant negative effect on Spain, Portugal, and Italy, whereas we identify a significant positive effect for Ireland, Germany, and France. Draghi's speech contributed to a decline in term premium for each country with the exception of Germany. With respect to the PSPP, we estimate a significant negative impact on the term premia of Portugal, and Italy. In contrast, with the introduction of the PSPP the term premium for France turned positive. The results for the CSPP indicate a positive impact on term premia for Portugal, Spain, Ireland, Germany, and France, whereas for Italy a negative effect was observed.

In summary, we primarily observe a decrease in CDS spreads as a result of the QE programs. Their effects on term premia across the Euro area are not as distinct, which can be explained by the fact that the effect of QE on term premia likely diminished over the course of each of the announcement days, and we cannot capture the effect without intraday data.

6 Conclusion

In this paper we present a intelligible theoretical model, which is applicable to evaluate the effects of QE and its mere announcement on the financial system, and from this model we derive and test hypotheses regarding the effect of QE on sovereign bonds yields and its channels of transmission.

Our model consists of a bank credit market, where money is created by banks, and a bond market, where money is redistributed among non-banks and banks. While our model is capable of depicting how central banks are able to influence both markets via the refinancing rate in conventional times, the introduction of the bond market into our model allows us to depict the effects of Quantitative Easing and its mere announcement. By purchasing bonds central banks are able exert an expansionary stimulus on the supply of money on the bond market. Therefore, the first hypothesis we derive from our model is that the central bank achieves a reduction of long-term bond yields by acting as an additional supplier of credit. When testing the announcement effects of several QE programs on 5-year sovereign bond yields, applying an error correction model, we indeed identify significant negative effects.

The second and third hypotheses derived from our model state two transmission channels of QE in decreasing long-term yields, one being the reduction of credit risk and the other being the reduction interest rate expectations. By applying an event based regression, we find a decrease in credit risk for most asset purchase program announcements and in terms of interest rate expectations, we are not able to identify a clear-cut effect on term premia, neither for the individual programs nor for the respective countries. In total, the empirical assessment supports the results of our model and legitimates its use for the understanding of the effects of QE on bond market interest rates and sovereign bond yields in particular.

Further research might successfully be directed at the effects our model implies on the interest rate for bank credit, caused by the decreased interest rate on the non-banking market, which we have shown to be an effect of QE in this paper. In addition, our model could be extended to include an equity market, to endogenously determine the interest rate on equity, which in turn determines the bank credit interest rate as a key factor of the banks' credit supply.

Appendix

Table 2: Data sources

Variable	Source
Sovereign bond yields	Datastream
CDS spreads	Datastream
Equity Index	Datastream
EONIA	Datastream
VSTOXX	Datastream
TED spread	Datastream
forward rates	Bloomberg

Table 3: Unit root tests for EONIA

Variable	Test	P-val.		Test-stat.	Critical-val.: 5%	Decision
EONIA	ADF (w. Trend)	0.443				not stat.
	ADF (wo. Trend)	0.052				not stat.
	Phillips-Perron (w. Trend)	0.395				not stat.
	Phillips-Perron (wo. Trend)	0.111				not stat.
	KPSS (w. Trend)			0.643	0.146	not stat.
	KPSS (wo. Trend)			3.155	0.463	not stat.

ADF = Augmented Dickey Fuller test.
KPSS = Kwiatkowski-Phillips-Schmidt-Shin test.
w.= with; wo.=without.

Table 4: Unit root tests for sovereign bond yields of each country

Country	Test	P-val.		Test-stat.	Critical-val.: 5%	Decision
Spain	ADF (w. Trend)	0.758				not stat.
	ADF (wo. Trend)	0.836				not stat.
	Phillips-Perron (w. Trend)	0.690				not stat.
	Phillips-Perron (wo. Trend)	0.787				not stat.
	KPSS (w. Trend)			1.055	0.146	not stat.
	KPSS (wo. Trend)			3.202	0.463	not stat.
France	ADF (w. Trend)	0.080				not stat.
	ADF (wo. Trend)	0.606				not stat.
	Phillips-Perron (w. Trend)	0.070				not stat.
	Phillips-Perron (wo. Trend)	0.572				not stat.
	KPSS (w. Trend)			0.187	0.146	not stat.
	KPSS (wo. Trend)			5.249	0.463	not stat.
Germany	ADF (w. Trend)	0.191				not stat.
	ADF (wo. Trend)	0.368				not stat.
	Phillips-Perron (w. Trend)	0.253				not stat.
	Phillips-Perron (wo. Trend)	0.387				not stat.
	KPSS (w. Trend)			0.479	0.146	not stat.
	KPSS (wo. Trend)			5.100	0.463	not stat.
Ireland	ADF (w. Trend)	0.488				not stat.
	ADF (wo. Trend)	0.525				not stat.
	Phillips-Perron (w. Trend)	0.630				not stat.
	Phillips-Perron (wo. Trend)	0.634				not stat.
	KPSS (w. Trend)			0.807	0.146	not stat.
	KPSS (wo. Trend)			2.582	0.463	not stat.
Italy	ADF (w. Trend)	0.663				not stat.
	ADF (wo. Trend)	0.766				not stat.
	Phillips-Perron (wi. Trend)	0.600				not stat.
	Phillips-Perron (wo. Trend)	0.718				not stat.
	KPSS (w. Trend)			0.919	0.146	not stat.
	KPSS (wo. Trend)			3.366	0.463	not stat.
Portugal	ADF (w. Trend)	0.789				not stat.
	ADF (wo. Trend)	0.580				not stat.
	Phillips-Perron (w. Trend)	0.822				not stat.
	Phillips-Perron (wo. Trend)	0.620				not stat.
	KPSS (w. Trend)			0.914	0.146	not stat.
	KPSS (wo. Trend)			1.255	0.463	not stat.
Euro area	ADF (w. Trend)	0.273				not stat.
	ADF (wo. Trend)	0.877				not stat.
	Phillips-Perron (w. Trend)	0.297				not stat.
	Phillips-Perron (wo. Trend)	0.859				not stat.
	KPSS (w. Trend)			0.644	0.146	not stat.
	KPSS (wo. Trend)			5.154	0.463	not stat.

ADF = Augmented Dickey Fuller test.
KPSS = Kwiatkowski-Phillips-Schmidt-Shin test.
w.= with; wo.=without.

Table 5: Unit root tests for credit risk spreads of each country

Country	Test	P-val.		Test-stat.	Critical-val.: 5%	Decision
Spain	ADF (wo. Trend)	0.332				not stat.
	Phillips-Perron (w. Trend)	0.665				not stat.
	Phillips-Perron (wo. Trend)	0.365				not stat.
	KPSS (w. Trend)			1.121	0.146	not stat.
	KPSS (wo. Trend)			1.145	0.463	not stat.
France	ADF (w. Trend)	0.493				not stat.
	ADF (wo. Trend)	0.269				not stat.
	Phillips-Perron (w. Trend)	0.431				not stat.
	Phillips-Perron (wo. Trend)	0.218				not stat.
	KPSS (w. Trend)			0.861	0.146	not stat.
	KPSS (wo. Trend)			1.021	0.463	not stat.
Germany	ADF (w. Trend)	0.094				not stat.
	ADF (wo. Trend)	0.102				not stat.
	Phillips-Perron (w. Trend)	0.102				not stat.
	Phillips-Perron (wo. Trend)	0.113				not stat.
	KPSS (w. Trend)			0.506	0.146	not stat.
	KPSS (wo. Trend)			0.810	0.463	not stat.
Ireland	ADF (w. Trend)	0.512				not stat.
	ADF (wo. Trend)	0.522				not stat.
	Phillips-Perron (w. Trend)	0.617				not stat.
	Phillips-Perron (wo. Trend)	0.598				not stat.
	KPSS (w. Trend)			0.776	0.146	not stat.
	KPSS (wo. Trend)			2.149	0.463	not stat.
Italy	ADF (w. Trend)	0.508				not stat.
	ADF (wo. Trend)	0.207				not stat.
	Phillips-Perron (w. Trend)	0.573				not stat.
	Phillips-Perron (wo. Trend)	0.249				not stat.
	KPSS (w. Trend)			0.923	0.146	not stat.
	KPSS (wo. Trend)			0.927	0.463	not stat.
Portugal	ADF (w. Trend)	0.795				not stat.
	ADF (wo. Trend)	0.471				not stat.
	Phillips-Perron (w. Trend)	0.777				not stat.
	Phillips-Perron (wo. Trend)	0.448				not stat.
	KPSS (w. Trend)			0.948	0.146	not stat.
	KPSS (wo. Trend)			0.945	0.463	not stat.
Euro area	ADF (w. Trend)	0.498				not stat.
	ADF (wo. Trend)	0.199				not stat.
	Phillips-Perron (w. Trend)	0.674				not stat.
	Phillips-Perron (wo. Trend)	0.332				not stat.
	KPSS (w. Trend)			1.180	0.146	not stat.
	KPSS (wo. Trend)			1.182	0.463	not stat.

ADF = Augmented Dickey Fuller test.
KPSS = Kwiatkowski-Phillips-Schmidt-Shin test.
w.= with; wo.=without.

Table 6: Unit root tests for term premium for each country

Country	Test	P-val.		Test-stat.	Critical-val.: 5%	Decision
Spain	ADF (w. Trend)	0.723				not stat.
	ADF (wo. Trend)	0.440				not stat.
	Phillips-Perron (w. Trend)	0.679				not stat.
	Phillips-Perron (wo. Trend)	0.387				not stat.
	KPSS (w. Trend)			1.232	0.146	not stat.
	KPSS (wo. Trend)			1.253	0.463	not stat.
France	ADF (w. Trend)	0.245				not stat.
	ADF (wo. Trend)	0.140				not stat.
	Phillips-Perron (w. Trend)	0.204				not stat.
	Phillips-Perron (wo. Trend)	0.092				not stat.
	KPSS (w. Trend)			0.152	0.146	not stat.
	KPSS (wo. Trend)			0.910	0.463	not stat.
Germany	ADF (w. Trend)	0.412				not stat.
	ADF (wo. Trend)	0.203				not stat.
	Phillips-Perron (w. Trend)	0.400				not stat.
	Phillips-Perron (wo. Trend)	0.196				not stat.
	KPSS (w. Trend)			0.199	0.146	not stat.
	KPSS (wo. Trend)			0.827	0.463	not stat.
Ireland	ADF (w. Trend)	0.535				not stat.
	ADF (wo. Trend)	0.346				not stat.
	Phillips-Perron (w. Trend)	0.644				not stat.
	Phillips-Perron (wo. Trend)	0.449				not stat.
	KPSS (w. Trend)			0.819	0.146	not stat.
	KPSS (wo. Trend)			1.252	0.463	not stat.
Italy	ADF (w. Trend)	0.662				not stat.
	ADF (wo. Trend)	0.390				not stat.
	Phillips-Perron (w. Trend)	0.614				not stat.
	Phillips-Perron (wo. Trend)	0.341				not stat.
	KPSS (w. Trend)			1.022	0.146	not stat.
	KPSS (wo. Trend)			1.069	0.463	not stat.
Portugal	ADF (w. Trend)	0.865				not stat.
	ADF (wo. Trend)	0.474				not stat.
	Phillips-Perron (w. Trend)	0.816				not stat.
	Phillips-Perron (wo. Trend)	0.517				not stat.
	KPSS (w. Trend)			0.940	0.146	not stat.
	KPSS (wo. Trend)			0.943	0.463	not stat.
Euro area	ADF (w. Trend)	0.452				not stat.
	ADF (wo. Trend)	0.333				not stat.
	Phillips-Perron (w. Trend)	0.408				not stat.
	Phillips-Perron (wo. Trend)	0.294				not stat.
	KPSS (w. Trend)			0.649	0.146	not stat.
	KPSS (wo. Trend)			1.180	0.463	not stat.

ADF = Augmented Dickey Fuller test.
KPSS = Kwiatkowski-Phillips-Schmidt-Shin test.
w.= with; wo.=without.

Table 7: Unit root test for logarithm of equity indexes of each country

Country	Test	P-val.		Test-stat.	Critical-val.: 5%	Decision
Spain	ADF (w. Trend)	0.092				not stat.
	ADF (wo. Trend)	0.017				stat.
	Phillips-Perron (w. Trend)	0.141				not stat.
	Phillips-Perron (wo. Trend)	0.028				stat.
	KPSS (w. Trend)			0.531	0.146	not stat.
	KPSS (wo. Trend)			0,.876	0.463	not stat.
France	ADF (w. Trend)	0.016				stat.
	ADF (wo. Trend)	0.041				stat.
	Phillips-Perron (w. Trend)	0.022				stat.
	Phillips-Perron (wo. Trend)	0.056				not stat.
	KPSS (w. Trend)			0.578	0.146	not stat.
	KPSS (wo. Trend)			1.817	0.463	not stat.
Germany	ADF (w. Trend)	0.009				stat.
	ADF (wo. Trend)	0.747				not stat.
	Phillips-Perron (w. Trend)	0.010				stat.
	Phillips-Perron (wo. Trend)	0.778				not stat.
	KPSS (w. Trend)			0.323	0.146	not stat.
	KPSS (wo. Trend)			4.835	0,463	not stat.
Ireland	ADF (w.Trend)	0.041				stat.
	ADF (wo. Trend)	0.565				not stat.
	Phillips-Perron (w. Trend)	0.033				stat.
	Phillips-Perron (wo. Trend)	0.588				not stat.
	KPSS (w. Trend)			0.858	0146	not stat.
	KPSS (wo. Trend)			3.008	0.463	not stat.
Italy	ADF (w. Trend)	0.105				not stat.
	ADF (wo. Trend)	0.018				stat.
	Phillips-Perron (w. Trend)	0.102				not stat.
	Phillips-Perron (wo. Trend)	0.017				stat.
	KPSS (w. Trend)			0.727	0.146	not stat.
	KPSS (wo. Trend)			0.761	0.463	not stat.
Portugal	ADF (w. Trend)	0.057				not stat.
	ADF (wo. Trend)	0.046				stat.
	Phillips-Perron (w. Trend)	0.063				not stat.
	Phillips-Perron (wo. Trend)	0.044				stat.
	KPSS (w. Trend)			0.247	0.146	not stat.
	KPSS (wo. Trend)			3.379	0.463	not stat.
Euro area	ADF (w. Trend)	0.021				stat.
	ADF (wo. Trend)	0.013				stat.
	Phillips-Perron (w. Trend)	0.029				stat.
	Phillips-Perron (wo. Trend)	0.020				stat.
	KPSS (w. Trend)			0.590	0.146	not stat.
	KPSS (wo. Trend)			1.048	0.463	not stat.

ADF = Augmented Dickey Fuller test.
KPSS = Kwiatkowski-Phillips-Schmidt-Shin test.
w.= with; wo.=without.

Table 8: Regressions for ECM- Full sample

	France	Germany	Ireland	Italy	Portugal	Spain	Euro area
Constant	-0.042	0.055	0.082	-0.150	-0.077	-0.225***	-0.081
Lagged variables							
Bond yield, ($i_{NB_{t-1}}$)	-0.003*	-0.004	-0.005**	-0.002*	-0.005***	-0.005***	-0.001
Credit risk spread [1], $c_{NB_{t-1}}$	3.62E-05	-4.18E-05	1.24E-05	2.43E-05	1.62E-05	8.17E-05***	0.002
EONIA, $i_{R_{t-1}}$	0.002	0.002	-0.001	0.001	0.003**	0.003**	0.001
log(Equity index), $log(Y_{t-1})$	0.005	-0.006	-0.009	0.015	0.009	0.024***	0.010
Term premium, i^e_{t-1}	0.003*	0.003	0.004**	0.003*	0.004***	0.002	0.001
First differences							
ΔCredit risk spread [1], Δc_{NB_t}	0.001	-0.002***	0.001***	0.001***	2.40E-04***	0.001***	0.342***
ΔEONIA, Δi_{R_t}	-0.013	-0.003	-0.017	-0.015	-0.018*	-0.017*	-0.006
Δlog(Equity index), $\Delta log(Y_t)$	0.262***	0.602***	-0.066	-0.035	-0.086	0.023***	0.550***
ΔTerm premium, Δi^e_t	0.660***	0.491***	0.919***	0.763***	0.950***	0.859***	0.461
QE announcements							
CBPP1	0.111***	0.058***	0.008**	0.032***	0.017***	0.022***	0.064***
CBPP2	0.053***	0.020***	0.043***	0.025***	0.030***	0.027***	0.041***
CBPP3	-0.051***	-0.049***	-0.030***	-0.038***	-0.028***	-0.029***	-0.056***
SMP	0.029***	0.035***	-0.069***	-0.009	-0.008	-0.046***	-0.059***
Draghi speech	-0.032***	-0.005**	-0.006	-0.106***	0.002	-0.005	-0.046***
OMT	0.005*	0.029***	0.011***	0.013	-0.015***	0.026***	0.010***
PSPP	-0.025***	-0.029***	-0.020***	-0.027***	-0.017***	-0.015***	-0.036***
CSPP	-0.015	0.030***	-0.066***	-0.048***	-0.074***	-0.070***	0.021***
Sovereign bail-out and default announcements							
Portugal	0.013***	0.005***	0.024***	0.002	-0.004	0.011***	0.007***
Ireland	-0.015***	-0.020***	-0.013***	-0.018***	-0.013***	-0.008***	-0.019***
Greece	-0.016***	-0.014	0.010	0.011***	0.001	-0.016	-0.015***
Greece Default	0.032***	0.029***	0.039***	0.016***	0.052***	0.015***	0.021***
Adjusted R^2	0.684	0.611	0.944	0.849	0.972	0.890	0.635
Number of observations	2283	2283	2082	2283	2253	2275	2283

Dependent variable: Δbond yield, i_{NB_t}.

[1] Credit risk spread for individual countries are measured by CDS spreads and for euro area benchmark bond by bond spread to 5-year Germany sovereign bond.

Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Two-tailed test.

Table 9: Regressions for ECM- pre-crisis

	France	Germany	Ireland	Italy	Portugal	Spain	Euro area
Constant	0.322	-0.034	0.338	0.417	0.496**	-0.050	0.106
Lagged variables							
Bond yield, ($i_{NB_{t-1}}$)	-0.076***	-0.060***	-0.050***	-0.071***	-0.073***	-0.066***	-0.064***
Credit risk spread [1], $c_{NB_{t-1}}$	2.36E-05	1.09E-04	2.09E-04**	1.02E-04	2.58E-04***	2.37E-04**	0.022
EONIA, $i_{R_{t-1}}$	0.028***	0.021***	0.014**	0.029***	0.025***	0.025***	0.020***
log(Equity index), $log(Y_{t-1})$	-0.017	0.020	-0.028	-0.025	-0.035	0.022	0.007
Term premium, i^e_{t-1}	0.033***	0.028**	0.020**	0.033***	0.035***	0.022*	0.021**
First differences							
ΔCredit risk spread [1], Δc_{NB_t}	-0.001	-0.002*	0.001***	0.001**	0.001***	-3.43E-04	0.119
ΔEONIA, Δi_{R_t}	-0.020	-0.001	-0.026	-0.020	-0.009	-0.024	-0.008
Δlog(Equity index), $\Delta log(Y_t)$	0.349****	0.598***	0.041	0.097	0.337**	0.047	0.545***
ΔTerm premium, Δi^e_t	0.503***	0.457***	0.624***	0.543***	0.551***	0.412***	0.461***
QE announcements							
CBPP1	0.141***	0.067***	0.014**	0.037***	0.017***	0.028***	0.060***
Adjusted R^2	0.633	0.626	0.713	0.606	0.650	0.670	0.564
Number of observations	418	418	400	418	418	418	418

Dependent variable: Δbond yield, i_{NB_t}.

[1] Credit risk spread for individual countries are measured by CDS spreads and for euro area benchmark bond by bond spread to 5-year Germany sovereign bond.

Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Two-tailed test.

Table 10: Regressions for ECM- during the crisis

	France	Germany	Ireland	Italy	Portugal	Spain	Euro area
Constant	-0.180	-0.140	-0.307	0.062	0.481**	0.020	-0.440**
Lagged variables							
bond yield, ($i_{NB_{t-1}}$)	-0.040***	-0.010	-0.023***	-0.011	-0.021**	-0.012*	-0.017**
Credit risk spread [1], $c_{NB_{t-1}}$	-3.92E-05	-5.03E-05	-5.10E-06	5.67E-08	-3.37E-05	2.88E-05	0.012**
EONIA, $i_{R_{t-1}}$	-0.014*	-0.003	-0.014*	-0.017**	-0.019***	-0.017**	-0.002
log(Equity index), $log(Y_{t-1})$	0.034	0.018	0.047*	-0.003	-0.046*	0.001	0.060**
Term premium, i^e_{t-1}	0.024***	0.005	0.022***	0.012*	0.022***	0.012*	0.007
First differences							
ΔCredit risk spread [1], Δc_{NB_t}	1.41E-04	-0.001**	0.001	3.8E-04**	7.98E-05	3.51E-04**	0.357***
ΔEONIA, Δi_{R_t}	-0.024**	-0.010	-0.021*	-0.026**	-0.029**	-0.026**	-0.011
Δlog(Equity index), $\Delta log(Y_t)$	0.264**	0.828***	0.092	0.067	0.120	0.068	0.804***
ΔTerm premium, Δi^e_t	0.847***	0.566***	0.976***	0.913***	0.982***	0.919***	0.514***
QE announcements							
CBPP2	0.037***	0.020***	0.041***	0.032***	0.036***	0.030***	0.034***
SMP	-0.001	0.019***	-0.031***	-0.017	-0.021	-0.036***	-0.057***
Draghi speech	-0.026***	-0.020***	-0.006	-0.053***	-0.018***	-0.021***	-0.048***
Sovereign bail-out and default announcements							
Portugal	0.009**	0.006**	0.007	0.005	0.002	0.012***	0.009***
Ireland	-0.007**	-0.017***	4.42E-04	-0.005*	4.53E-04	-0.001	-0.015***
Greece	-0.004	-0.011	0.005	0.009	0.005	-0.005	-0.012***
Greece Default	0.034***	0.027***	0.036***	0.030***	0.044***	0.026***	0.020***
Adjusted R^2	0.847	0.728	0.985	0.944	0.993	0.944	0.795
Number of observations	595	595	595	595	595	595	595

Dependent variable: Δbond yield, i_{NB_t}.

[1] Credit risk spread for individual countries are measured by CDS spreads and for euro area benchmark bond by bond spread to 5-year Germany sovereign bond.

Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Two-tailed test.

Table 11: Regressions for ECM- post-crisis

	France	Germany	Ireland	Italy	Portugal	Spain	Euro area
Constant	-0.002	0.105	0.070	-0.063	0.128	0.003	-0.153*
Lagged variables							
bond yield, $(i_{NB_{t-1}})$	-0.005*	-0.009**	-0.010***	-0.007*	-0.007	-0.017***	-0.018**
Credit risk spread [1], $c_{NB_{t-1}}$	6.25E-05	-1.86E-04	7.36E-06	4.26E-05	-1.72E-05	1.28E-04**	0.025***
EONIA, $i_{R_{t-1}}$	0.005	0.013	-0.016*	-0.003	0.002	0.006	0.007
log(Equity index), $log(Y_{t-1})$	3.29E-04	-0.011	-0.007	0.007	-0.014	4.31E-04	0.019*
Term premium, i^e_{t-1}	0.002*	0.002	0.012***	0.007**	0.008**	0.013***	0.007***
First differences							
ΔCredit risk spread [1], Δc_{NB_t}	2.40E-04	-0.001	0.001*	0.003***	0.001**	0.001	0.396***
ΔEONIA, Δi_{R_t}	-0.010	-0.017	-0.022	-0.009	-0.020	-0.033	-0.022
Δlog(Equity index), $\Delta log(Y_t)$	0.020*	0.242***	-0.236***	-0.234**	-0.248**	-0.052	0.0915
ΔTerm premium, Δi^e_t	0.435***	0.376***	0.651***	0.614***	0.882***	0.886***	0.358***
QE announcements							
CBPP3	-0.059***	-0.048***	-0.034***	-0.038***	-0.027***	-0.025***	-0.050***
OMT	0.015***	0.048***	0.021***	0.048***	-0.035***	0.038*	0.032***
PSPP	-0.023***	-0.025***	-0.023***	-0.027***	-0.018***	-0.014***	-0.030***
CSPP	-0.018***	0.042***	-0.029***	-0.025***	-0.071***	-0.072***	0.029***
Adjusted R^2	0.442	0.394	0.688	0.791	0.934	0.904	0.528
Number of observations	1087	1087	1087	1087	1087	1087	1087

Dependent variable: Δbond yield, i_{NB_t}.

[1] Credit risk spread for individual countries are measured by CDS spreads and for euro area benchmark bond by bond spread to 5-year Germany sovereign bond.

Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Two-tailed test.

Table 12: Event based regression for credit risk spreads

	France	Germany	Ireland	Italy	Portugal	Spain	Euro area
Constant	0.002	0.004	0.043	0.063	0.116	0.046	3.08E-04
ΔCredit risk spread [1], $\Delta c_{NB_{t-1}}$	0.477***	0.477***	0.477*	0.442***	0.465***	0.441***	0.442***
QE announcements							
CBPP1	-3.513***	-4.090***	-10.898***	-7.542***	-8.485***	-6.727***	-0.054***
CBPP2	2.168***	-3.555***	6.429***	5.316***	33.109***	4.540***	-0.036***
CBPP3	0.220	0.188***	1.003**	-0.545	-3.300***	-1.020***	0.006***
SMP	0.446	-0.662	-14.647**	-8.447	-70.503***	-8.376	-0.091***
Draghi speech	-0.892***	-0.856***	-4.325***	-7.259***	-8.521***	-7.959***	-0.040***
OMT	-1.787***	-0.117	-14.006***	-34.630***	-13.403***	-38.343***	-0.068***
PSPP	0.930***	0.919***	1.981***	-2.140***	-4.887***	0.023	-0.005***
CSPP	-0.893***	-0.121**	-2.187***	-6.318***	-3.174***	-5.300***	-0.041***
Control variables							
EFSM/ESM	-0.630	0.201	-7.412	-10.102*	-12.482***	-12.366**	-0.049
Zero lower bound	3.911***	-0.872***	-5.459***	7.629***	16.486***	9.394***	0.016***
ΔVSTOXX_t	0.096	0.064*	-0.013	0.132	0.347	0.219	0.001*
ΔTED_t	0.001	0.003	0.143**	-3.19E-05	0.008	-0.010	1.69E-05
$\Delta \text{EuroStoxx}_t$	-0.007***	-0.003**	-0.033***	-0.036***	-0.100***	-0.030***	-1.08E-04***
Adjusted R^2	0.528	0.560	0.469	0.572	0.522	0.577	0.541
Number of observations	2281	2281	2080	2281	2251	2281	2281

Dependent variable: ΔCredit risk spread [1], Δc_{NB_t}.

[1] Credit risk spread for individual countries are measured by CDS spreads and for euro area benchmark bond by bond spread to 5-year Germany sovereign bond.

Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Two-tailed test.

Table 13: Event based regression for term premia

	France	Germany	Ireland	Italy	Portugal	Spain	Euro area
Constant	-0.001	-0.001	9.35E-05	4.57E-05	0.001	-2.28E-04	-2.38E-04
ΔTerm premium, Δi^e_{t-1}	0.492***	0.468***	0.491***	0.489***	0.495***	0.494***	0.494***
QE announcements							
CBPP1	0.221***	0.128***	0.033***	0.032***	0.030***	0.102***	0.075***
CBPP2	0.058***	0.073***	0.021***	-0.034***	0.147***	0.035***	0.036***
CBPP3	-0.017***	-0.023***	-0.008	-0.022***	-0.004	0.032***	-0.015***
SMP	0.003	-0.054***	-0.346**	0.014	-0.299*	-0.143*	-0.127***
Draghi speech	-0.046***	0.005	-0.124***	-0.113***	-0.027**	-0.003*	-0.022***
OMT	0.042***	0.062***	0.044***	-0.196***	-0.524***	-0.134***	-0.005
PSPP	0.003	-0.008	-4.67E-04	-0.033***	-0.030***	-0.003	-0.011***
CSPP	0.041***	0.073***	0.037***	-0.010**	0.016***	0.089**	0.027***
Control variables							
EFSM/ESM	-0.005	-0.007	-0.187	-0.122	-0.136	-0.094	-0.037
Zero lower bound	-0.158***	-0.088***	-0.055***	-0.041***	-0.147***	0.151***	-0.083***
ΔVSTOXX$_t$	-0.003*	-0.001	0.002	0.002	0.005	-0.001	6.61E-04
ΔTED$_t$	3.23E-04	2.63E-04	0.001	1.67E-04	0.001	1.25E-04	2.83E-04
ΔEuroStoxx$_t$	3.09E-05	2.26E-04***	6.29E-05	-8.95E-05	1.17E-04	-6.61E-05	1.19E-04***
Adjusted R^2	0.520	0.540	0.483	0.528	0.483	0.497	0.504
Number of observations	2281	2281	2281	2281	2281	2281	2281

Dependent variable: ΔTerm Premium, Δi^e_t.
Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Two-tailed test.

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