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An empirical analysis of the ECB quantitative easing programme

by

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Abstract

On 22 January 2015, the ECB finally announced its expanded asset repurchase programme, better known as quantitative easing (ECB, 2015c). In this thesis, we are examining the effect of this announcement on sovereign bond yields in the Eurozone using the event study methodology and by time series forecasting (ARMA). We are particularly interested to see if there have been some abnormal variations (i.e. changes) in yields following the above-mentioned announcement. Furthermore, we also examine the announcement on 4 September 2014, during which the precursor programmes to QE were announced.

We found statistically and economically significant abnormal variations in yields for our event study across all investment grade euro area government bonds, i.e. yields have generally dropped following the announcements. The graphs we obtained using ARMA forecasting help illustrate this.

JEL codes: C58, E52, E58, G14, G17

Key words: European Central Bank, quantitative easing, event study, ARMA modelling, forecasting, sovereign bonds, yields

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Table of contents

Abstract	iii
Acknowledgements	iv
Table of contents	v
List of figures	vii
List of tables	vii
1. Introduction	1
1.1. Background.....	1
1.2. Research aim and objectives.....	3
1.3. Research limitations	3
1.4. Outline of the thesis	3
2. Theoretical perspectives on monetary policy and QE.....	5
2.1. ECB conventional monetary policy.....	5
2.2. ECB unconventional monetary policy.....	7
2.3. Details of the ECB QE programme	9
2.4. Theoretical frameworks for the effects of QE	11
3. Event study	13
3.1. Econometric methodology.....	13
3.2. Motivation of input choices	16
3.2.1. Country selection.....	16
3.2.2. Data selection	16
3.2.3. Event window.....	17
3.3. Event study results.....	18
3.3.1. Results for AAA-rated euro area yields	18
3.3.2. Results for selected euro area countries	19
3.3.3. Results for selected non-euro area countries	21
4. Forecasting bond yields with ARMA modelling	23

4.1. Theory on univariate time series modelling	23
4.1.1. Moving average process (MA).....	23
4.1.2. Autoregressive process (AR)	24
4.1.3. ARMA process	25
4.1.4. ARMA modelling.....	25
4.1.5. Forecasting with ARMA	26
4.2. Estimating our model.....	28
4.2.1. Data and announcement specifications	28
4.2.2. Results and interpretation.....	30
5. Conclusion.....	32
Bibliography.....	33
Appendix	35
A1. Acronyms and definitions.....	35
A2. Event timeline.....	35
A3. A quick review of bond valuation	36
A3.1. Zero-coupon bonds.....	36
A3.2. Coupon bonds.....	37
A3.3. The behaviour of bond prices.....	38
A4. Akaike´s information criteria.....	40
A4.1. Germany	40
A4.2. Italy.....	40
A4.3. Spain.....	41
A5. Forecast of yields using an ARMA model	42
A5.1. Germany	42
A5.2. Italy.....	44
A5.3. Spain.....	46
A6. Miscellaneous graphs	47

List of figures

Figure 1: Development of major European equity indices (base 100 at $t_0 = 2014-01-01$)	2
Figure 2: Euro area AAA-rated government bond yields ($t_0 = 2014-01-02$).....	2
Figure 3: ECB key interest rates from 1999-01 to 2014-09	6
Figure 4: Distribution of significant results for the euro area	20
Figure 5: General example of a forecasting time line	26
Figure 6: Forecasting time line for our model.....	29
Figure 7: Example of a graph forecasted with ARMA (Italy 10Y).....	30
Figure 8: Forecast Germany 3Y Yield	42
Figure 9: Forecast Germany 5Y Yield	42
Figure 10: Forecast Germany 10Y Yield	43
Figure 11: Forecast Italy 3Y Yield.....	44
Figure 12: Forecast Italy 5Y Yield.....	44
Figure 13: Forecast Italy 10Y Yield.....	45
Figure 14: Forecast Spain 3Y Yield.....	46
Figure 15: Forecast Spain 5Y Yield.....	46
Figure 16: Forecast Spain 10Y Yield	47
Figure 17: Euro area countries by GDP size (market prices).....	47

List of tables

Table 1: Summary of ECB QE programme	10
Table 2: Event study results for AAA-rate euro area countries	18
Table 3: Event study results for euro area countries	19
Table 4: Event study results for non-euro area countries	21
Table 5: Best model fit according to AIC	29
Table 6: Bond properties	38

1. Introduction

1.1. Background

“By adopting unconventional measures of monetary easing, central banks seek mainly to stimulate growth, bring down joblessness to reasonable levels and support their banking systems by pumping more money into the economy to boost spending” (Hausken & Ncube, 2013).

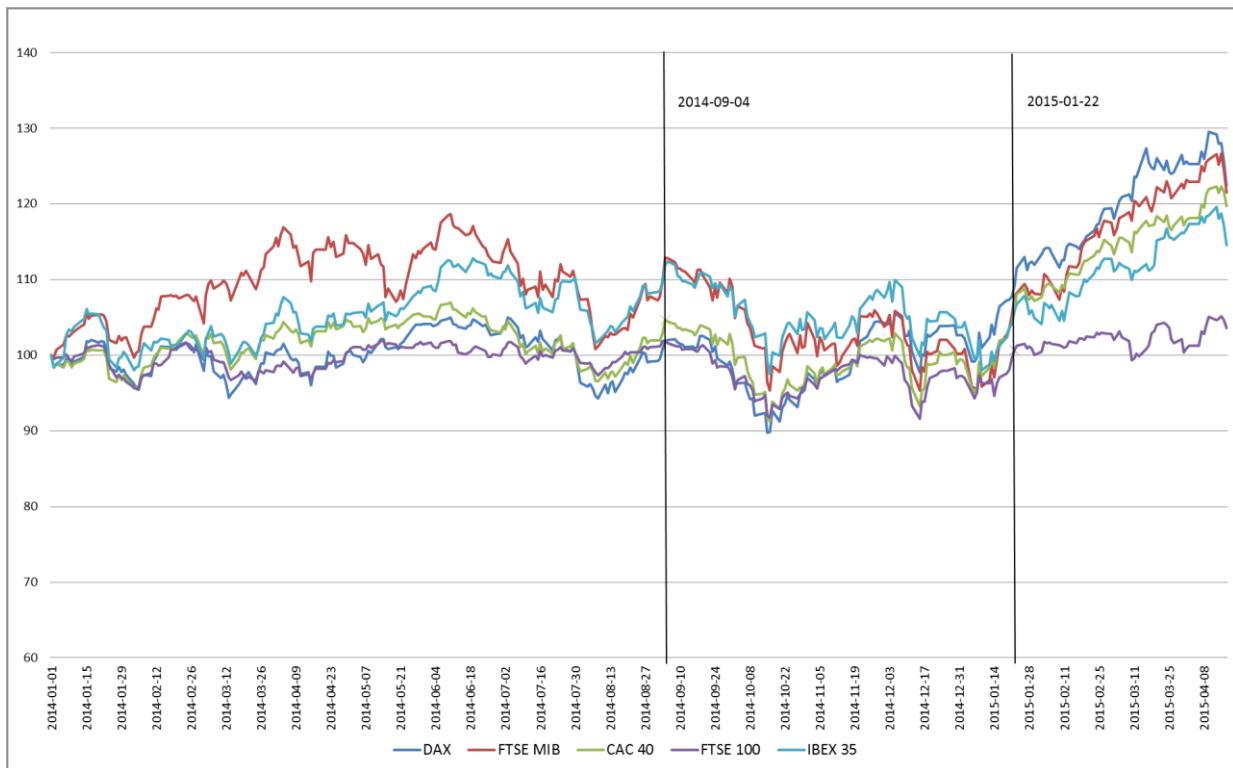
Since Europe has not fully recovered from the sovereign debt crisis, with sluggish economic growth figures and low inflation levels in the Eurozone, the ECB has decided to embark on unconventional monetary policies. As we shall discuss later in more detail, the conventional monetary tools of the ECB are the control over the key interest rates, at which they provide money for financial institutions in the Eurozone. However, now the ECB has chosen to start a QE programme, like we already have seen in Japan, the US and the UK. It is a controversial method that is relatively new and on which there has been conducted significantly less research than on other macroeconomic fields.

Empirical research has shown that the Fed’s QE programme has been effective in lowering interest rates, particularly for medium and longer term debt securities. On average, a drop in the yield of 140 basis points for treasuries with maturities over 5 years has been observed and of 60 basis points for shorter maturities (Hausken & Ncube, 2013, p. 37). Thus, we expect to observe a similar phenomenon in the Eurozone. Furthermore, the portfolio rebalancing channel assumes that since QE lowers interest rates on government bonds, investors will lean more towards buying shares, which will offer superior returns, since they are riskier. Intuitively, this makes sense, since if risk-free assets generate virtually zero return; the only way to generate return for an investor is to hold risky assets.

As one can see from Figure 1 below, equity indices from the euro area have increased dramatically following the ECB’s announcement of its big Public Sector Purchase Programme (PSPP) on 22 January 2015. When it comes to sovereign bond yields, those have been decreasing more or less steadily since the beginning of 2014 (and even before) as one can see from Figure 2 below.¹ One contributing factor to this is the fact that safe bonds have had increased demand, which resulted in higher prices and thus lower yields (to maturity).

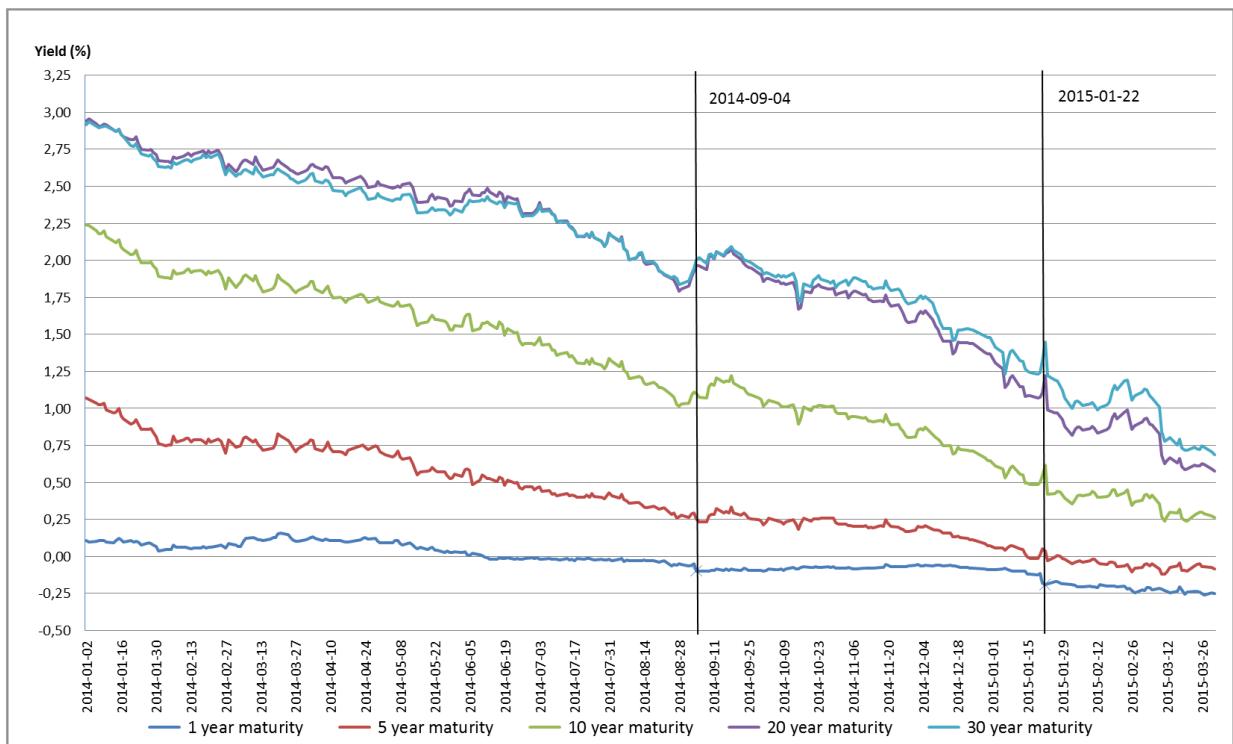
¹ N.B.: We are talking about AAA-rated bonds here that are considered risk-free

Figure 1: Development of major European equity indices (base 100 at $t_0 = 2014-01-01$)



Source: Datastream

Figure 2: Euro area AAA-rated government bond yields ($t_0 = 2014-01-02$)



Source: (ECB, 2015a)

1.2. Research aim and objectives

The ECB QE programme is a relatively new phenomenon, and few, if any, studies have been published about it at the time writing. Thus, we have decided to empirically analyse the announcement of the programme, especially with regard to its effect on asset prices. Instead of investigating equity prices, we have decided to study the impact of the announcement on government bond yields. This is because the impact on sovereign bonds is a direct one, since they are being purchased directly by the ECB in secondary markets. For equities, the impact is only an indirect one, as those are not being purchased by the ECB and thus the impact arises from investors altering their portfolios following the QE announcement.

Our aim is to show that there has been an immediate market reaction following the announcement(s) of the QE programme. This reaction should be illustrated by asset price changes. More specifically, and in accordance with QE theory that shall be discussed in chapter 2, we are expecting bond yields to drop as a result of the announcement. This drop in yields will then be quantified with an event study that should return the negative change in yields. This phenomenon will also be illustrated with ARMA modelling (see chapter 4), where we expect to find that yields forecasted with the pre-event time series data will be above the actual yield observed following the announcement on 22 January 2015.

1.3. Research limitations

The only data we can use at this moment in time are bond yields. These are available in daily frequency and are thus suitable for an event study. Furthermore, to our knowledge, there do not exist any event studies yet on the announcement of the QE programme of the ECB. Thus, we cannot compare our results to those of other researchers. However, there are studies on the previous QE programmes of the Bank of Japan, the Fed in the US and the Bank of England.

1.4. Outline of the thesis

In the following, we shall give a short outline of the structure of this paper. The first part (chapter 2) describes the ECB's conventional and unconventional monetary policies. Then, we will describe in more detail the technical aspects of the recently announced QE programme. To conclude chapter 2, we will outline a theoretical framework explaining the mechanisms through which QE works, and which effects we will be expecting as a result of our empirical analysis.

In the core part (chapters 3 and 4), we will present the empirical research methods that we are going to use. Chapter 3 is focused on the event study. First, we will illustrate the econometric techniques applied. Then, we will present and discuss the results obtained from this model. Chapter 4 will first cover theoretical aspects of univariate time series modelling and forecasting in section 4.1. Subsequently, we will present the methodology used to obtain our models in section 4.2. We will also present and discuss our results in said section.

Finally, in chapter 5, we will draw a conclusion on this paper.

2. Theoretical perspectives on monetary policy and QE

2.1. ECB conventional monetary policy

Before implementing our models, we shall briefly discuss what QE consists of, what its motivations are, how it is implemented and what its expected effects are. First, we should however discuss how monetary policy decisions in the Eurozone are made. Those decisions are made by the Eurosystem, which consists of the ECB and the 19 national central banks of this monetary zone. The role of the Eurosystem can be compared to the role of the Federal Reserve in the United States. Decisions are made by a vote of the ECB governing council, which consists of the ECB executive board that has six members, including the ECB president, currently Mario Draghi, and the heads of the national central bank in the Eurozone (Krugman, et al., 2015, pp. 674-675).

By the power of the treaty of Maastricht, the ECB has the mandate to pursue price stability. According to its own website, the ECB has the aim to keep inflation rates below, but close to 2% over the medium term (ECB, 2015b). To assess inflation levels, it uses the Harmonised Index of Consumer Prices (HICP). Like any central bank, the ECB's main policy tool is the adjustment of the key interest rates at which commercial banks can borrow or deposit money with the Eurosystem. They are decided upon when the governing council meets, which is twice a month. These key interest rates are (ECB, 2015b):

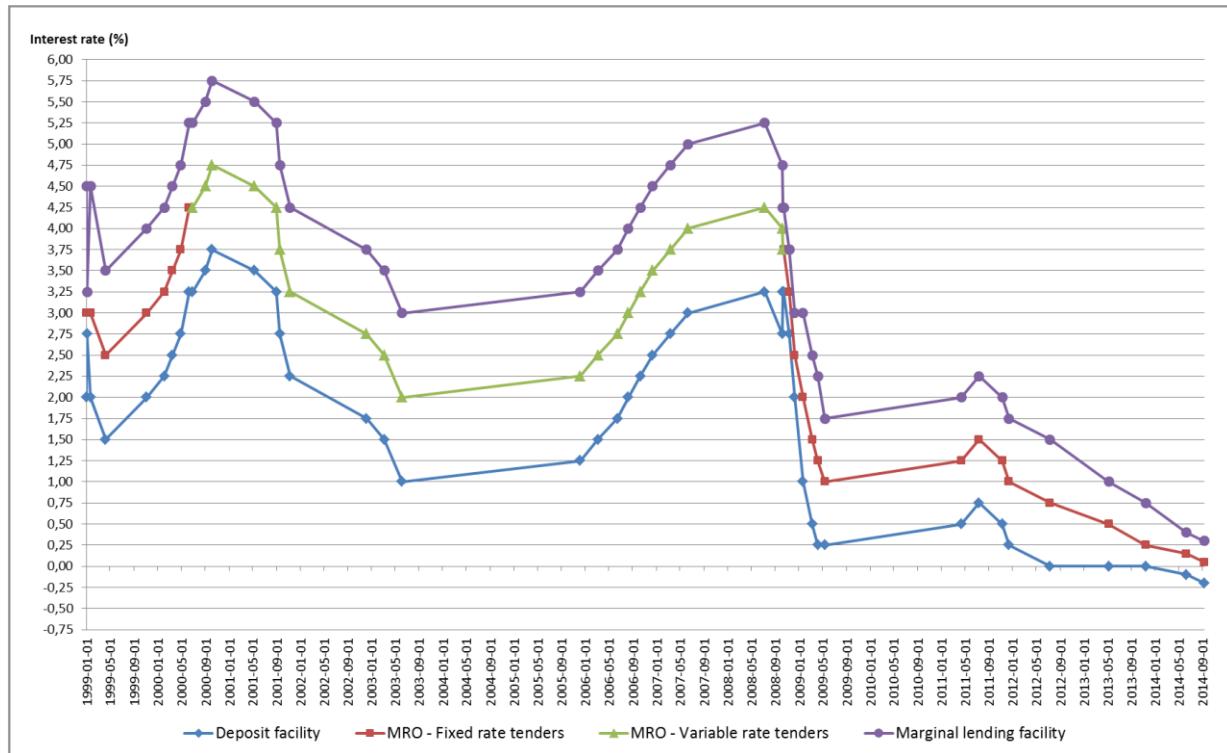
- The interest rate on **main refinancing operations** (MROs): one-week liquidity-providing operations (short term). MROs are conducted by weekly tenders (fixed or variable rate)².
- The rate of the **deposit facility**: the interest banks receive for overnight deposits.
- The rate of the **marginal lending facility**: the interest banks have to pay for overnight credits.

These three key interest rates influence the general level of interest rates in the Eurozone. During the recent financial and sovereign debt crises, we have seen these interest rates being lowered over and over, until they have reached zero or even slightly negative values.

² Fixed rate tenders have the interest rates fixed by the ECB. Banks only communicate the amount of money needed. For a variable rate tender, the banks communicate both amounts needed and the interest they are willing to pay. Thus banks can influence the interest level for variable rate tenders.

This is illustrated in figure 3 below, which maps the ECB key interest rates from its origin in 1999 until now.³

Figure 3: ECB key interest rates from 1999-01 to 2014-09



Source: (ECB, 2015d)

As one can see from the figure above, key interest rates were relatively high during the first years of the ECB's and the euro's existence. They then lowered, but started to climb up again in the advent of the financial crisis of 2007-2009. As a response to the crisis, the ECB decided to cut interest rates to a historic low in 2009. They have then slightly increased again, but have been lowered further with the outbreak of the European sovereign debt crisis. Thus, since 2012, key interest rates have been steadily declining until reaching their lowest point on 10 September 2014. At that point, the deposit facility had become negative, with -0.20%, meaning that financial institutions had to effectively pay the ECB for the privilege of parking their excess liquidity there. The other two key interest rates, the MRO and the marginal lending facility had reached the low of 0.05% and 0.30%, respectively. One must note that key interest rates have not changed since 10 September 2014. This change was announced on 4 September 2014, which as you will see coincides with our first announcement date for the ABSPP and the CBPP3.

³ N.B.: No key interest rate changes have been made after 2014-09-10 (effective date of last change). The announcement day for this change was on 2014-09-04 (the date of the ABSPP and CBPP3 announcement).

The graph illustrates that there was not much room left for the ECB to conduct conventional monetary policy, since the lower bound for key interest rates had been reached. However, it would have still been possible to further lower the key interest rates, meaning making increasingly negative the deposit facility and setting to zero both the MRO and the marginal lending facility.⁴ But this, as mentioned before, is not a lot of room to play with. With these conventional policies being exhausted, the ECB can result to unconventional methods, among which is QE. In the following section, we will outline some examples of ECB unconventional monetary policy, other than QE, to which we will come back later.

2.2. ECB unconventional monetary policy

Since the outbreak of the financial crisis in 2008, the ECB has not only responded by adjusting (downwards) key interest rates, as we have illustrated before. It has also embarked on unconventional (or non-standard) monetary policies, of which we will present a few in this chapter. The first example of those policies is Long Term Refinancing Operations (LTROs).

LTROs can be split into two different subgroups (Fratzscher, et al., 2014):

- **Supplementary Long Term Refinancing Operations (SLTROs):** maturities between six months to one year
- **“Very” Long Term Refinancing Operations (VLTROs):** maturity of three years

These are collateralized loans with longer maturities than the usual MROs. The ECB has conducted 20 SLTROs with six-month maturities between 2008 and 2011. The largest of those has been €50 billion. In May 2009, the ECB started the first 12-month SLTRO and subsequently conducted four of them until December 2011. The largest 12-month SLTRO auction has been as big as €442 billion. These SLTROs have increased the ECB balance sheet. It peaked at €160 billion in March 2009 for the six-month operations and peaked at €660 billion in early 2010 for the 12-month operations. When the sovereign debt crisis intensified in late 2011, the ECB announced two VLTROs, both with three-year maturities. During both VLTROs, €1019 billion were allotted in total (Fratzscher, et al., 2014).

Another example of a non-standard monetary policy is the Securities Markets Programme (SMP). It was announced on 10 May 2010 and consisted of direct purchases (in the secondary markets) of sovereign bonds of countries experiencing financial distress. Bonds were to be held

⁴ N.B.: The MRO and the marginal lending facility cannot become negative since this would mean the ECB would pay financial institutions for borrowing its money.

until maturity and purchases were initially limited to government bonds most affected by the crisis, i.e. Greek, Portuguese and Irish government bonds. The SMP was later extended to Italian and Spanish government bonds in a second round of purchases starting in August 2011. In early 2012, when market conditions improved, the ECB stopped purchases. By February 2012, €220 billion of sovereign bonds were bought. During the SMP, purchases were made on a daily basis if deemed necessary by market conditions. No predetermined targets of prices or quantities existed. In fact, there were not many operational details available for the SMP (Fratzscher, et al., 2014).

The SMP was officially deactivated when a new monetary instrument was introduced in September 2012, called Outright Monetary Transactions (OMT). This consisted of the possibility of unlimited purchases of government bonds with maturities of up to three years, i.e. with a focus on the short term. A further condition was that the debt had to be issued by countries that were under a macroeconomic adjustment programme of the European Stability Mechanism (ESM). The aim of the OMT was to “maintain an ‘appropriate monetary policy transmission and the singleness of the monetary policy’ by lowering bond yields and therefore decreasing borrowing costs” (Rivolta, 2014). Before the OMT was announced, Mario Draghi, the president of the ECB, made the important and famous declaration in late July 2012: “Within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough” (Mario Draghi, 2012 cited in Rivolta, 2014). This was indeed a very powerful statement and according to Fratzscher et al. (2014), the subsequent announcement of the OMT was sufficient to calm markets. However, by the time of writing their report, in November 2014, no purchases of government bonds had actually been made under the OMT programme (Fratzscher, et al., 2014).

These unconventional monetary policies have given rise to many event studies over the past years that were assessing their impact on financial markets, i.e. asset prices and bond yields. An example is the event study of Rivolta (2014), who studied the impact of LTROs on sovereign bond yields. We will use parts of her event study methodology to study the impact of the QE announcement later in chapter 3. Since some of these unconventional monetary policy programmes involved the purchasing of government bonds in some form, they have somewhat paved the way to QE.

2.3. Details of the ECB QE programme

Now, in the following, we shall describe in more detail the QE programme of the Eurosystem, officially baptised the Extended Asset Purchase Programme (EAPP). The EAPP consists in fact of three different programmes: the Asset Backed Securities Purchase Programme (ABSPP) and the 3rd Covered Bond Purchase Programme (CBPP3), which were both announced on 4 September 2014 and the PSPP, announced on 22 January 2015. Together these amount to 60 billion euros of monthly asset purchases. The lion's share of this is the PSPP to which 50 billion euros are appointed. The remaining 10 billion euros are attributed to the ABSPP and the CBPP3. These programmes are running until at least September 2016, but are officially open-ended (Claeys, et al., 2015).

The 50 billion euros of the PSPP are broken down the following way: 6 billion euros will go towards the purchase of the debt of supranational institutions located in the euro area. The remaining 44 billion euros will be used to purchase sovereign debt securities, i.e. government bonds. Of those, 4 billion will be held by the ECB and the remaining 40 billion by the national central banks (NCB). Each NCB can only purchase securities of its own government and the profits shall be attributed to its own national economy. The ECB has imposed some limits to the programme, so that it does not violate its prohibition of monetary financing. Claeys et al. (2015) estimate that this operation constrains the length and size of the programme. Even if the programme were to be renewed after September 2016, given that the limits will be strictly applied, only €799.7 billion of government bonds are expected to be purchased out of the 836 billion currently planned (Claeys, et al., 2015).

According to Claeys et al. (2015), the PSPP is already benefitting European public finances since yields have already significantly fallen since mid-2014 in anticipation of the programme. The exact impact however still remains to be seen, as purchases of the PSPP have just started on 9 March 2015. With falling yields, governments will be able to issue bonds with a lower coupon that is equal (or at least close to) the yield required by investors at the time of the auction. Consequently, governments will benefit from a cheaper cost of borrowing that should ease their public finances.

Regarding the amount of outstanding sovereign debt securities, there was a total outstanding amount of €6.2 trillion at face value, estimated at €7.3 trillion market value. 80 percent of this debt comes from the four biggest European economies (France: €1.5 trillion, Italy: €1.4 trillion, Germany: €1.2 trillion and Spain: €0.8 trillion). For the PSPP, only securities with maturities between 2-30 years are eligible. Furthermore, bonds have to yield more than the deposit facility

rate. Hence, this excludes German government bonds with a yield below -0.2%. Thus the total eligible amount for the PSPP is about €4.3 trillion at face value and €5.3 trillion at market value (Claeys, et al., 2015). This eligibility will have an impact on the yield variation following the announcement, since short-term bonds with a maturity of less than two years will not be directly affected by the ECB purchases.

For the ABSPP and the CBPP3, no minimum maturities or other eligibility criteria have been communicated on the press conference on 4 September 2014. Mario Draghi stated instead that “the detailed modalities of these programmes will be announced after the Governing Council meeting of 2 October 2014” (ECB, 2014). This, and the fact that Asset Backed Securities and Covered Bonds are derivatives that may have as the underlying asset public or private debt, means that we cannot be certain for our event study, that any abnormal variations in yields are due to the announcement of the ABSPP and CBPP3 programmes. Instead, abnormal variations might simply be due to the announcement of the lowering of the three key interest rates by 10 basis points each. This, as explained before, has occurred on the same day. On the contrary, for the PSPP, the technical annex has been published the same day that the announcement was made. This, and the fact that key interest rates remained unchanged, means that for the 22 January 2015 announcement, we expect any abnormal variations being due to the announcement only.

In the following table, we will give a brief summary of the complete ECB QE programme, based on information from Claeys et al. (2015) and Goldman Sachs (2015).

Table 1: Summary of ECB QE programme

Aspect	Details
Program Size	€60 billion monthly
Time Frame	Start: March 2015. Until: September 2016. Officially open-ended.
Eligible Asset Classes	All EUR denominated government bonds incl. agency and European institution bonds. Corporate bonds not eligible.
Eligible Asset Rating	Investment Grade (BBB and above). Additional criteria for countries under an EU/IMF adjustment programme.
Eligible Asset Maturity	Between 2 – 30 years
Eligible Asset Type	Floating rate and interest rate linked securities are eligible, incl. those with negative yields (but greater than the deposit rate).
Issuer Limit	Up to 33% of an issuer's total can be purchased.
Issue Limit	Up to 25% of a single security can be purchased.
Risk Sharing	20% of bond risk mutualised across NCBs. 80% remains with the holding NCB.

According to Goldman Sachs (2015), “this scale of purchases could expand the ECB’s balance sheet from its current €2.2 trillion to more than €3 trillion in early 2016, and potentially beyond €3.5 trillion if the outlook for inflation doesn’t materially improve.”

To conclude this section, the scope of the ECB QE programme might have come as a surprise for many investors. This is because its size of bond purchases is unprecedented for the Eurozone. However, because of previous bond purchase programmes such as the SMP or the OMT, it was certainly expected by markets that the ECB would at some point launch a QE programme. The announcement of the decoupling of the Swiss franc the week before (see results discussion in section 3.3.2.) has drawn special attention to the ECB Governing Council meeting on 22 January 2015. However, information of scope and technical details of said programme should not have been available to investors before the Governing Council’s press conference on 22 January 2015. Therefore, we can expect this announcement to result in significant abnormal drops in yields across eligible euro area bonds. This is because we expect investors rushing to buy those before the ECB does (starting on 9 March 2015), thus increasing their prices through increased demand, and thus lowering the yields. However, before embarking on our event study, we will outline the mechanisms through which QE works, based on articles written about previous QE programmes of other central banks.

2.4. Theoretical frameworks for the effects of QE

Generally speaking, QE increases the liquidity of private-sector balance sheets by the central bank injecting money into the economy in return for assets. The fact that assets are purchased with central bank money pushes asset prices up. This should then in return lower the cost of borrowing and thus encourage higher consumption and investment spending. Higher spending occurs also since asset holders’ wealth increases with higher asset prices. A more intuitive way of thinking about it is the central bank printing more money (Lu, 2013, p. 351).

More precisely, QE works through the three following main channels (Hausken & Ncube, 2013, pp. 5-6):

- Portfolio balance channel
- Signalling channel (or macro/policy news channel)
- Liquidity premia channel

In the following, we will give a brief explanation as to how these channels work. Those are based on a journal article by Joyce et al. (2011) that was published by the Bank of England.

The first channel, which is the portfolio rebalance channel, reflects the direct impact on asset prices through the fact that investors will rebalance their portfolios as a response to the ECBs asset purchases. This relies on the assumption that if “assets are not perfect substitutes, then a change in the quantity of a specific asset will lead, ceteris paribus, to a change in its relative expected rate of return” (Joyce, et al., 2011, p. 117). The base money that the central bank issues and the assets purchased during QE are not perfect substitutes. As a consequence, investors seek to rebalance their portfolio by purchasing assets similar to the ones sold. This pushes the prices of these assets up further and thus reduces yields. The effect of this channel is most significant for assets similar to those purchased by the central bank (Hausken & Ncube, 2013).

The signalling channel is also called the macro/policy news channel. It captures news about expected future policy rates. For example, a QE programme could signal lower policy rates in the short term, but it could also signal higher policy rates in the future. Thus, the effects on yields and prices could either be positive or negative. According to Hausken & Ncube (2013), purchasing a large quantity of long-term assets through a QE programme serves as a credible commitment of a central bank to keep interests low in the future. This is because if it would choose to raise interest rates later, it would incur big losses on the assets purchased.

The liquidity premia channel works through reducing the premia for illiquidity and thus improving the market functioning. Since the central bank is purchasing assets in big quantities, selling the assets becomes less costly for investors. Especially during crises, there may be big illiquidity premia, since there are not enough buyers for all the investors wishing to sell their assets. However, this channel only works while the central bank is repurchasing assets (Hausken & Ncube, 2013).

These three channels mean that we are expecting to see the following results as a consequence of the ECB QE programme: Asset prices in the euro area will generally go up. Government bond prices, given that they are eligible, will be directly affected by the ECB purchases. So we expect the price of those to rise, as well as the price of similar bonds, i.e. with similar credit ratings and maturities. Since bond prices will increase, the yields (to maturity) will lower.⁵ Those bonds will then be trading at a premium, i.e. their yield will be lower than their coupon rate.

Since sovereign bonds, especially if AAA-rated, are considered risk-free, the general risk-free rate for the Eurozone is expected to decrease. As a consequence of this, investors need to

⁵ See: bond pricing formulas in appendix A3.

increasingly turn towards risky assets to help them generate the returns needed. Thus, as a consequence, we expect equity prices to increase.

In the next chapter, we will proceed to the empirical analysis, starting by presenting the econometric methodology used for the event study.

3. Event study

3.1. Econometric methodology

In order to measure the effect on bond yields caused by the unconventional monetary policy announcement, we decided to implement the event study methodology. The original purpose of this method is to evaluate the effect of certain economic events on firm value (such as M&A activities, issuing of new debt or equity, or announcements of macroeconomic data) by looking at abnormal asset price changes. The general model relies on the measurement of normal and abnormal returns. The normal return, that we define as $E[R_{it}^*|\Omega_{it}]$, is the return that we are expecting given that the event did not take place. R_{it}^* represents the return for firm i at time t and Ω_{it} is the conditioning information for the normal performance model. The abnormal return, that is the return of our interest, is defined by $\varepsilon_{it}^* = R_{it}^* - E[R_{it}^*|\Omega_{it}]$. After obtaining the abnormal return, its statistical significance needs to be tested. If we get a significant abnormal return, we can assume that the event of our interest had a statistically significant effect on asset prices (Asgharian, 2014).

In our case however, we are not directly studying changes in asset prices. Hence, using the word “return” and using R in the formulas is not technically correct and might be misleading. What we are studying here, are changes (or variations) in yields. Thus we will later use the letter v (for variation) instead of R in our formulas.

There are different methods for estimating the expected normal returns, since these cannot be observed. In the following, we will quickly show some of them for purely illustrative purposes, as described by Asgharian (2014).

- **Constant-mean return model:** Used if the mean return of a given security is assumed to be constant over time.
- **Market model:** Used when there is a stable relation between the market return and the security return.
- **Multifactor model:** Used when other factors in addition to the market portfolio are being included. Examples for factors are industry indices or firm size based portfolios.

Our initial idea was to implement an event study methodology using a multifactor model for calculating normal variations. Our dependent variables would have been yields of different countries and the multi-factor regressors would have been different macroeconomic variables that are correlated with those bond yields. The problem of this method is that yields are calculated on a daily basis (or even with faster frequencies), while most macroeconomic variables are only available on a monthly or quarterly basis. Previous studies have shown that using low frequency data for an event study about changes in bond yields will lead to insignificant results. Such a study was conducted by Modigliani & Sutch (1966), who performed an event study of Operation Twist during the Kennedy administration using quarterly data, without finding any significant results. This means that for our study, we have to use high-frequency data, i.e. daily yields.

For our model we then decided to perform the method implemented originally by Swanson, et al. (2011). For this research, a high-frequency event study was implemented to find significant abnormal changes in yields around the announcement days of the Operation Twist. This research tried to find significant results where Modigliani & Sutch (1966) previously failed. The authors used 1- or 2- day changes in treasury yields, affirming that this difference should be sufficient for explaining the effects of a particular announcement on the yield curve. This method relies on the assumption of rational expectations in financial markets that states that current market expectations reflect the future state of the general economy. As a consequence, asset prices will already reflect all the relevant information included in every particular announcement shortly after it has been made. In accordance with Swanson's (2011) research, we thus chose the one-day change (or variation) in yields for conducting our event study.

We decided to consider as a null hypothesis that our bond yields do not change (abnormally) following the announcements. Our alternative hypothesis is that there is a significant change in bond yields. Let v_0 be the null of there being no variation in the bond yields. Since we will conduct a two-sided test, we have the following two hypotheses:

$$H_0: v_0 = 0 \quad (1)$$

$$H_1: v_0 \neq 0 \quad (2)$$

Here we have a Student's t distribution with $T-1$ degrees of freedom. For a sample size of 30 days, this gives us 29 degrees of freedom. We can then look up the critical value at the 95% confidence level for a two-sided test in a probability table, which can be found in many statistical and econometric textbooks, e.g. Introductory Econometrics for Finance by Chris

Brooks (2008).⁶ We have chosen to compute it ourselves with the TINV function in Excel.⁷ Both the Brooks table and our computation yielded the critical value of 2.0452. (N.B.: Brooks uses $\alpha = 0.025$ for a two-sided test at the 95% confidence level). This means that we reject the null if our test statistic exceeds the critical values of the interval (-2,0452 ; 2,0452). If we reject the null, our results are statistically significant, and if we cannot reject it, they are statistically insignificant.

As the next step, we had to calculate the t-statistic. For this, we used Rivolta's (2014) formula expressed by the following equation:

$$t_{cij} = \frac{v_{cij,t} - v_0}{sd_{cij,t}} \sim T(T - 1) \quad (3)$$

$v_{cij,t}$ is the one day variation in the yield for bond i (which represents the maturity), country c during the event of interest j at time t . The one-day calculation for the yield variation is the following:

$$v_{cij,t} = y_{cij,t} - y_{cij,t-1} \quad (4)$$

According to the model presented by Swanson, et al. (2011), we can thus examine if $v_{cij,t}$ is statistically significant. If this is the case, $v_{cij,t}$ is our abnormal return during the announcement day. We calculated the standard deviation for the 30 days variation previous to the announcement day, so it cannot be influenced by the event itself. We were doubtful about the length of the window for the standard deviation, so we decided to use 30 days, since it is the same length that Rivolta (2014, p. 12) suggests.

Thus, our standard deviation calculation is:

$$sd_{cij,t} = \sqrt{\frac{\sum_{t=1}^n (v_{cij,t} - \bar{v}_{cij,t})^2}{T-1}} \quad (5)$$

Where the sample size T is 30 (days prior to the announcement, i.e. without the announcement itself).

Thus, as mentioned before, if statistically significant, $v_{cij,t}$ is our abnormal return. Before asserting this, however, we have make two major assumptions according to Rivolta (personal communication, 3 April 2015):

⁶ Critical values can be found in Table A2.2, p.617 in Brooks (2008).

⁷ This function returns the two tailed inverse of the Student's t-distribution. (= the critical value).

- Variation around the dates of our interest is only due to the announcement of unconventional monetary policy measure (i.e. no key interest rates have been adjusted the same day).
- Variations are following a random walk process $y_t = y_{t-1} + e_t$ since expected variation is equal to zero. The random walk needs to be without drift, otherwise this has to be accounted for in the model.

Using Excel we then developed this model to get the first results of our research. We calculated the abnormal returns around our two announcements of interest (4 September 2014 and 22 January 2015) for each country we had selected. In the following section 3.2, we will outline which countries we selected and for which reasons, as well as how we obtained our data.

3.2. Motivation of input choices

3.2.1. Country selection

We decided to perform this event study analysis for euro area and non-euro area countries. For the euro area countries we have picked the biggest economies in terms of GDP. These are the following (in alphabetical order): Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal and Spain. Of these 11 countries, the four biggest economies (Germany, France, Italy and Spain) represent over 75% of the GDP of the whole euro area. A pie chart of these countries can be found in the appendix (figure 17 in A6).

As non-euro area countries, we chose Denmark, Norway, Sweden, Switzerland and the United Kingdom. We decided to choose non-euro area countries, even if we do not expect any significant results, since we suspect that their economies are not totally independent from the euro area countries, i.e. there might be some spill over effects.

3.2.2. Data selection

We retrieved our data from two different sources. First, in order to get the general euro area yield curve, we downloaded data from the ECB website where we have found daily yield values with maturities of 1Y, 5Y, 10Y, 20Y and 30Y. These yields represent AAA-rated Euro area central government bonds (ECB, 2015a). These yields are updated every trading day at noon (12.00 PM CET).

To get yields for individual countries we used Datastream. Thomson Reuters calculates daily yields for every country across different maturities. For our model, we decided to pick the

following maturities (if available) for each country: 1M, 3M, 6M, 1Y, 3Y, 5Y, 10Y, 20Y and 30Y. We chose these maturities since they reflect the short, medium and long-term perspectives. Datastream expresses each yield that has been used under the following name format:

'TR name of the country GVT ZERO maturity'

These yields are calculated by Thomson Reuters using the bootstrapping method, which is a way to calculate zero-coupon yield curves, in order to make all the government bonds comparable. Unfortunately, for some countries not all of these maturities were available, so we simply put an ‘x’ in our results tables where these values were not available.

3.2.3. Event window

For both the 4 September 2014 and the 22 January 2015 announcements, we chose a one-day event window. We assume that one day is sufficient to capture the direct market response to the announcement. This is because both programs were announced at 14.30 CET (time of the press conferences) and looking at intraday prices using Thomson Reuters Eikon, we have seen an immediate market reaction in the minutes following the announcements on e.g. Italian 10y government bond prices and by consequence also yields (prices went up, thus yields went down).

However, concerning the AAA-rated bond data from the ECB, these have been calculated at 12.00 CET. This meant that we had to use a two-day variation from January 21 to January 23 instead, in order to properly capture the effect of this announcement, which was made shortly after the yields had already been calculated.

3.3. Event study results

3.3.1. Results for AAA-rated euro area yields

In this section, we are going to present the results of our event study. Table 2 shows the variation and the t-test for the AAA euro area yields calculated by the ECB.⁸ Statistically significant returns are highlighted in green. They exceed the interval of the critical values of +/- 2.0452 and thus the null is rejected. However, the ECB did not provide data for maturities shorter than 1Y.

Table 2: Event study results for AAA-rated euro area countries

Date		1Y	5Y	10Y	20Y	30Y
2014-09-04	<i>2-day variation</i>	-0,0024	-0,0606	-0,0352	0,0369	0,0689
ABSPP and CBPP3 announcement	<i>t-statistic</i>	-0,1941	-2,8880	-0,8745	0,6865	1,3453
2015-01-22	<i>2-day variation</i>	0,0030	-0,0810	-0,1240	-0,1137	-0,1004
PSPP announcement (QE)	<i>t-statistic</i>	0,2240	-3,4654	-2,6557	-1,7043	-1,2487

We can clearly see that the first announcement (ABSPP and CBPP3) is statistically significant only for the medium term maturity (5Y). Regarding the announcement of the PSPP, there are statistically significant results for all the 5Y and 10Y yields, with no significant results for the 1Y and 20Y and 30Y yields. So, for the first announcement, there was only an abnormal variation in the 5Y yields of -0.06063. This means that the yield fell from 0.296054% to 0.235421%. In relative percentage terms, this is a drop in the yield of -20.48%, which makes the result seem all the more economically significant. However, as we shall show later, these findings might be merely coincidental for the first announcement. This is because on that announcement day, we found more significant results in the short term than the long term across euro area countries. We believe the reason for this to be that the ECB lowered the key interest rates the same day, on 4 September 2014. Thus, for that day, another model that could isolate the effect of lowering the key interest rates might have been more appropriate here.

⁸ According to the S&P Sovereigns Rating List (2015), the AAA-rated central government bonds are Germany, Finland and Luxembourg

3.3.2. Results for selected euro area countries

The following table shows all the results we obtained through our event study for our selected euro area countries.

Table 3: Event study results for the 11 biggest euro area countries (in alphabetical order)

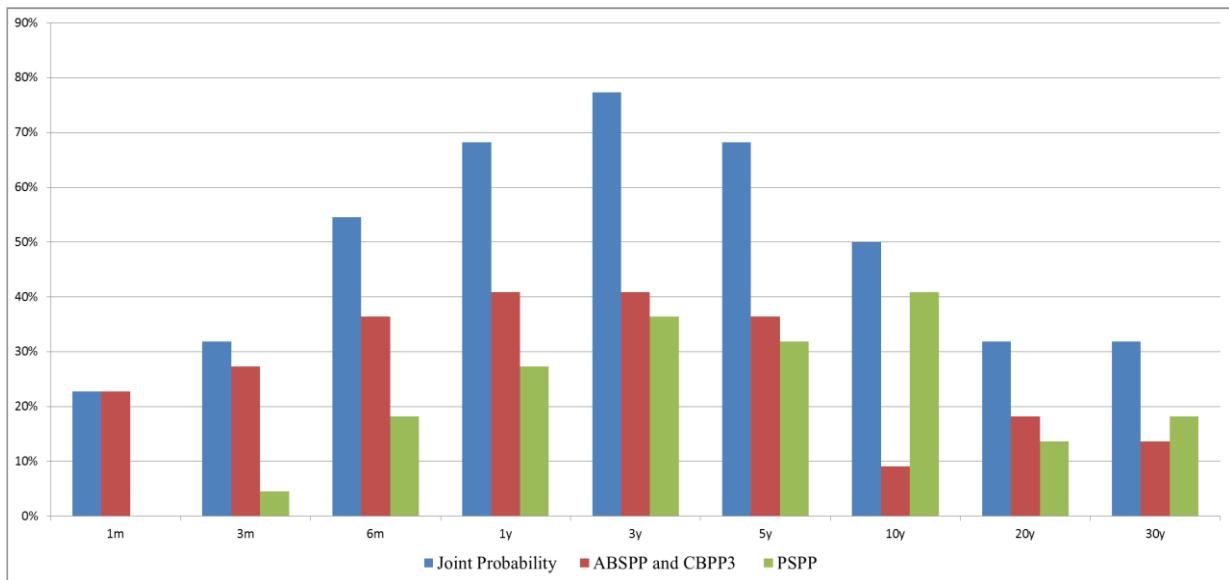
Country	Date		1m	3m	6m	1y	3y	5y	10y	20y	30y
Austria	2014-09-04	<i>I-day variation</i>	x	x	-0,0334	-0,0401	-0,0538	-0,0511	0,0018	0,0712	0,0728
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	x	x	-3,0629	-4,5231	-4,4922	-2,7050	0,0566	2,0966	2,1752
	2015-01-22	<i>I-day variation</i>	x	x	-0,0502	-0,0395	-0,0271	-0,0385	-0,0610	-0,0673	-0,0759
	PSPP announcement (QE)	<i>t-statistic</i>	x	x	-2,7902	-3,2890	-2,7031	-2,3016	-1,9629	-1,5693	-1,7393
Belgium	2014-09-04	<i>I-day variation</i>	-0,0592	-0,0527	-0,0541	-0,0645	-0,0702	-0,0657	-0,0244	0,0093	0,0136
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	-5,2190	-8,5326	-12,7093	-12,9063	-5,2159	-3,0921	-0,7342	0,2476	0,3404
	2015-01-22	<i>I-day variation</i>	-0,0189	-0,0195	-0,0216	-0,0257	-0,0299	-0,0417	-0,0819	-0,0877	-0,0795
	PSPP announcement (QE)	<i>t-statistic</i>	-0,9399	-2,0078	-2,8916	-3,3239	-3,0976	-2,2770	-2,7300	-2,3872	-1,9062
Finland	2014-09-04	<i>I-day variation</i>	x	x	-0,0424	-0,0547	-0,0677	-0,0610	-0,0041	0,0789	0,0751
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	x	x	-0,7700	-3,3858	-4,8469	-2,8731	-0,1282	2,2279	1,7646
	2015-01-22	<i>I-day variation</i>	x	x	-0,0069	-0,0161	-0,0276	-0,0392	-0,0720	-0,0530	-0,0677
	PSPP announcement (QE)	<i>t-statistic</i>	x	x	-0,4275	-1,8361	-2,5535	-2,2084	-2,3262	-1,1769	-1,7996
France	2014-09-04	<i>I-day variation</i>	-0,0329	-0,0586	-0,0747	-0,0721	-0,0721	-0,0715	-0,0203	0,0206	0,0243
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	-2,2823	-7,9399	-16,0902	-15,5919	-5,6932	-3,4357	-0,6275	0,5599	0,6250
	2015-01-22	<i>I-day variation</i>	0,0014	-0,0015	-0,0041	-0,0068	-0,0190	-0,0379	-0,0810	-0,0803	-0,0809
	PSPP announcement (QE)	<i>t-statistic</i>	0,0694	-0,1048	-0,3588	-0,8187	-1,8923	-2,0450	-2,6728	-1,9683	-1,9438
Germany	2014-09-04	<i>I-day variation</i>	-0,0230	-0,0346	-0,0473	-0,0589	-0,0515	-0,0428	0,0246	0,0769	0,0833
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	-1,1219	-3,1661	-7,1036	-6,7257	-3,5557	-2,0258	0,7610	1,9801	2,1100
	2015-01-22	<i>I-day variation</i>	0,0297	0,0193	0,0072	-0,0065	-0,0182	-0,0323	-0,0673	-0,0537	-0,0524
	PSPP announcement (QE)	<i>t-statistic</i>	1,6705	2,0557	0,9858	-0,9224	-2,2403	-2,4131	-2,1999	-1,2126	-1,2263
Greece	2014-09-04	<i>I-day variation</i>	0,0184	0,0028	-0,0200	-0,0509	-0,1344	-0,1766	-0,1988	-0,1251	0,0832
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	0,1613	0,0419	-0,4294	-0,8916	-1,1872	-1,3961	-1,7588	-1,5784	1,3048
	2015-01-22	<i>I-day variation</i>	-0,2962	-0,2178	-0,1728	-0,2630	-0,4472	-0,4233	-0,1841	-0,1046	-0,4731
	PSPP announcement (QE)	<i>t-statistic</i>	-0,4997	-1,0290	-0,5113	-0,4097	-0,6199	-0,6786	-0,5253	-0,6580	-3,3434
Ireland	2014-09-04	<i>I-day variation</i>	x	x	-0,0157	-0,0100	-0,0592	-0,0845	-0,0504	x	x
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	x	x	-0,6480	-0,7241	-3,2656	-2,6326	-1,3223	x	x
	2015-01-22	<i>I-day variation</i>	x	x	-0,0289	-0,0247	-0,0355	-0,0579	-0,0938	x	x
	PSPP announcement (QE)	<i>t-statistic</i>	x	x	-1,4138	-1,6670	-2,1007	-2,2061	-3,2144	x	x
Italy	2014-09-04	<i>I-day variation</i>	-0,0612	-0,0779	-0,0891	-0,1040	-0,1210	-0,1330	-0,1212	-0,0704	-0,0398
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	-2,9321	-4,6564	-5,0601	-5,1816	-3,3990	-3,1797	-2,6317	-2,2507	-0,9103
	2015-01-22	<i>I-day variation</i>	-0,0530	-0,0569	-0,0590	-0,0613	-0,0831	-0,1038	-0,1457	-0,2432	-0,2918
	PSPP announcement (QE)	<i>t-statistic</i>	-0,6915	-1,5100	-2,7913	-2,7279	-2,1358	-2,2593	-3,1276	-5,6024	-5,8727
Netherlands	2014-09-04	<i>I-day variation</i>	-0,0350	-0,0421	-0,0477	-0,0523	-0,0641	-0,0577	-0,0076	0,0663	0,0822
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	-2,9916	-6,9198	-9,2511	-8,7446	-4,8890	-2,6169	-0,2250	1,7860	2,2251
	2015-01-22	<i>I-day variation</i>	0,0019	-0,0113	-0,0192	-0,0217	-0,0242	-0,0371	-0,0731	-0,0580	-0,0458
	PSPP announcement (QE)	<i>t-statistic</i>	0,0883	-0,8960	-2,0466	-2,6232	-1,9858	-1,4887	-2,3669	-1,3823	-1,0408
Portugal	2014-09-04	<i>I-day variation</i>	0,0304	0,0031	-0,0293	-0,0807	-0,1211	-0,0769	-0,0753	-0,0518	0,0764
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	1,7859	0,3143	-2,5290	-4,8824	-1,8800	-0,9331	-1,0756	-1,1015	0,8288
	2015-01-22	<i>I-day variation</i>	0,0085	0,0036	-0,0092	-0,0481	-0,1276	-0,1397	-0,1960	-0,2301	-0,1755
	PSPP announcement (QE)	<i>t-statistic</i>	0,2155	0,1463	-0,7042	-2,5379	-2,3482	-2,1317	-2,8864	-4,3822	-3,0236
Spain	2014-09-04	<i>I-day variation</i>	-0,0708	-0,0709	-0,0703	-0,0744	-0,1010	-0,1226	-0,1365	-0,0872	-0,0860
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	-2,3224	-2,8560	-2,9703	-2,9172	-2,7187	-2,6776	-2,7272	-1,9608	-1,8442
	2015-01-22	<i>I-day variation</i>	-0,0347	-0,0483	-0,0601	-0,0711	-0,0819	-0,0879	-0,1560	-0,2691	-0,2895
	PSPP announcement (QE)	<i>t-statistic</i>	-0,3528	-0,7631	-1,8110	-4,0243	-2,3549	-1,9931	-3,2651	-5,7345	-6,3058

Our results confirm our expectations: there is clearly evidence of statistical significant drops in yields across all the euro area countries (except for Greece). Almost all countries have significant abnormal variations on the two announcement days. It is also noticeable that the variations have been the highest for Italy, Portugal and Spain. However, one must bear in mind that these countries had experienced much higher yields prior to the announcement dates. Thus it makes more sense to compare abnormal variations in relative percentage terms. When it comes to Greece, we believe that the effect of the announcement is mostly not significant, since

they do not meet the credit quality criteria of guideline ECB/2011/14 (ECB, 2011), i.e. their credit rating was lower than the minimum BBB- required to be eligible for the QE programme.

But looking more deeply into figure 4, we can see from the distribution of these results, that the significant results are most present in the medium-term (3Y). This figure shows the percentage of significant results for each maturity tested.

Figure 4: Distribution of significant results for the euro area



One can see that the histogram of significant results seems to follow a bell-shaped normal distribution for the three programmes combined. However, they are slightly skewed towards the left (short term) for the ABSPP and the CBPP3 announcement and skewed to the right (long term) for the PSPP announcement. A possible explanation for this is that, as mentioned before, the PSPP excludes assets with maturities shorter than two years. This means that bonds with longer maturities are more affected by QE than those with shorter maturities. The fact that the announcement of the ABSPP and CBPP3 seems to affect short term maturities more is likely due to the fact that the ECB lowered their key interest rates (which are short term) by 10 basis points each on the same day, as mentioned before in chapter 2.3.

3.3.3. Results for selected non-euro area countries

Regarding the non-euro area countries in Table 4, we have found less statistically significant results. This is what we expected, since those bonds are not eligible for the QE programme and thus will not be purchased by the ECB. However, we wanted to test if they are somewhat indirectly affected by potential spill over effects.

Table 4: Event study results for selected non-euro area countries

Country	Date		1m	3m	6m	1y	3y	5y	10y	20y	30y
Denmark	2014-09-04	<i>1 day variation</i>	-0,0217	-0,0060	-0,0313	-0,0405	-0,0541	-0,0448	0,0159	0,0830	0,0879
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	-1,8327	-0,6697	-3,6591	-4,6529	-3,2823	-2,0437	0,5367	2,3726	1,6628
Norway	2015-01-22	<i>1 day variation</i>	0,0247	0,0130	-0,0020	-0,0246	-0,0431	-0,0383	-0,0625	-0,0677	-0,0455
	PSPP announcement (QE)	<i>t-statistic</i>	0,6567	0,3867	-0,0668	-0,9820	-1,9433	-1,6948	-2,0952	-1,6790	-0,8241
Sweden	2014-09-04	<i>1 day variation</i>	-0,0247	-0,0320	-0,0058	0,0004	0,0117	0,0134	0,0061	x	x
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	-0,9068	-2,2696	-0,5355	0,0413	0,7728	0,6804	0,2198	x	x
Switzerland	2015-01-22	<i>1 day variation</i>	-0,0132	-0,0010	-0,0631	-0,0754	-0,0777	-0,0733	-0,0751	x	x
	PSPP announcement (QE)	<i>t-statistic</i>	-0,4314	-0,0388	-2,3925	-2,4733	-1,7310	-1,4218	-1,6503	x	x
UK	2014-09-04	<i>1 day variation</i>	-0,0379	-0,0247	-0,0128	-0,0093	-0,0331	-0,0294	0,0025	0,0021	0,0506
	ABSPP and CBPP3 announcement	<i>t-statistic</i>	-1,9970	-2,5606	-1,5680	-1,1183	-1,8526	-1,2453	0,0804	0,0608	1,3902
	2015-01-22	<i>1 day variation</i>	-0,0168	-0,0159	-0,0138	-0,0068	0,0012	-0,0021	-0,0185	-0,0242	-0,0242
	PSPP announcement (QE)	<i>t-statistic</i>	-0,5809	-0,8485	-1,1860	-0,7606	0,0875	-0,1102	-0,7037	-0,6923	-0,6923

As one can see, there are only significant variations in yields for bonds with short maturities for Switzerland and Norway for the PSPP announcement. When it comes to Denmark, we found several significant changes in yields for the first announcement. However, we suspected this, since the Danish krone is pegged to the euro in the ERM II (Exchange Rate Mechanism). Since Denmark joined this mechanism in 1999, the Danish National Bank keeps the krone within a +/- 2.25% fluctuation margin of the exchange rate 7.46038 DKK = 1.00000 EUR (European Commission, 2013).

Regarding Switzerland, we found significant negative variations in yields for the second announcement. However, we should take these with a grain of salt, since the Swiss National Bank had just announced the decoupling of the Swiss franc from the euro a week earlier, on 15 January 2015. This resulted in the Swiss franc appreciating dramatically and the exchange rate dropping from 1.20 CHF = 1 EUR to 0.85 CHF = 1 EUR. During the financial crisis, the Swiss franc had become a ‘safe haven’ for investors which led to an enormous demand for this currency. To keep its exchange rate low, the Swiss national bank had created new francs that were being used to purchase euros. This increased the money supply and thus caused the franc

to fall in value. Through this mechanism, the exchange rate had been pegged for several years (The Economist, 2015).

According to this article from The Economist (2015) from 18 January 2015, “many expect[ed] the European Central Bank to introduce ‘quantitative easing’... something that is happening this Thursday [22 January 2015]”. This article proves that the QE announcement on that day had been widely expected by investors and that the unpegging of the Swiss franc a week earlier was most likely not an independent event. This means that an observed fall in the Swiss yields is likely due to the announcement of the Swiss National Bank from 15 January 2015 and thus not independent from the announcement of the ECB. It is possible that either central bank might have made their announcement as a reaction towards the other’s announcement.

Having presented and discussed the results of our event study, we will now conduct a further empirical analysis of the PSPP announcement on 22 January 2015, which will involve time series forecasting.

However, before continuing, we must highlight one particular weakness of our model in this chapter. We have been made aware of this by our examiner after our defence of this paper. The simple random walk model that we used fails to account for the negative drift of the random walk time series, which is clearly visible in figure 2. The bond yields have been drifting downwards for a long period of time prior to the announcements. The ARMA models that we are establishing in the next chapter capture these negative drift terms, as can be seen by the negative μ terms in the equations above the forecasted graphs shown in appendix A5. Had we used ARMA forecasting to model expected normal returns, by effectively combining both our models in chapters 3 and 4, we would have obtained better overall results.

4. Forecasting bond yields with ARMA modelling

The purpose of this section is to estimate how bond yields would have moved if our event of interest, the PSPP announcement on January 22, did not take place. We constructed an ARMA model for nine different bond yields and by using forecast tools on EViews, we retrieved a new time series (i.e. a dynamic forecast) for each yield of interest. Before starting, we were expecting the forecasts to be above the actual yields because through the QE programme, yields should become lower in the future, and markets should immediately react to this. In the following sections we will go through theory and methodology for our ARMA model.

4.1. Theory on univariate time series modelling

This theory part, including its formulas, is based on chapter 5 of Chris Brooks's book "Introductory Econometrics for Finance" (2008, pp. 206-264) and on the lecture notes provided by Jens Forssbæk during the course "Financial Econometrics BUSN80" at Lund University School of Economics (Forssbæk, 2014).

A univariate time-series model is represented by a single variable that follows a stochastic process that evolves over time. This process is determined only by past values of the variable itself. The purpose of this kind of technique is to build a conceivable model able to establish how this variable evolves over time. In the following we will discuss which time series processes exist and briefly outline the theory behind them.

4.1.1. Moving average process (MA)

A moving average (MA) process represents the first type of time series model we are describing. Let u_t ($t = 1, 2, 3, \dots$) be a white noise process⁹, with mean $E(u_t) = 0$ and variance $\text{var}(u_t) = \sigma^2$. The q^{th} order moving average process is then:

$$y_t = \mu + u_t + \theta_1 u_{t-1} + \theta_2 u_{t-2} + \dots + \theta_q u_{t-q} \quad (6)$$

This can also be written using sigma notation:

$$y_t = \mu + \sum_{i=1}^q \theta_i u_{t-i} + u_t \quad (7)$$

⁹ A white noise process is one with no discernible structure. Its definition is:

- $E(y_t) = \mu$ (constant mean)
- $\text{var}(y_t) = \sigma^2$ (constant variance)
- $\gamma_s = \begin{cases} \sigma^2 & \text{if } s = 0 \\ 0 & \text{otherwise} \end{cases}$ (zero auto-covariance)

So, a moving average process is a linear regression of a white noise process where the dependent variable (y_t) depends on current and past values of white noise disturbance.

The properties implied by an MA (q) process are:

$$E(y_t) = \mu \quad (8)$$

$$\text{var}(y_t) = \gamma_0 = (1 + \theta_1^2 + \theta_2^2 + \dots + \theta_q^2)\sigma^2 \text{ (recall that } \sigma^2 = \text{var}(u_t)) \quad (9)$$

$$\text{cov}(y_t, y_{t-s}) = \gamma_s = \begin{cases} (\theta_s + \theta_{s+1}\theta_1 + \theta_{s+2}\theta_2 + \dots + \theta_q\theta_{1-s})\sigma^2 & \text{for } s = 1, 2, \dots, q \\ 0 & \text{for } s > q \end{cases} \quad (10)$$

What is important to highlight for an MA (q) process, is that the autocorrelation function (ACF)¹⁰ will drop to zero after lag q .

4.1.2. Autoregressive process (AR)

In this process, the dependent variable (still represented by y_t) depends only on the value that it took during the previous period and an error term. An AR(p) process is then given by the following equation:

$$y_t = \mu + \phi_1 y_{t-1} + \phi_2 y_{t-2} + \dots + \phi_p y_{t-p} + u_t \quad (11)$$

Using sigma notation, it can be written as:

$$y_t = \mu + \sum_{i=1}^p \phi_i y_{t-i} + u_t \quad (12)$$

The properties of an AR(p) model are:

$$E(y_t) = \frac{\mu}{1-\phi_1-\phi_2-\dots-\phi_p} \quad (13)$$

$$\text{var}(y_t) = \gamma_0 = \phi_1\gamma_1 + \phi_2\gamma_2 + \dots + \phi_p\gamma_p + \sigma^2 \quad (14)$$

$$\text{cov}(y_t, y_{t-1}) = \gamma_s = \phi_1\gamma_{s-1} + \phi_2\gamma_{s-2} + \dots + \phi_p\gamma_{s-p} \quad (15)$$

One of the most important properties of an AR(p) process is that the autocovariance implies that the ACF decays gradually as long as $\phi_i < 1 \forall i = 1, 2, \dots, p$.

¹⁰ The dependence of y_t on itself across time is measured by its autocorrelation. Therefore, the autocorrelation function (ACF) represents the autocorrelations of the number of lags

- $\text{corr}(y_t, y_t) = \frac{\gamma_0}{\gamma_0} = 1$
- $\text{corr}(y_t, y_{t-1}) = \frac{\gamma_1}{\gamma_0} = \tau_1$
- *Etc.*

The ACF is usually illustrated by a correlogram.

An AR(1) process can be either stationary or non-stationary. For the process to be stationary, we need $\phi < 1$. This means that any shocks to the series will gradually die away and the series will tend towards its mean value. Thus a stationary process is also called a ‘mean-reverting process’. For the case where $\phi = 0$, we have a so called ‘zero-mean white-noise process’. For non-stationarity, we need to have $\phi \geq 1$. In the case where $\phi = 1$, shocks will persist and never die away. This is called a ‘random walk’ (if $\mu = 0$). If $\mu \neq 0$, we have a so-called ‘random walk with drift’. In the other case when $\phi > 1$, we have a so-called ‘explosive process’. This means a shock will become more influential if time goes on, and the time series will drift away quickly from its mean value (Forssbæk, 2014).

4.1.3. ARMA process

If we combine together the AR(p) and the MA(q) models, we obtain an ARMA(p,q) model:

$$y_t = \mu + \phi_1 y_{t-1} + \phi_2 y_{t-2} + \cdots + \phi_p y_{t-p} + \theta_1 u_{t-1} + \theta_2 u_{t-2} + \cdots + \theta_q u_{t-q} + u_t \quad (16)$$

The characteristics for the white noise process are:

$$E(u_t) = 0; E(u_t^2) = \sigma^2; E(u_t, u_s) = 0, t \neq s \quad (17)$$

The mean of ARMA model series is given by:¹¹

$$E(y_t) = \frac{\mu}{1-\phi_1-\phi_2-\cdots-\phi_p} \quad (18)$$

The stationary condition for an ARMA(p,q) model is:

$$1 - \sum_{i=1}^p \phi_i > 0 \quad (19)$$

4.1.4. ARMA modelling

Box and Jenkins (1976) were the first to estimate an ARMA model using a specific systematic method. This method is called the three-step approach:

- **Identification:** determining the right order of the model.
- **Estimation:** OLS or other methods.
- **Diagnostic checking:**
 - Over fitting (meaning that all the unnecessary items will be insignificant)
 - Residual Diagnostics (checking for autocorrelation in residuals)

¹¹ The mean of the ARMA model is identical to the AR(p) mean. This is because the ACF for an ARMA process exhibits combinations of attitude derived from AR and MA parts, but for all lags ahead q , the ACF will simply be likewise the individual AR(p) model.

The identification of the model's p-q order can be done by graphical methods, meaning the plotting of ACF and PACF correlograms. However, a better and somewhat simpler approach is using the *information criteria (IC)*. ICs are a method that accounts for two different factors: the first term represents the sum of squares (RSS), while the second term serves as some kind of penalty due to the loss of degrees of freedom from adding additional parameters. The three most commonly used *information criteria*¹² are:

- Akaike's (AIC) = $\ln(\hat{\sigma}^2) + 2K/T$
- Schwarz's Bayesian (SBIC) = $\ln(\hat{\sigma}^2) + \frac{K}{T} \ln T$
- Hannan-Quinn (HQIC) = $\ln(\hat{\sigma}^2) + \frac{2K}{T} \ln(\ln(T))$

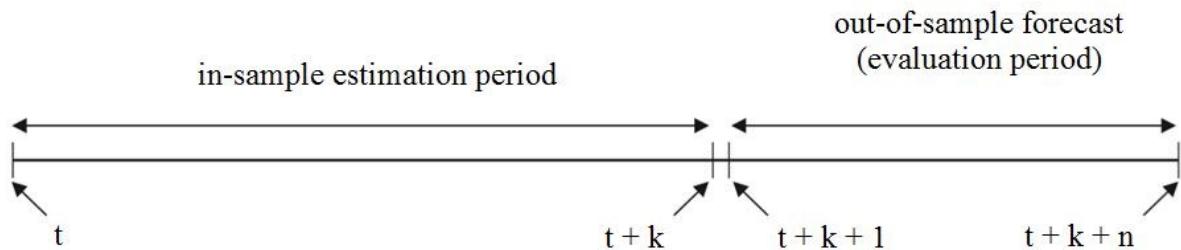
Thus, the question arises as to which IC should be adopted. According to theory, SBIC is strongly consistent but inefficient, while AIC is the opposite. In other words, SBIC is able to deliver the right order for the model, although AIC will result, on average, in too large a model. Consequently, there is not a specific criterion or rule preferable or superior to another¹³.

Having chosen the AIC, the easiest way to identify the appropriate model order is to take the one that minimizes the value of the *IC*. (Minimize IC s.t. $p \leq \bar{p}$, $q \leq \bar{q}$). In practice, we will choose the model with the lowest AIC value.

4.1.5. Forecasting with ARMA

Using the information criteria approach, we choose the model ARMA(p,q) model that best suits our variable. After estimating the model, our focus is now to use it to forecast future values of the dependent variable. The period we used to estimate the regression is called the 'in-sample estimation period' while the evaluation period is called the 'out-of-sample forecast'. This gives us the following time line (adapted from Brooks (2008)):

Figure 5: General example of a forecasting time line



¹² $\hat{\sigma}^2 = \frac{RSS}{T-k}$, $k = p + q + 1$, $T = \text{sample size}$

¹³ We decided to use the AIC to determine the best model fit, since it is the most widely used.

This is a generalised time-line for a k-days ‘in-sample estimation period’ starting at time t and ending at $t + k$. The n-days ‘out-of-sample forecast’ thus starts at time $t + k + 1$ and finishes at time $t + k + n$.

It is important to highlight the following rules when forecasting with MA and AR:

- MA(q) has a memory only for q periods. Therefore, $f_t(y_{t+s}) = \mu \forall s > q$
- AR(p) can make infinite-horizon forecasts. This is done by using past and present values and/or forecasted values of y

For constructing the time series of the forecasts, there are two different approaches available in EViews; dynamic forecasts and static forecasts. According to the definition provided by Brooks (2008, p. 256), a **dynamic forecast** calculates “multistep-forecasts starting from the first period in the forecast sample”. A **static forecast** calculates “a sequence of one-step-ahead forecasts, rolling the sample forwards one observation after each forecast to use actual rather than forecasted values for lagged dependent variables” (Brooks, 2008, p. 256). In other words, only the actual data until the end of the “in-sample estimation period” are being used for both forecasts. For the dynamic forecast, only this data is being used exclusively. However, the static forecast will incorporate the forecasted values into the ‘in-sample estimation period’ for the next value being forecasted. Thus the ‘in-sample estimation period’ always grows by one lag for every additional value being forecasted in the ‘out-of sample forecast’. For our analysis we decided to use only the dynamic forecast since, by using this technique, the ‘in-sample estimation period’ will not change and thus, we can be certain not to take into account any values after 21 January 2015.

Our purpose for conducting the forecast is not to predict how the government bond yields will move in the future, but to see, by comparing the forecasted yields with the actual yield values, how the bond yields were expected to have moved given that the PSPP announcement had not taken place.

4.2. Estimating our model

4.2.1. Data and announcement specifications

The objective of this analysis is to confirm our hypothesis of the forecasted yields calculated after the announcement being above the actual yields. We are expecting this, since through unconventional monetary policy measures, yields should become lower in the future, as discussed in the section about QE theory. Consequently, markets should reflect this information immediately after the announcement by adjusting bond prices and thus yields.

We selected three maturities (3Y, 5Y and 10Y), three countries (Germany, Italy and Spain) and the PSPP announcement. The reasons for these choices are various:

- 3Y, 5Y and 10Y are very commonly used maturities and the ones that offered the most significant results (see event study Table 3).
- Germany, Italy and Spain offered significant results for all of these maturities.¹⁴
- The purpose of this analysis is to confirm theory and our hypothesis, not to do it for all the countries and maturities.
- The PSPP represents the official QE program.

As we explained in the previous chapter, we started by estimating 16 models for each country and maturity (ARMA (p,q) with $0 \leq p \leq 3$ and $0 \leq q \leq 3$) in order to find the best model fit for each of them. These regressions represent the ‘in-sample estimation period’, i.e. 146 observations, from 2014-07-01 to 2015-01-21 (the day before the PSPP announcement).

To do that, we transformed the yields into single-period net returns using the formula below to induce stationarity:

$$R_t = \frac{y_t - y_{t-1}}{y_{t-1}} \quad (20)$$

After that, we created a table (see appendix A4) with all the Akaike’s information criteria, where we highlighted in bold (and choose) the values that minimize the AIC. This resulted in the following models:¹⁵

¹⁴ With exception for Spain 5Y (t-test statistic of $-1,9931 > -2.0452$).

¹⁵ For Italy 10Y, Germany 5Y and Germany 3Y we have had problems related to over fitting for MA terms. This means that all the unnecessary items will be insignificant. Due to this problem we selected, respectively, ARMA (2, 2), ARMA (1, 1) and ARMA (1, 1).

Table 5: Best model fit according to AIC

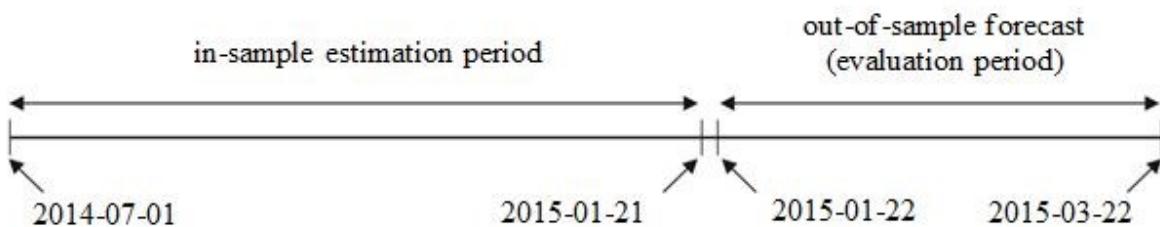
	3Y yield	5Y yield	10Y yield
Germany	ARMA(3,3)	ARMA(1,1)	ARMA(1,1)
Italy	ARMA(2,2)	ARMA(3,3)	ARMA(2,2)
Spain	ARMA(2,3)	ARMA(2,3)	ARMA(2,2)

Given these nine models above expressed in Table 5, we were ready to estimate the nine regressions. For each estimated regression, we have checked if they were stationary. Through the regression output in EViews, it is possible to go directly to the forecast tool. The “out-of-sample forecast” is expressed by 42 observations, from 2015-01-22 to 2015-03-22¹⁶. Using this tool, we retrieved the new forecasted time-series for each regression. For example, for the German 10Y yield, we have two time series now:

- 10Y_yield (actual observations)
- 10Y_yield_dynamic_forecast

Inputting our selected dates into the general forecasting time line gives us the following time line:

Figure 6: Forecasting time line for our model



After obtaining these results, we exported the time series into Excel. Obviously, since the forecasts are also expressed in return terms, we had to convert the results into yields by using the inverse formula for calculating returns, i.e. to obtain the yield calculated by using the dynamic forecast:

$$y_{forecast(t)} = R_{forecast(t)} * y_{t-1} + y_{t-1} \quad (21)$$

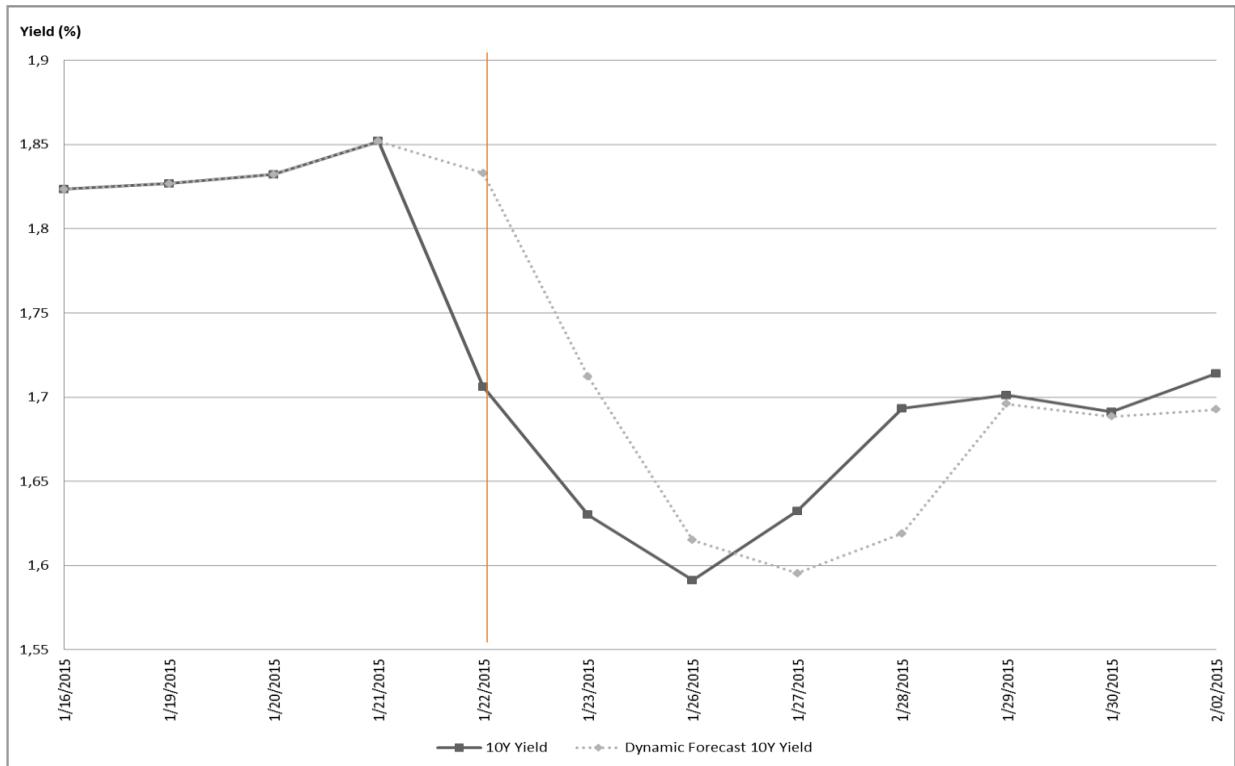
¹⁶ Even though we have 42 observations for the forecast, we will show only the first 8 of them. Our purpose is to illustrate the short term effect.

The graphs shown in appendix A5 are our results¹⁷.

4.2.2. Results and interpretation

Before conducting this ARMA model we were expecting the forecasts calculated after the announcement to be above the actual yields. Looking at all of the nine graphs, we can confirm that they support our initial hypothesis. The forecasted yields during the announcement day, 22 January 2015, are always above the actual yields.

Figure 7: Example of a graph forecasted with ARMA (Italy 10Y)¹⁸



As one can see in Figure 7 above, the forecasted yield for the 10Y Italian bond on 22 January 2015 was 1.8331%, whereas the actual yield had dropped to 1.7062%. A few days later, the forecasted line and the actual line crossed, before converging finally. Here, the abnormal variation can be interpreted as the difference between the black line and the dotted grey line. The other graphs of our forecasts are included in the appendix (see A5) and all give a similar picture.

After performing this analysis, we were surprised about how precise the forecasts were. We agreed that this is due to the lower volatility of bond prices as Reilly, et al. (2000) had stated as

¹⁷ The time expressed in the graph is from 1/16/2015 to 2/02/2015. ($t=12$ days) (We used the American date format due to EViews).

¹⁸ We used the vertical red line to highlight the event day (1/22/2015).

a finding of their empirical research. They found that the annual bond volatility is dependent on the prior year's bond return volatility and this means bond volatility is relatively persistent. Given this behaviour of bond yields, with our ARMA model, we are now able to confirm the results of our previously conducted event study. Recalling that the maturities and countries we have used gave significant results in the event study analysis, we can confirm our findings also with the ARMA forecasts that showed actual observed yields being lower than expected yields. If the PSPP announcement did not take place, the yields would not have decreased by that much, meaning that the markets reacted immediately to the announcement. This is because investors are expecting the yields of euro area sovereign bonds to decrease in the future, when the ECB will start the purchase programme on 9 March 2015. These expectations are immediately reflected in the lower yields following the announcement on 22 January 2015.

5. Conclusion

We have examined the effect of the ABSPP/CBPP3 and the PSPP announcements on bond yields in the Eurozone using the event study methodology and found significant abnormal variations in yields around these two announcements. These changes were mostly negative (with very few exceptions, such as the Austrian 20Y and 30Y bonds, as well as Dutch 30Y bonds) suggesting that the yields dropped as an immediate effect of the announcement. This is due to investors expecting lower future yields for sovereign euro area bonds as a consequence of the ECB QE programme. The monthly asset purchases of up to €60 billion will result in a higher demand for sovereign debt securities and thus increase their prices and thus in return will lower their yields (see bond pricing formulas in appendix A3).

We then used ARMA models in order to forecast how bond yields were expected to move if the PSPP announcement, on January 22, had not taken place. The results confirmed our initial hypothesis, and we have found that forecasted yields, calculated after the announcement, were above the actual yields. Thanks to these two analyses, we clearly state that the market reacted to the ECB announcements of unconventional monetary policy. By doing so, the market is expecting yields in the euro area to decrease in the near future.

The program officially started on 9 March 2015, so it is still too early for us to discuss about the long term effects of the program. Our aim was to identify, quantify and analyse the immediate market reaction right after the announcements. We could confirm that a significant market reaction happened. This may somewhat be surprising, since many had expected the ECB to announce QE on that day. But according to Flanders (2015) this reaction can reflect what investors needed to hear: that the ECB is willing to achieve its inflation target by adopting unconventional monetary policy measures. Flanders (2015) also states that such a program was also needed to give a proper response to the deflation that is currently threatening the Eurozone. If this response of the ECB was an effective one, we cannot and dare not say with our research. We are expecting to see more research being published soon about the ECB quantitative easing policy. For long term effects however, this might still take several years.

Finally, we would like to highlight again the weakness of our model used in chapter 3, which fails to account for the negative drift terms in the yield time series. A possible remedy for this would be to merge our models and thus using ARMA forecasting to model expected normal returns. This would have improved our results and thus should be recommended for any future event studies on this topic.

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Appendix

A1. Acronyms and definitions

ABSPP:	Asset Backed Securities Purchase Programme
CBPP3:	3 rd Covered Bond Purchase Programme
EAPP:	Extended Asset Purchase Programme (= ABSPP + CBPP3 + PSPP)
ESM:	European Stability Mechanism
LTRO(s):	Long Term Refinancing Operations
OMT(s):	Outright Monetary Transactions
PSPP:	Public Sector Purchase Programme
QE:	Quantitative Easing
SMP:	Securities Markets Programme

A2. Event timeline

4 September 2014: ABSPP and CBPP3 announcement

20 October 2014: CBPP3 start

21 November 2014: ABSPP start

22 January 2015: PSPP announcement

9 March 2015: PSPP starts

A3. A quick review of bond valuation

In the following, we will quickly review how bonds are valued in order to help our evaluation of our results. This review, including all the formulas, is based on chapter 6 of Berk & DeMarzo's book "Corporate Finance" (2014, pp. 169-204).

Bonds are debt securities that are sold either by corporations or governments. This allows them to raise big amounts of debt financing in the capital markets. A bond usually has two types of payments to the investors: the interest payment, called the coupon and the principal, called the face value. Coupons are paid periodically, often semi-annually, and the face value is paid back upon the bond's maturity, at which it expires. The maturity can be regarded as the time horizon of a loan, which can range from one month (short term) to 30 years (very long term). Typically, a bond's face value are standard increments, e.g. 100€ or 1000€.

Conventionally, the coupon rate is expressed as an APR (Annual Percentage Rate) and determines the amount of each coupon that is being paid. Let C denote a coupon payment expressed as a function of the coupon rate, the face value and the frequency of coupon payments:

$$C = \frac{\text{Coupon rate} \times \text{face value}}{\text{no.of annual coupon payments}} \quad (22)$$

Thus, a bond with face value 1000€, a 10% coupon (APR) and a semi-annual coupon payment, has payments of $1000\text{€} \times 10\%/2 = 50\text{€}$ twice a year.

A3.1. Zero-coupon bonds

There is also another common type of bonds that actually do not pay any coupons. These are called zero coupon bonds, or pure discount bonds, which are the simplest type of bond. Thus, the only cash flow towards investors is the face value upon maturity. This means that those bonds must be issued at a discount (hence the name), and the difference between this discounted issue price and the face value presents the interest paid to investors.

Another important concept for bond valuation is the yield to maturity (YTM)¹⁹. It is the discount rate that sets the present value of the bond payments equal to its current market price. For an n -year zero coupon bond, YTM is given by the following formula:

$$YTM_n = \left(\frac{FV}{P} \right)^{1/n} - 1 \quad (23)$$

¹⁹ N.B.: It is more common to just talk about the "yield" of a bond, although the term YTM would be more correct.

Where:

- P: Current market price of bond
- FV: Face value
- n: no. of periods to maturity
- YTM: Yield to maturity

The YTM in the equation above is the rate of return per period for holding the bond from today until maturity at date n. (Berk & DeMarzo, 2014) For a default-free zero-coupon bond maturing at date n, the YTM equals the risk-free (interest) rate. Thus, the risk-free rate with maturity n is given by:

$$r_n = YTM_n \quad (24)$$

A3.2. Coupon bonds

Coupon bonds pay back the face value at maturity, like zero-coupon bonds, but in addition also pay regular coupon interest payments. For a coupon bond, YTM is the interest rate y that solves the following equation for the current coupon bond market price:

$$P = C \times \frac{1}{y} \left(1 - \frac{1}{(1+y)^n} \right) + \frac{FV}{(1+y)^n} \quad (25)$$

Where:

- y: interest rate or YTM
- C: coupon payment
- FV: face value
- n: no. of periods to maturity

With this equation, if we know three of the four variables, we can easily calculate the missing one. For example, if we know the yield, the coupon payment, the face value and the number of periods to maturity, we can calculate the current market price of the bond. This formula also shows us that if the price of bond increases, its yield decreases, and vice-versa. Thus, yields and prices are often used interchangeably. In fact, usually yields are quoted by traders instead of prices. If prices are quoted, than it is usually as a percentage of its face value, e.g. a price of 95,432 implies an actual price of 954,32€ if the face value is 1000€.

A3.3. The behaviour of bond prices

Coupon bonds can trade at a discount (price < face value), at par (price = face value), or at a premium (price > face value). In the following, we shall discuss what this means and how bond prices change due to the passage of time and through fluctuations in interest rates.

When a bond trades at a discount, investors will earn a return on both the face value and the coupons. Hence, the bond's YTM exceeds the coupon rate.

For bond that trades at a premium, investors' return is diminished by a price that is higher than the face value. Thus, the YTM is lower than the coupon rate. An alternative explanation would be that a bond becomes more valuable, reflected in a higher price, the higher its coupon rate is relative to the interest rate required by investors for its level of risk.

When a bond trades at a price equal to its face value, then it is said to trade at par. This means that its coupon rate is equal to the YTM.

Table 6 below summarizes the above mentioned properties, assuming $R_f > 0$

Table 6: Bond properties

Price and face value	Bond trades	Coupon rate and YTM
$P > FV$	“above par” / “at a premium”	$CR > YTM$
$P = FV$	“at par”	$CR = YTM$
$P < FV$	“below par” / “at a discount”	$CR < YTM$

Usually, when a coupon bond is issued, the coupon rate is chosen so that a bond trades at or close to par, i.e. at face value. The passage of time affects bond prices in the following way: For a zero-coupon bond, when the YTM stays constant, the bond price increases with the passage of time (that reduces the time to maturity), since the discount gets smaller. Ultimately, the bond price will approach face value.

For a coupon bond, the situation is a bit more complicated. Whenever a coupon is paid, the bond price drops by the amount of that coupon. The value of a coupon bond increases until the coupon is paid and then drops after it has been paid. This results in a kind of saw tooth pattern. Since this pattern is quite predictable, investors are more interested in price changes due to changes in the yield. Thus, the clean price is often quoted instead of the dirty price:

$$\text{Clean price} = \text{Cash(dirty)price} - \text{Accrued interest} \quad (26)$$

Where:

$$\text{Accrued interest} = \text{Coupon} \times \left(\frac{\text{days since last coupon}}{\text{days in coupon period}} \right) \quad (27)$$

By deducting accrued interest, which also follows a saw tooth pattern, the initial saw tooth pattern is eliminated.

When it comes to interest rate changes and bond prices, we note the following: as interest rates in the economy fluctuate, the yields demanded by investors change accordingly. Assuming interest rates increase, the investors' required yields will also increase, resulting in bond prices to fall. For a decrease in yields on the other hand, bond prices will increase. The bond's duration is a formal measure of its sensitivity towards interest rate changes.

A4. Akaike's information criteria

A4.1. Germany

Germany_3Y

ARMA(1,1)

AIC

AR/MA	0	MA(1)	MA(2)	MA(3)
0		3,687431	3,700871	3,714464
AR(1)	3,694405	3,708060	3,721669	3,734762
AR(2)	3,715038	3,728826	3,438433	3,451074
AR(3)	3,736022	3,749225	3,707019	3,718494

Germany_5Y

ARMA(1,1)

AIC

AR/MA	0	MA(1)	MA(2)	MA(3)
0		2,29417	2,307759	2,319410
AR(1)	2,302706	2,314541	2,317101	2,326104
AR(2)	2,321873	2,323407	2,336871	2,339718
AR(3)	2,342997	2,186841	2,346379	2,360350

Germany_10Y

ARMA(3,3)

AIC

AR/MA	0	MA(1)	MA(2)	MA(3)
0		-3,717207	-3,720311	-3,706966
AR(1)	-3,707472	-3,717719	-3,704369	-3,693825
AR(2)	-3,711268	-3,699426	-3,688553	-3,709467
AR(3)	-3,695992	-3,683018	-3,800606	-3,808271

A4.2. Italy

Italy_3Y

ARMA(2,2)

AIC

AR/MA	0	MA(1)	MA(2)	MA(3)
0		-2,865208	-2,851527	-2,844597
AR(1)	-2,861428	-2,849714	-2,858358	-2,853562
AR(2)	-2,848698	-2,871032	-2,891647	-2,877766
AR(3)	-2,837759	-2,836637	-2,865133	-2,881146

Italy_5Y

ARMA(3,3)

AIC

AR/MA	0	MA(1)	MA(2)	MA(3)
0		-3,668688	-3,657493	-3,652787
AR(1)	-3,672046	-3,684857	-3,675831	-3,663896
AR(2)	-3,671830	-3,671830	-3,702397	-3,669595
AR(3)	-3,652508	-3,676082	-3,690911	-3,706188

Italy_10Y		ARMA(2,2)				
AIC		AR/MA	0	MA(1)	MA(2)	MA(3)
0			-4,941091	-4,933930	-4,930218	
AR(1)		-4,951790	-4,963238	-4,949445	-4,935699	
AR(2)		-4,940555	-4,945807	-4,932066	-5,082469	
AR(3)		-4,932550	-4,927249	-4,938922	-4,950421	

A4.3. Spain

Spain_3Y		ARMA(2,2)				
AIC		AR/MA	0	MA(1)	MA(2)	MA(3)
0			-2,80394	-2,791018	-2,836435	
AR(1)		-2,803820	-2,792308	-2,822614	-2,825151	
AR(2)		-2,791970	-2,810213	-2,847570	-2,846360	
AR(3)		-2,811826	-2,814396	-2,824871	-2,811513	

Spain_5Y		ARMA(2,3)				
AIC		AR/MA	0	MA(1)	MA(2)	MA(3)
0			-3,369047	-3,364827	-3,388908	
AR(1)		-3,376468	-3,392837	-3,400742	-3,384499	
AR(2)		-3,367710	-3,393743	-3,383632	-3,427304	
AR(3)		-3,386914	-3,401606	-3,422512	-3,409494	

Spain_10Y		ARMA(2,3)				
AIC		AR/MA	0	MA(1)	MA(2)	MA(3)
0			-4,816331	-4,822573	-4,850397	
AR(1)		-4,832150	-4,873593	-4,887833	-4,876270	
AR(2)		-4,835895	-4,880792	-4,874010	-4,899046	
AR(3)		-4,869008	-4,870316	-4,884737	-4,884323	

A5. Forecast of yields using an ARMA model

A5.1. Germany

Figure 8: Forecast Germany 3Y Yield

$$\text{ARMA (1,1)} \quad y_t = -0,0270 - 0,1392y_{t-1} + 0,0965u_{t-1}$$

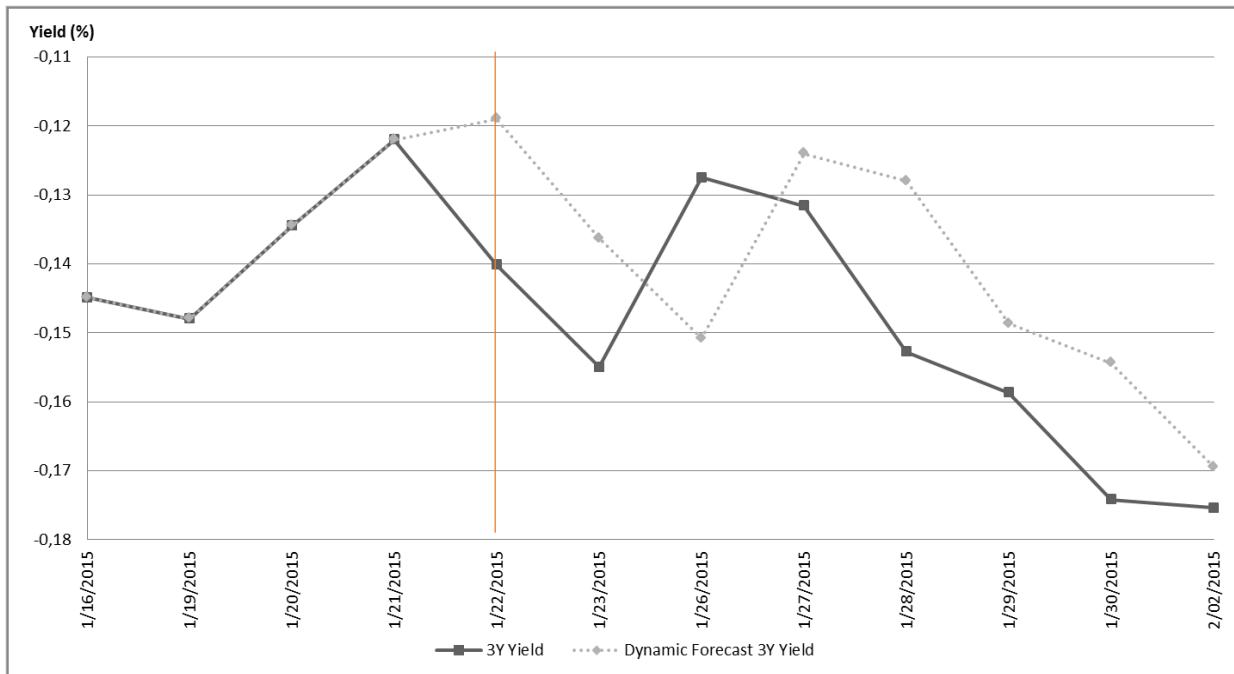


Figure 9: Forecast Germany 5Y Yield

$$\text{ARMA (1,1)} \quad y_t = -0,1053 + 0,0744 y_{t-1} + 0,1930 u_{t-1}$$

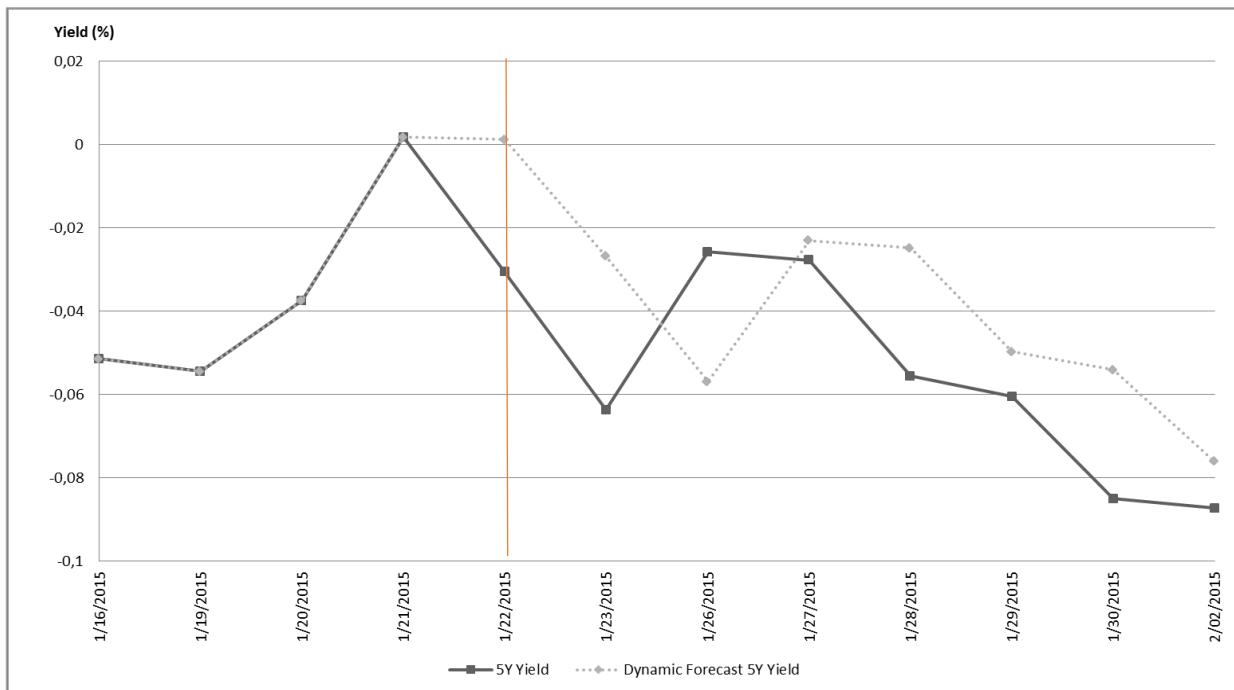
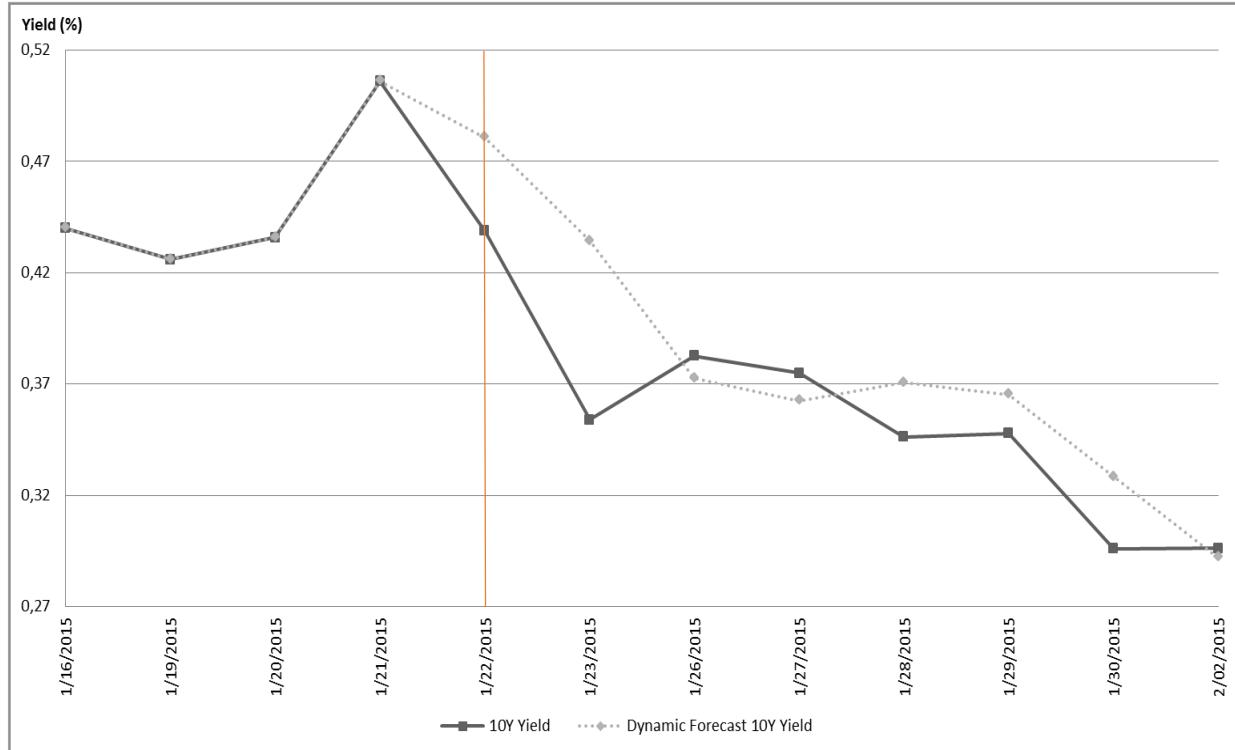


Figure 10: Forecast Germany 10Y Yield

ARMA (3,3) $y_t = -0,0063 - 0,0883y_{t-1} + 0,0964y_{t-2} + 0,9628y_{t-3} + 0,0227u_{t-1} - 0,0130u_{t-2} - 0,9514u_{t-3}$



A5.2. Italy

Figure 11: Forecast Italy 3Y Yield

ARMA (2,2) $y_t = -0,0018 + 1,5403y_{t-1} - 0,9832y_{t-2} - 1,5437u_{t-1} + 0,9669u_{t-2}$

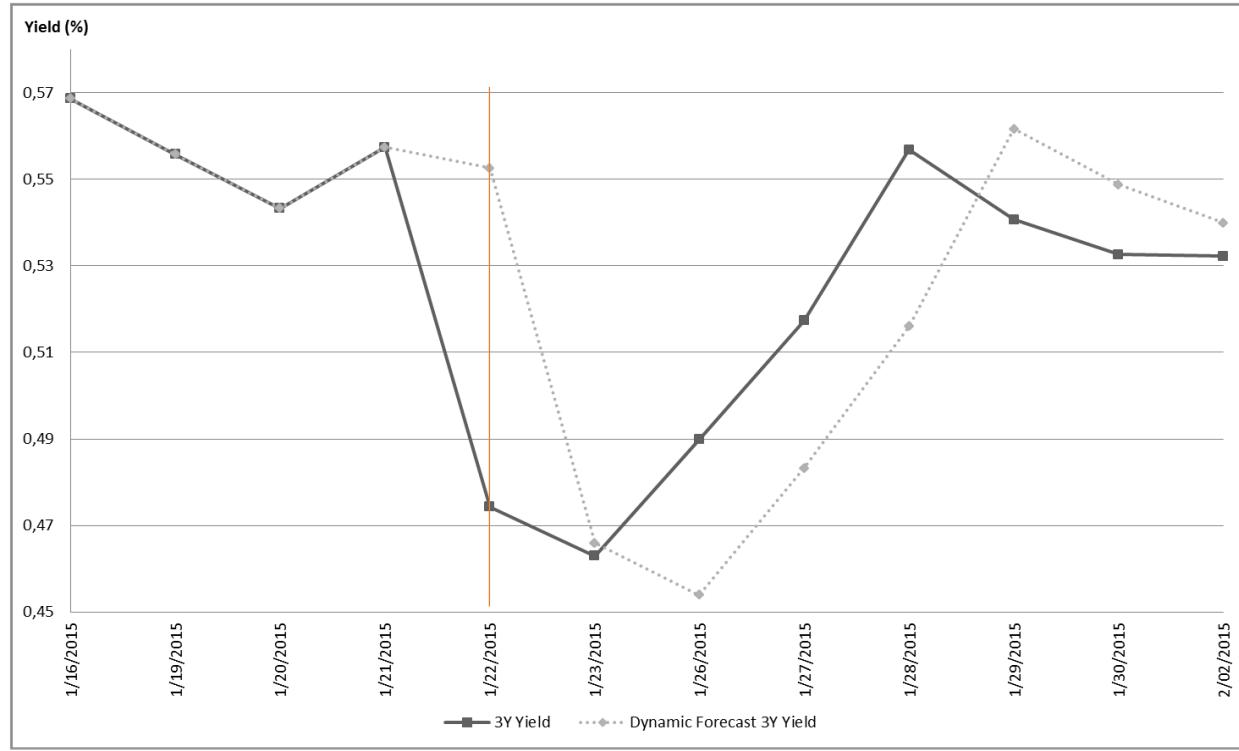


Figure 12: Forecast Italy 5Y Yield

ARMA (3,3) $y_t = -0,0027 + 0,5963y_{t-1} + 0,4882y_{t-2} - 0,9466y_{t-3} - 0,6530u_{t-1} - 0,4236u_{t-2} + 0,8760u_{t-3}$

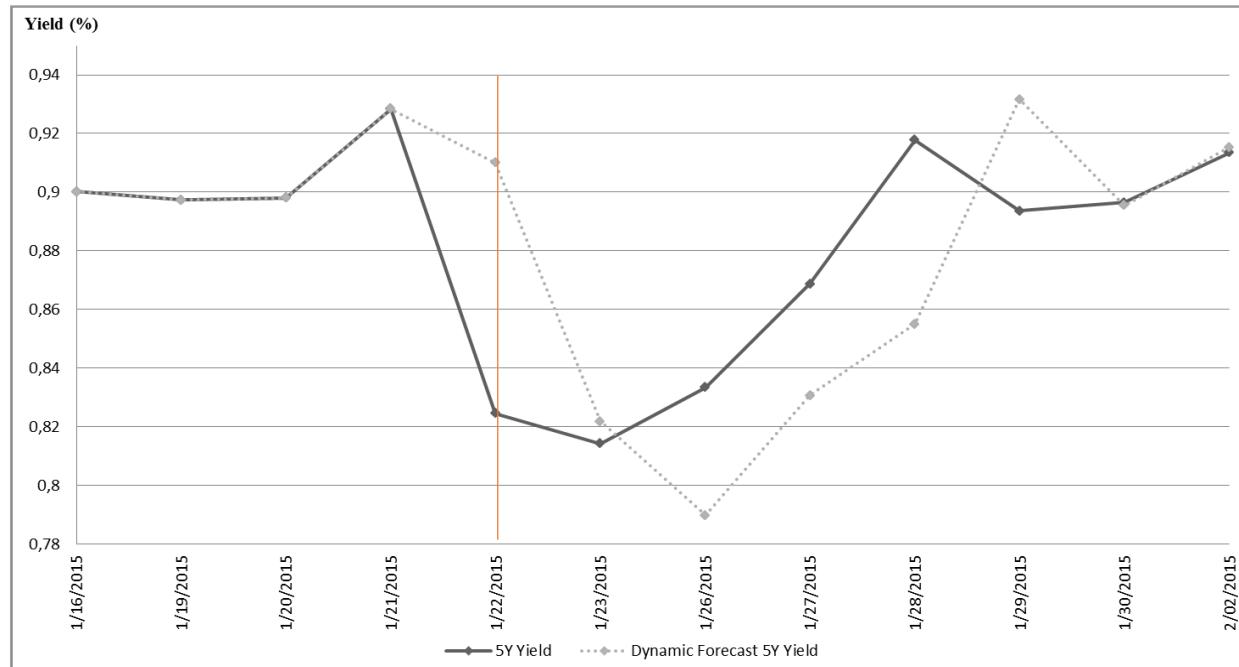
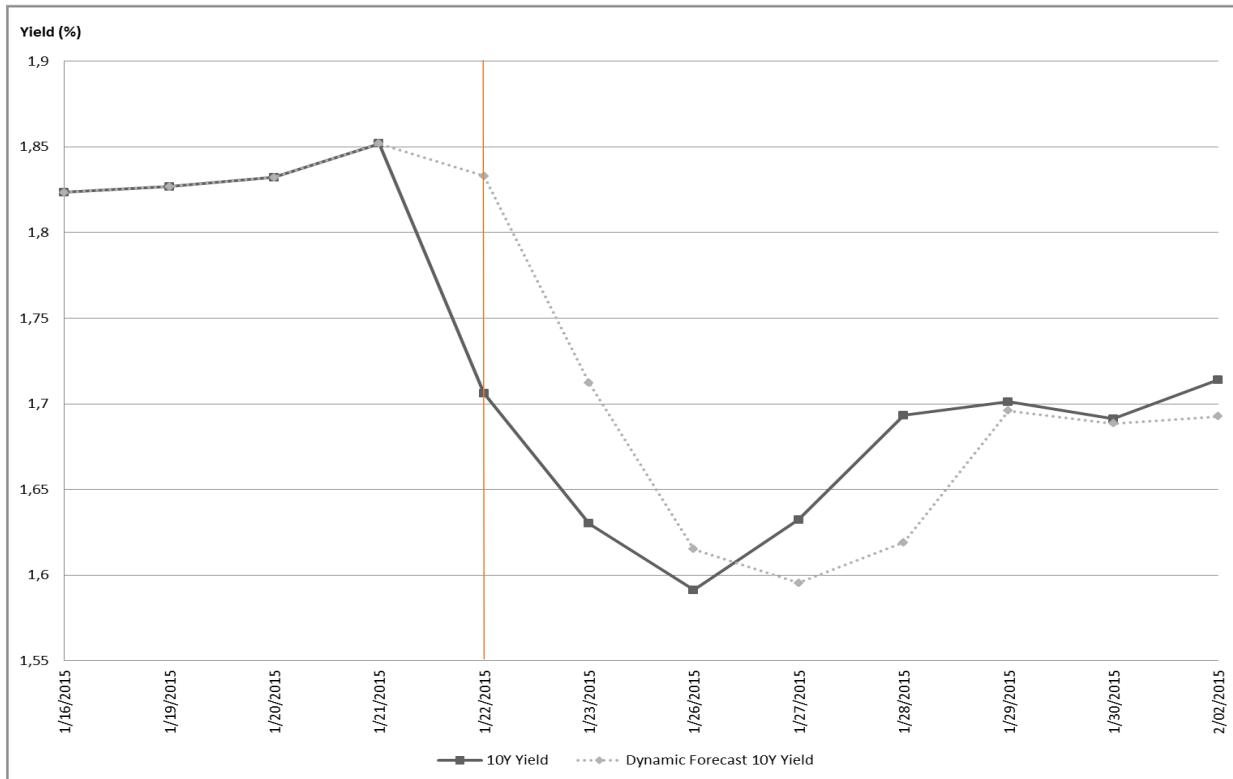


Figure 13: Forecast Italy 10Y Yield

ARMA (2,2) $y_t = -0,0030 - 0,9967y_{t-1} - 0,0710y_{t-2} + 0,9250u_{t-1} - 0,0755u_{t-2}$



A5.3. Spain

Figure 14: Forecast Spain 3Y Yield

ARMA (2,2) $y_t = -0,0005 - 0,8474 y_{t-1} - 0,8129 y_{t-2} + 0,9803 u_{t-1} + 0,9849 u_{t-2}$

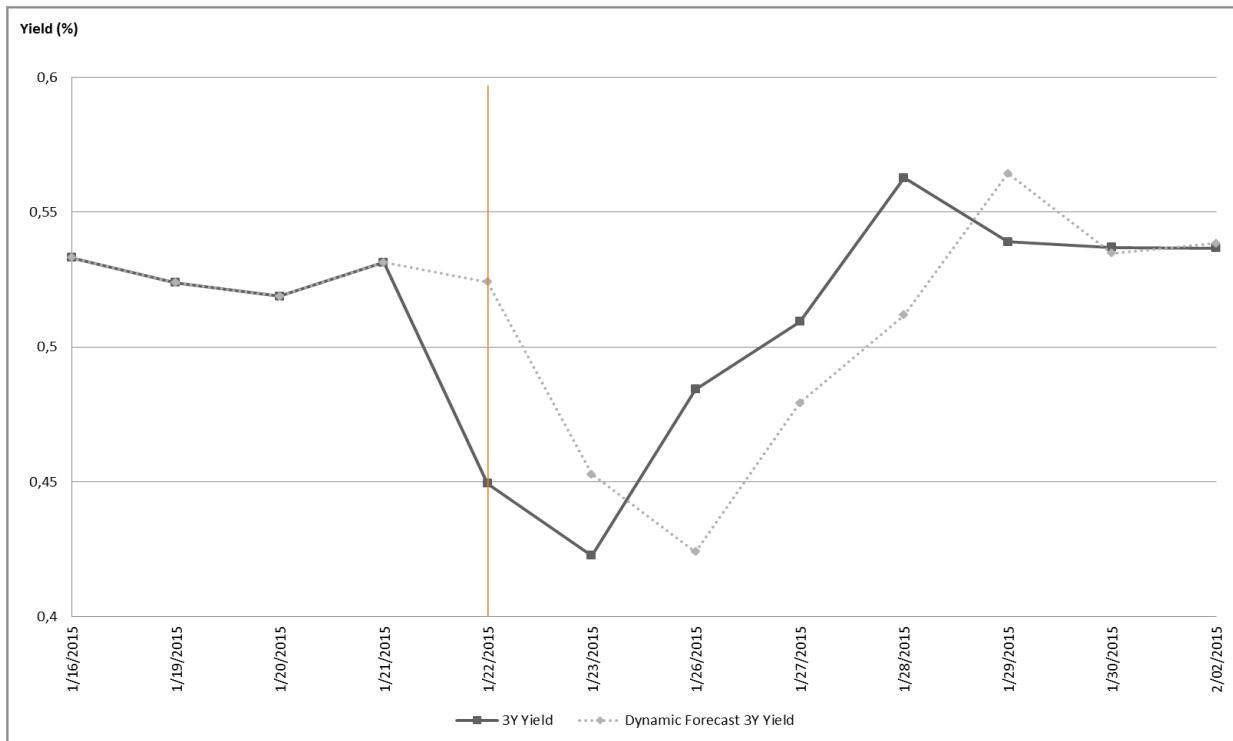


Figure 15: Forecast Spain 5Y Yield

ARMA (2,3) $y_t = -0,0010 - 0,0266 y_{t-1} + 0,7417 y_{t-2} + 0,0278 u_{t-1} - 0,7879 u_{t-2} - 0,2398 u_{t-3}$

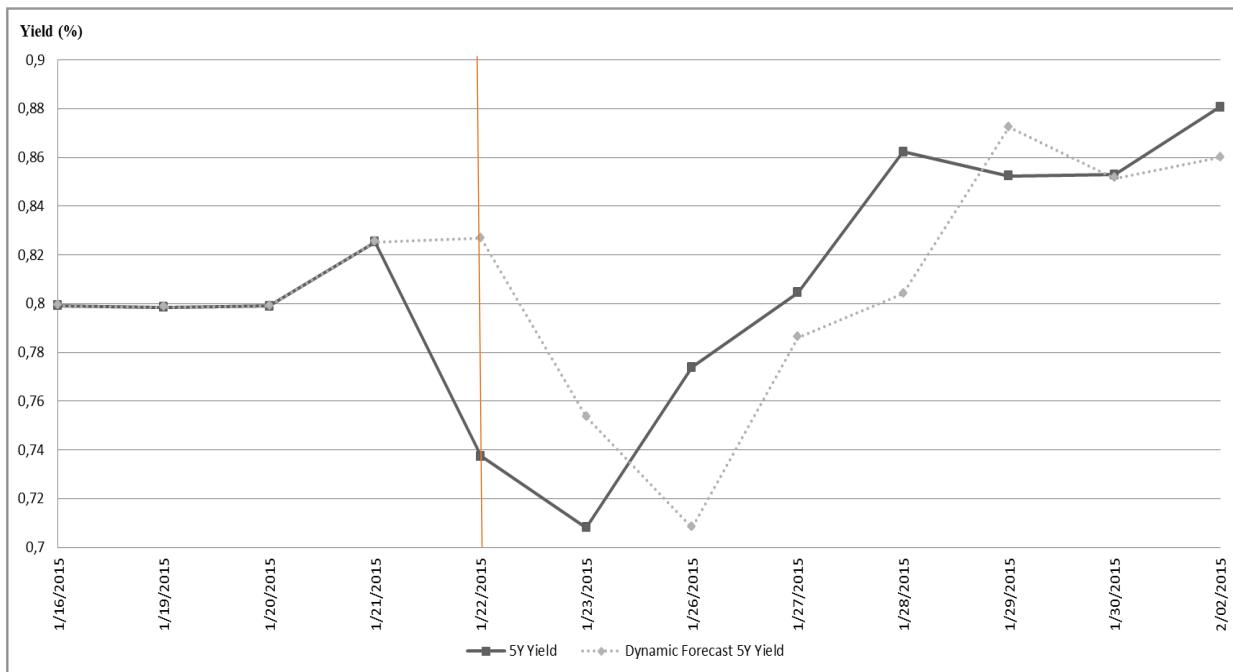
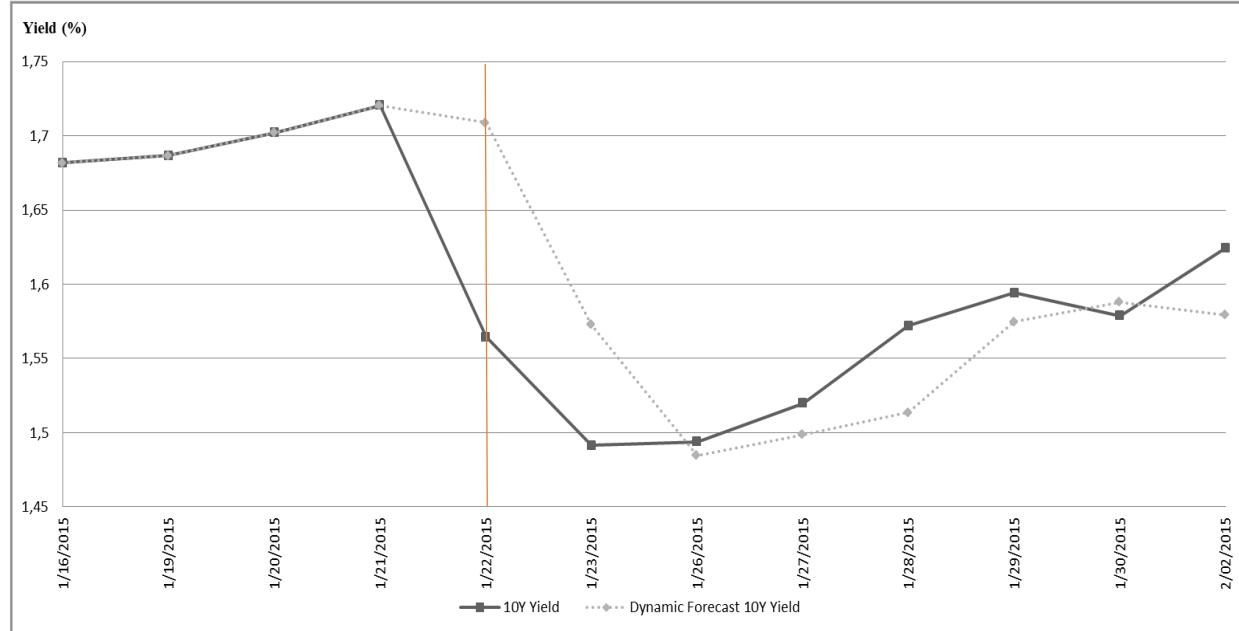


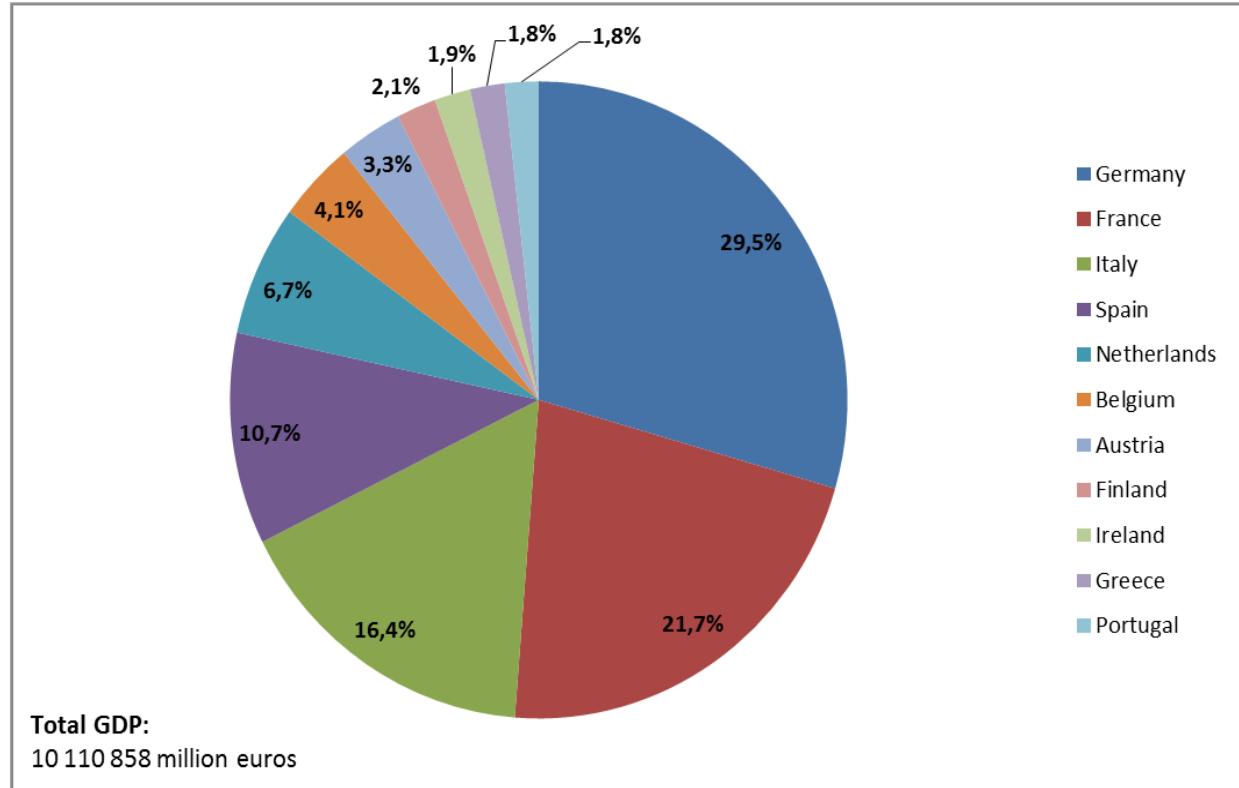
Figure 16: Forecast Spain 10Y Yield

ARMA (2,3) $y_t = -0,0033 + 0,0141y_{t-1} + 0,7550y_{t-2} - 0,0078u_{t-1} - 0,7228u_{t-2} - 0,2468u_{t-3}$



A6. Miscellaneous graphs

Figure 17: Euro area countries by GDP size (market prices)



Source: (Eurostat, 2015)