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Ph.D. Candidate:

GIULIA RIVOLTA

Ph.D. Supervisor:

Prof. ALESSANDRO MISSALE

Ph.D. Coordinator:

Prof. MICHELE SANTONI

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Introduction

The peculiarity of the European Monetary Union is that member countries are fiscally independent but they share the same currency since January 1st 1999, when they locked their national currencies together by fixing their exchange rates against each other. The monetary union implied the creation of a unique central bank for the Euro area and the national central banks had to transfer many of their powers to the European Central Bank (ECB henceforth) that became responsible for conducting monetary policy.

The objective of the ECB is price stability in the Euro area. In conducting monetary policy towards the achievement of this goal the ECB has to face several issues. The main problem is due to the fact that the implemented policy measures might not be optimal for all countries if they are in different phases of the business cycle or they have different fundamentals and economic structures. These last aspects are related also to the issue of the monetary policy transmission mechanism: even though a policy action is optimal for all members, its ultimate effects might differ across countries because of different propagation mechanisms. These issues have been extensively studied by both theoretical and empirical literature.

After 2008, with the spread of the financial and sovereign debt crisis, the short-term rate turned out not to be anymore sufficient to achieve price stability and the ECB had to intervene with unconventional measures and macro-prudential instruments in order to maintain financial stability. The deep changes in the economic environment brought about by the crisis did not shift away the attention from the original issues of optimal monetary policy and its transmission mechanism. Instead, they gained new attention as it became necessary to design new monetary policy interventions and study their effects across countries.

This thesis wants to contribute to this literature analysing the effects of unconventional measures, the conduct of monetary policy in the Euro area and the effects of the crisis on the economic structures of member countries.

The effects of ECB unconventional measures on government bond yields

The first chapter deals with the effects of unconventional monetary policy measures implemented by the European Central Bank since 2007 to cope with the financial and sovereign debt crisis. These measures had different scopes but their implementation was aimed at restoring a correct monetary policy transmission mechanism so that assessing their actual propagation mechanism is of crucial interest. In particular, the chapter focuses on government bond yields in secondary markets, as they became the direct expression of the sovereign debt crisis in the Euro area, and it deals with two aspects of the transmission mechanism: the first one is the expectational channel and the second one is the effect of liquidity injections. Both analyses are based on event-study techniques.

The analysis of policy announcements shows that the expectational channel actually shaped market movements. The announcements that produced the most relevant effects were the ones about the Covered Bond Purchase Programmes, the Securities Markets Programme, the Outright Monetary Transaction programme and the rumors about the lengthening in the maturity of LTROs in early December 2011.

The analysis of liquidity injections (LTROs) considers 10-year government bond yields of 10 Euro-area countries and 6 extra Euro-area countries and it allows to evaluate if there had been positive spillovers from the banking to sovereign debt. Results show that the unfolding of the European sovereign debt crisis completely changed the impact of liquidity injections as they led to a rise in interest rate spreads for highly indebted countries. This finding raises some issues about the effectiveness of monetary policy during unconventional times especially when market tensions are not due to monetary issues like the lack of liquidity but rather they are caused by fiscal issues like debt sustainability. In this context liquidity injections had the effect of exacerbating rather than mitigating market tensions.

The ECB monetary policy reaction function

In order to assess the conduct of monetary policy in the Euro area since the beginning of the EMU and also considering the crisis period, the second chapter estimates a monetary policy reaction function for the ECB over the period 1999-2013. The reaction function features time-varying coefficients and heteroskedasticity so to allow for different responses depending on actual economic conditions.

To better understand the behaviour of the ECB, this chapter considers several different specifications for the monetary policy reaction function. The baseline specification is a Taylor rule where the monetary authority is considered to target the current annual inflation rate and the output gap. Then the monetary policy reaction function is extended by adding other variables that might have been considered by the ECB, namely M3 growth, a commodity price index, the real exchange rate, a government bond yield spread index, a stock market volatility index and bank loans.

The results for the two main variables, i.e. output gap and inflation, show that the ECB stabilized output mainly during the peak of both the dot-com bubble in 2001 and the crisis in 2009. Instead the coefficient of inflation is rarely significant and only over the period 1999-2001 and in 2007. Among the other variables considered, only the government bond yield spread index and bank loans have been found to be able to significantly explain the conduct of monetary policy. Overall, in line with the related literature, I found evidence of a shift in the conduct of monetary policy during the crisis as from 2008 on the ECB increased again its sensitivity towards output but it also started to track new variables like sovereign bond yield spreads and bank loans.

The effects of the crisis on cross-country heterogeneity in the Euro area

The last chapter studies the effects of the recent economic crisis on the macroeconomic developments in the Euro area focusing on cross-country heterogeneity. The aim is not to study the the crisis mechanism but rather to provide a better understanding of what happened during the crisis in light of historical structural macroeconomic relationships.

The type of heterogeneity considered here is the asymmetry in macroeconomic fundamentals generated by the crisis shock. The focus is on Euro-area aggregates and the four biggest European economies, namely France, Germany, Italy and Spain, as they also well represent the different macroeconomic developments occurred during the crisis. The analysis is based on a conditional forecast exercise from mid 2007 on by which Euro-area variables are predicted conditioning on the actual path of some US variables which are intended to capture the crisis shock. By comparing the forecast with the actual path of the variables it is possible to evaluate whether, given the effects of the crisis in US, pre-crisis structural macroeconomic relationship are able to explain Euro-area economic developments from 2008 on. When this is not the case, it means that either a structural break or an idiosyncratic shock occurred.

Results show that the effects of the crisis have been much more heterogeneous than what implied by structural relationships and the crisis shock. The conditional forecast of single-country variables shows that their evolution is much more less predictable than the one of Euro-area aggregate variables suggesting that either a structural break or a strong idiosyncratic shock affected the Euro area after 2008. Finally, the sovereign debt crisis by itself seems not to be able to explain neither business-cycle and inflation heterogeneity, nor the recent recession and economic slack.

Chapter 1

An Event-Study Analysis of ECB Unconventional Monetary Policy Measures

1.1 Introduction

This chapter aims to evaluate the effects of the recent unconventional monetary policy measures implemented by the European Central Bank on government bond yields using an event-study approach.

Unconventional measures became necessary since the main European policy rate (interest rate on the main refinancing operations) had already been lowered to almost zero and this raises a large number of issues concerning the conduct of monetary policy. First of all, when the nominal rate is low it is likely that the real short term rate differs from the value necessary to ensure stable prices. In particular, if inflation expectations are negative, the real rate will be higher than needed while when inflation is expected to be high the real interest rate becomes negative. A second issue concerns the interest rate rule that loses its effectiveness when the nominal rate reaches the zero level. This in turns puts forward the problem of how to conduct monetary policy when the main instrument of the central bank is not anymore at its disposal.

Bernanke and Reinhart (2004) analyse three types of actions to overcome the policy problems connected to the zero-lower bound. A communicative strategy should be used to influence expectations over the future path of interest rates and inflation but then the central bank should also directly intervene by expanding and changing the composition of its balance sheet to provide liquidity and to affect yields.

These three actions have been actually implemented by several central banks around the world to respond to the financial crisis.

This work deals with the effectiveness of such extraordinary measures in particular on European government bond yields.

The reason why I focus on government bond yields is that, starting from the second half of 2009, the financial crisis, which as for then was mainly a liquidity crisis of the banking sector, spilled over involving the public finance of Euro-area countries. Therefore, the ECB had to face a double problem: ensure the correct functioning of the credit market and mitigate tensions on government debt markets.

I use an event-study methodology: I focus on the days surrounding policy announcements and policy actions because it allows me to capture the direct effects on bond yields. By studying yield changes on a day-by-day basis I can sweep aside the macroeconomic context as it is assumed to be fixed in a short period of time. Therefore significant changes in yields around some key dates can be attributed to the effects of policy news and interventions on markets.

The literature analysing the effects of ECB interventions is mainly based on the estimation of structural macroeconomic models. For example, the papers by Lenza, Pill, and Reichlin (2010), Giannone, Lenza, Pill, and Reichlin (2011, 2012), and Giannone, Lenza, and Reichlin (2012) aim at studying the monetary policy transmission mechanism, the money market functioning and credit flows. They study the effect of unconventional monetary policy by estimating a VAR model on pre-crisis data and assume that the macroeconomic relationships remained unchanged during the crisis to simulate how the economy would have evolved without any policy intervention. The evaluation of the effects of the ECB measures is then possible by comparing the simulated paths of variables with actual data. Also Peersman (2011) studies the effect of non-standard policy measures in a VAR framework, where unconventional measures are identified as innovations in credit supply caused by monetary policy actions that are orthogonal to the policy rate, finding that their macroeconomic consequences are similar to those of a traditional interest rate innovation even though they work through different transmission channels. Finally, Gambacorta, Hofmann, and Peersman (2012) and Darracq Pariés and De Santis (2013) explore the effects of unconventional interventions of the ECB in a panel-VAR framework. On the other hand, the event-study approach is used by Altavilla, Giannone, and Lenza (2014), Falagiarda and Reitz (2013) and Szczerbowicz (2014).

The work is organized as follows. Section 1.2 summarizes the recent interventions of the European Central Bank to curb the financial crisis. Section 1.3 reviews the literature about the event-study methodology. Section 1.4 analyses the effects of the ECB announcements regarding its unconventional measures on government bond yields at different maturities of ten Euro-area countries. Section 1.5 presents a panel analysis to study the direct effects of liquidity injections (represented by six LTROs with very long maturity) on 10-year maturity government bonds of ten Euro-area countries and on six extra-Euro countries. Section 1.6 concludes.

1.2 The History of Unconventional Monetary Policy

Since October 2008 the European Central Bank started to implement non-standard policy measures to provide the financial sector with extra-sources of liquidity.

In normal times, weekly main refinancing operations are the ECB's main policy instrument to provide liquidity to the banking sector because the amount allotted is not predetermined but depends on the bids of the banks, i.e. on liquidity demand. On the other hand, longer-term refinancing operations (LTROs) are conducted through competitive tenders in which each bank demands an amount of liquidity and offers an interest rate to remunerate the central bank: the total amount of liquidity to be allotted is predetermined and only the bids at higher interest rates are satisfied. In implementing the recent unconventional monetary policy measures the ECB completely overturned the scope of LTROs, which have been conducted with fixed rate tender and full allotment procedure and they have become the main source of funding for banks.

The ECB interventions prevented the collapse of the financial sector and acted along different dimensions:

- maturity transformation (the maturities of repos were lengthened);
- liquidity transformation (illiquid assets were accepted as collateral);
- transaction services (the number of eligible counterparties was increased);
- adverse selection (the counterparties' credit risk was absorbed).

In the following the unconventional actions are presented in chronological order.

The intervention of the ECB with supplementary liquidity measures has started in August 2007 when it announced a 3-month LTRO for an amount of 40 billion euros in addition to the regular monthly one, with the aim of supporting the normalization of the functioning of the euro money market. In September 2007 a further supplementary LTRO was implemented. The renewal of both these LTROs was decided in November of the same year. After few weeks the ECB announced that "in line with its aim to keep very short term money market interest rates close to the minimum bid rate in the Eurosystem's main refinancing operations, it would reinforce its policy of allotting more than the benchmark allotment amount in main refinancing operations for as long as needed and at least until after the end of the year". However these measures cannot fully be considered "unconventional" because the terms and the allotment procedures were standard. At the beginning of February 2008 the ECB announced a further renewal of the previous LTROs to consolidate the normalization of the euro area money market.

The first 6-month LTRO was introduced in March 2008. The allotment procedure was standard and so, although the term of the operation was lengthened, this cannot be considered a fully unconventional measure yet.

In October 2008, after the Lehman Brothers' bankruptcy, the ECB started to lower interest rates. Concerning liquidity measures, the Governing Council decided to increase the frequency and the size of its LTROs, and to conduct all the refinancing operations through a fixed rate tender procedure with full allotment. This implied that the ECB gave the full amount of liquidity that banks requested at a previously announced fixed interest rate, subject to being able to provide sufficient collateral. Also the list of eligible collaterals was expanded to include securities (other than ABS) rated BBB or higher. In addition, the ECB started to offer funding in US dollars and Swiss francs through foreign exchange swaps. This represents the official beginning of unconventional monetary policy measures.

In May 2009 the ECB announced the Enhanced Credit Support programme by which it introduced three longer-term refinancing operations with maturity of 12 months at a quarterly frequency with fixed rate tender procedures and full allotment. Moreover, the European Investment Bank (EIB) became an eligible counterparty in the Eurosystem's monetary policy operations under the same conditions as any other counterparty, therefore supporting lending in the Euro area. Finally, the Governing Council announced the first Covered Bonds[1] Purchase Programme (CBPP1) (see Beirne, Dalitz, Ejsing, Grothe,

[1] Covered bonds are debt securities backed by cash flows from mortgages or public sector loans. The originator (usually

Manganelli, Monar, Sahel, Sušec, Tapking, and Vong (2011) for full details). The programme consists in the direct purchase, starting from July 2009, of Euro-denominated covered bonds (with a minimum rating of AA or equivalent) issued in the Euro area for an amount of 60 billion euros, in order to improve liquidity in private debt security markets, to ease banks funding conditions and to improve the risk profile of institutions holding covered bonds. As a matter of fact, the covered bond market is the most important privately issued bond segment in Europe and represents one of the main sources of banks' funding for mortgage lending. The financial crisis led to an increase in secondary-market spreads and then to a decrease in new issuances. This worsened the banks' liquidity condition, which was already jeopardized by the stall in money market activity so that an intervention by the ECB was necessary. The CBPP1 remained in place until June 2010. Figure 1.1 reports the purchases of covered bonds.

In May 2010 the Governing Council established the Securities Markets Programme (SMP). Under this decision the Eurosystem central banks purchased Euro-area marketable-debt instruments issued by central governments or public entities. The aim of the program was to address the severe tensions observed in certain market segments ensuring depth and liquidity in order to restore an appropriate monetary policy transmission mechanism. The actual implementation of purchases started on the same day of the announcement and figure 1.2 reports the weekly amounts of bonds purchased. This action was designed not to affect the monetary policy stance: the impact of the interventions has been sterilized through specific operations to re-absorb the injected liquidity[2]. In addition, LTROs with maturity of three and six months and fixed rate tender procedure with full allotment were scheduled. Finally, the temporary liquidity swap lines with the Federal Reserve System and US dollar liquidity-providing operations was reactivated. These operations took the form of repurchase operations against collateral and have been carried out as fixed rate tenders with full allotment. A second round of the SMP was implemented starting in August 2011.

In the following months the ECB repeatedly renewed its decision to conduct its main refinancing operations as a fixed rate tender procedure with full allotment, and it established several LTROs of different maturities (up to 12 months) always with fixed rate tender procedure and full allotment.

In October 2011, the ECB launched a new Covered Bond Purchase Programme (CBPP2) to be implemented from November 2011. The programme consisted in the direct purchase in primary and secondary markets of 40 billion euros of covered bonds with a minimum rating of BBB- or equivalent, maximum residual maturity of 10.5 years and underlying assets that include exposure to private and/or public entities. The CBPP2 was expected to be completed by the end of October 2012. Moreover, the CBPP2 portfolio was available for voluntary lending through security lending facilities offered by central securities depositories.

In the same month the ECB published the schedule of the refinancing operations from October 2011 to July 2012. Two LTROs were announced, one with a maturity of approximately 12 months, to be implemented in October 2011, and the other with a maturity of approximately 13 months, to be implemented in December 2011. Both operations would be conducted with the fixed-rate full allotment

a financial institution) remises a pool of assets to a special purpose vehicle that ask to the bank for a loan to buy the assets. The bank obtains the necessary liquidity by issuing bonds, namely "covered bonds". So the assets purchased by the SPV are the guarantee for the repayment of the bonds.

[2]Sterilization can happen, for example, through the sell of highly valued assets contemporaneously to the purchase of weaker securities (government bonds, in this case).

procedure. Moreover the Governing Council decided to continue conducting its MROs with fixed rate tender procedures and full allotment for as long as necessary and the same procedure would be applied to the monthly 3-month LTROs to be allotted in the first half of 2012.

In December 2011 the ECB surprised the markets by announcing two longer-term refinancing operations with a maturity of 36 months and the option of early repayment after one year. Not only the maturity of these operation is extraordinary, but also the amount of loans announced: almost 490 billion. The loans was not directly offered to governments but banks could use European government securities as collateral as well as mortgage securities and other commercial papers. Regarding this aspect, the ECB has extended the range of rating for asset-backed securities eligible as collateral in credit operations and it has reduced the reserve ratio from 2% to 1%. The first of this measures has been implemented in December 22nd 2011, while the second one has been put in place on March 1st 2012 for an amount of nearly 530 billion.

After the increase in the tensions on sovereign bond markets the ECB intervened announcing a new program labelled Outright Monetary Transactions (OMT) in August 2012. This program allows the Euro-area countries to ask for financial assistance to the ECB which will purchase government bonds with maturity from 1 to 3 years, provided that the country agrees to adopt specific economic measures (the so-called conditionality principle). The aim of the program is to restore and maintain "an appropriate monetary policy transmission and the singleness of the monetary policy" by lowering bond yields and therefore decreasing borrowing costs. The details of the program were published in September 2012. The official announcement of the OMT was preceded by an important declaration by the President of the ECB, at the end of July 2012, that stated that "Within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough.". An important thing to notice here is that, for the time being, no OMT purchases were carried out yet.

In the following sections I will analyse yield movements around policy announcements and actions. The long term yields of government bonds can be decomposed into the sum of the compounded short-term risk-free interest rate expected over the period to maturity and the risk premium. The SMP and the two CBPPs implemented by the ECB directly influenced the quantity of assets on the market and so it is likely that they had an effect on risk premia through a portfolio rebalancing effect or a liquidity premium effect. On the other hand, LTROs imply the injection of liquidity into the credit sector in exchange for securities to deliver as guarantee. These securities were pre-existing in the bank's balance sheet and so, in principle, this operation should not imply any direct change in yields. However a change in yields can occur depending on what banks decide to do with the liquidity. This chapter will explore this issue.

1.3 Literature Review

This section reviews the theoretical and econometric aspects of the event-study approach and presents some recent works in which this methodology is applied.

1.3.1 The Event-Study Methodology

The original application of the event-study methodology was in accounting and corporate finance research to study the wealth and price effects of mergers and acquisitions, earnings announcements, financing decisions by firms, change in the regulatory environment and macroeconomic variables. Pastorello (2001) explains the econometrics of event-studies and MacKinlay (1997) provides a review of the methodology with focus on corporate finance issues. An important contribution to this literature is the work of Fama, Fisher, Jensen, and Roll (1969) that formulated the methodology that is essentially the same as the one which is in use today. In general, the objective of an event study is to evaluate whether movements of a time series around a certain date are consistent with normal returns or they can be considered abnormal in a statistically significant way. As a matter of fact, the event study approach relies firmly on the efficient market hypothesis, by which prices and returns incorporates all the information available, and on the rational expectation hypothesis. Therefore, in the present framework, bond yields should react to announcements regarding monetary policy because expectations are affected by those announcements.

The first step to conduct an event-study analysis is to identify the events of interest and the event-period. Then it is necessary to decompose the observed returns into two components, the normal and the abnormal return. The objective of the analysis is to verify the statistical significance of abnormal returns for individual (or asset) i on an event date τ , which can be obtained as the difference between the actual return ($R_{i\tau}$) and the normal or expected return ($\mathbb{E}\left[R_{i\tau} \mid X_\tau\right]$):

$$AR_{i\tau} = R_{i\tau} - \mathbb{E}\left[R_{i\tau} \mid X_\tau\right]$$

Here X_τ is the information available to markets and that, combined with the market equilibrium relationship, allows to formulate expectations of future returns.

In general, the underlying assumption is that a security's return follows a general process of the form:

$$R_t = x_t\beta + \varepsilon_t \tag{1.1}$$

Then, when an event occurs the model is assumed to change:

$$R_\tau = x_\tau\beta + z\alpha + \varepsilon_\tau \tag{1.2}$$

Here x_t is a vector of independent variables at time t, β is the relative vector of parameters, z is a vector containing asset's characteristics that influence the return when the event occurs, α is a vector of coefficient measuring the effect of z and ε_t is a disturbance term with zero mean that possibly changes in event and non-event periods. So, the event study analysis amounts at evaluating the significance of the difference between the return generated by model 1.1 and the one coming from model 1.2, i.e. the abnormal return defined above.

This can be achieved in two different ways which differ from each other by the way they estimate the abnormal returns. The first approach estimates abnormal returns as forecast errors from a market equilibrium model and so the necessary tools are model 1.1 and the actual returns during the event of interest, which are assumed to be generated by model 1.2. The second approach estimates directly model 1.2 and evaluates the significance of parameters contained in α, where the null hypothesis is that such coefficients are zero. The second approach is the one I will apply for my study but it is useful to briefly review also the first approach.

Concerning the first approach, the models used to obtain market expectations are various in nature and types but generally they can be divided between statistical or economic models. The difference is that economic models are based on identifying assumptions while statistical models simply rely on statistical regularities. The selected model must be estimated on a pre-event sample and then the forecast will be used as expected returns to obtain estimated abnormal returns $\hat{AR}_{i\tau}$ for each asset. Then abnormal returns should be aggregated across assets and time to be able to perform statistical tests that will allow to draw inference about the overall effect of the event. In particular, the variable of interest is the average cumulative return:

$$C\bar{A}R = \frac{1}{N}\sum_{i=1}^{N} C\hat{A}R_i$$

Where $C\bar{A}R_i = \sum_{\tau} \hat{AR}_{i\tau}$ is the cumulative return of asset i, N is the total number of assets considered and τ is the event period.

Several different statistical tests can be applied and, in general, significance tests can be grouped in parametric and nonparametric tests. Parametric tests rely on the assumption that individual firm's abnormal returns are jointly normally and independently distributed, whereas nonparametric tests do not rely on any such assumptions. Normality is verified when the equilibrium model is estimated on a large sample, while independence is verified when both the event windows and the pre-event sample on which the equilibrium model is estimated do not overlap across individuals. The null hypothesis of the test is that the event had no effects on prices and so in this case a t-statistics can be used.

When the event windows are overlapping across individuals the covariance between abnormal prices is different from zero, i.e. we are in the case of clustering. Clustering leads to a distorted inference because the variance of $C\bar{A}R$ is underestimated and the null hypothesis is too often rejected, i.e. the test makes a type I error. This issue can be faced either without aggregating abnormal return by individuals but analysing them separately or estimating the equilibrium model directly on the portfolio of the N assets. On the other hand, the issue of clustering can be dealt with by accounting for cross-correlation among abnormal returns in the specification of statistical tests[3].

A more general and complementary approach for conducting an event-study analysis consists of

[3] There is an extensive literature on the specification of statistical tests for event studies as researchers tried to correct for several sources of bias like cross-correlation among abnormal returns and event-induced variance increases. Brown and Warner (1980) account for dependence across individuals' average residuals by estimating the the standard deviation of average residuals from the time series of average abnormal returns over the estimation period and then the test is constructed as the ratio between the average abnormal return in the event-time and this standard deviation. Patell (1976) and Brown and Warner (1985) proposed to use standardized abnormal returns when performing statistical tests. Standardized abnormal returns (SARs) are defined as the ratio between abnormal returns and the standard deviation of regression residuals. The purpose of the standardization is to weight less more volatile abnormal returns while giving more weight to less volatile observations. This test assumes that SARs have the same variance while Boehmer, Masumeci, and Poulsen (1991) build a test that adjusts for event-induced variance increases by estimating cross-sectionally the average volatility during the event-day with the sample standard deviation of standardized abnormal returns. However, when the event day is the same for all individuals, the scaled abnormal returns can be correlated with each other. To account for this additional source of bias in the variance of returns, Kolari and Pynnönen (2010) propose cross-correlation adjustments for both the Patell test and the Boehmer, Musumeci and Poulsen test.

estimating a multivariate regression model with dummy variables for the event date, which is the second methodology mentioned before. In particular, it is possible to define an event dummy which has value of one during the event of interest and zero otherwise. This dummy can be added to the market equilibrium model to capture the effect of the event in a specific date.

In section 1.5 I will apply a modified version of the latter approach as my regressors will only be time-varying dummy variables.

1.3.2 Applied Literature

Some drawbacks are connected to the event-study methodology. First of all, the assumptions of market rationality and efficiency are very strong and their indiscriminate application may invalidate any econometric study of financial markets. Another problem is the impossibility of controlling for other factors that occurs at the same time as the change in policy to analyse and that can by themselves justify the changes in prices and yields.

However, the event study methodology applied by Swanson (2011) seems to provide a solution to these two problems. He studies the first Operation Twist[4] implemented in 1961 to forecast the effects of the second quantitative easing operation[5] (QE2) of the Federal Reserve announced in November 2010. The methodology consists of looking at the major announcements regarding the first Operation Twist and of focusing the attention on changes in Treasury yields in a narrow window of time (about 2 days) around each announcement. This very narrow window allows to consider the macroeconomic framework as stable so that changes in prices and returns are only due to the policy announcement. Moreover, regarding the assumptions on efficiency and rationality, the considered announcements are the most relevant ones and so it is plausible that the market responded to them. The only drawback of this methodology is the inability to capture delayed effects of policy decisions. The econometric test is based on a two-sided t-test and the null hypothesis is the ineffectiveness of the announcements on the term structure at any maturity. Under the alternative hypothesis, long-term yields should decrease and short-term yields should increase or stay the same. Six different announcements are tested and the result is that four of them had significant effects on the yield curve. Their cumulative effect, although quite low (15 basis points), is also statistically significant. Finally he investigates the response of agency and corporate yields. His conclusion is that, given the similarities between Operation Twist and QE2, we should expect QE2 to lead to a decrease in long-term Treasury yields by about 15 basis points and to a much smaller effect on corporate bond yields. The result of this paper are opposite with respect to the findings of Modigliani and Sutch (1966), but at the end of their paper is stated that "any effects, direct or indirect, of Operation Twist in narrowing the spread which further study might establish, are

[4]With this operation the Federal Reserve aimed at influencing the term structure raising yields on short-term securities and lowering yields on long-term securities. Practically this was done by selling short-term bonds and purchasing long-term bonds. In September 2011 the Fed announced the "Maturity Extension Programme" which has been informally called "Operation Twist 2" for the similarities with the first Operation Twist. Following this programme, the Fed sold shorter-term Treasury securities, i.e. securities with maturities of 3 years or less, and used the proceeds to buy longer-term Treasury securities, i.e. securities with maturities between 6 and 30 years.

[5]In November 2010 the Fed announced a second large-scale asset purchase operation (LSAP2) also known as the second quantitative easing program (QE2). The programme consisted in the expansion of the Fed holdings of securities by purchasing a further $600 billion of longer-term Treasury securities by the end of June 2011. The Federal Open Market Committee declared that the aim of the program was to "promote a stronger pace of economic recovery and to help ensure that inflation, over time, is at levels consistent with its mandate".

most unlikely to exceed some ten to twenty base points", in line with the 15 basis points decline found by Swanson (2011).

Other examples of event-study analysis can be found in Bernanke, Reinhart, and Sack (2004), in Gagnon, Raskin, Remache, and Sack (2011), in Krishnamurthy and Vissing-Jorgensen (2011) and in Neely (2013).

Bernanke, Reinhart, and Sack (2004) conducted a wide range of econometric tests to evaluate the effectiveness of the Fed measures that could be used when the zero lower bound is reached. The results shows that the Fed's communications were successful in shaping market expectations and that assets purchases influenced the yield curve. On the other hand, the other three papers produce evidence on the effects of recent quantitative easing policies in the United States.

As regards the Euro area, Dell'Erba (2012) applies an event-study methodology to evaluate the effects of sovereign rating actions on yield spreads of European countries during the current debt crisis. The events of interest are both changes in ratings and outlooks by the three main credit rating agencies (Fitch, Moody's and Standard & Poor's). He builds two panel datasets: in the first one the dependent variables are 2-year and 10-year yield spreads of nine European countries while in the second one the dependent variables are credit default swap spreads. In both cases the regressors are time-varying dummy variables identifying periods surrounding rating and outlook changes. This methodology is very similar to the one that I apply in section 1.5.

The effect of policy measures related to the European crisis resolution is analysed also by Kilponen, Laakkonen, and Vilmunen (2015). They develop an empirical model for the long-term sovereign bond yield spreads of seven Euro-area countries where the regressors are proxies to capture the three main risk factors (credit risk, liquidity risk and general risk appetite) and, to allow for the possibility of contagion, also the lagged bond yield spread is included. Policy decisions are included as dummy variables on the day of the announcement. As they consider a wide set of events, policy decisions are grouped into ten categories and dummy variables belonging to the same category are combined. Results show that the proxies for credit and liquidity risk are significant while those for risk appetite do not seem to correctly capture the effect of uncertainty on the bond market. As regards policy decisions, the LTROs significantly reduced yields especially in the larger countries like France, Spain and Italy and appear to have had the strongest stabilizing effect in the short-run. Direct support to governments led to a decrease in yields of countries for which the ECB granted the purchases while increased those of Italy and Spain. The evidence on the remaining policy decisions is mixed but in general coefficients have the expected sign and some pieces of evidence can be also interpreted as a result of a flight to safety. Overall, announcements regarding the stabilization of the European debt crisis produced significant effects at least in the short run.

More recently, Falagiarda and Reitz (2013) study the effects of ECB communications about unconventional monetary policy measures on the perceived sovereign risk of Italy over the period 2008-2012. The event-study analysis considers the changes in government bond yield spreads around announcement dates finding that they have been able to reduce the sovereign risk of Italy. Stronger yields reductions are associated mainly to announcements of the CBPP, the SMP and OMTs and more in general to all announcements in the period 2010-2012. The second part of the analysis is based on a GARCH model estimated with high-frequency data. The first difference of the spread is regressed on its first and second lag, on a monetary policy surprise indicator and on a set of control variables. Results confirm the previous findings.

Szczerbowicz (2014) measures the impact of ECB announcements on money market spreads, covered bond spreads and sovereign bond spreads in the Euro area by estimating event-based regressions and she finds that the SMP, OMTs, CBPP1, CBPP2 and 3-years LTROs succeed in diminishing the borrowing costs for banks and governments. An interesting finding is that the ECB's asset purchases had important spillover effects. As a matter of fact, sovereign bond purchases had an impact also on covered bond spreads and covered bond purchases affected also sovereign bond spreads.

Finally, Altavilla, Giannone, and Lenza (2014) focused on the effect of OMT announcements with both an event-study analysis and a conditional scenario exercise. They find that the announcements had major effects on the Italian and Spanish economy by reducing their bond yields by about 200 basis points and fostering credit and economic growth with limited spillover effects in France and Germany.

1.4 Analysis of Policy Announcements

In this section I will consider all the main policy announcements of the European Central Bank from 2007 on. In particular I will focus on announcements regarding unconventional measures such as supplementary LTROs, the Securities Markets Programme, the Covered Bonds Purchase Programme and the Outright Monetary Transactions. The aim is to evaluate whether policy announcements had the power to move markets, i.e. if an expectational channel was operative, for which type of announcements and to what extent.

From a theoretical point of view, announcements regarding unconventional monetary policy measures can influence financial markets because the central bank provides the market with a signal of its willingness to restore the correct functioning of some market segments (in the case of the ECB, interventions involved the banking sector and sovereign debt markets) but also because they push upwards inflation expectations so that the real interest rates stay low leading to an expansionary effect on the economy. The existence of such transmission channels would reinforce the effectiveness of the recent extraordinary policy actions.

To conduct this analysis I will apply the same methodology as Swanson (2011) and my variables of interest are government bond yields with maturities from 3 months to 30 years.

By looking through the ECB website, 20 interesting events among the ones described in section 1.2 have been identified and they are summarized in table 1.1. The considered events cover a timely broad sample starting with the very first announcement of a supplementary liquidity injection in August 2007, when market tensions were low, and ending with the OMT program announced in the summer of 2012.

In particular, most of the selected events are "pure" announcements in the sense that I take note of the days in which ECB communicated his future plans to the public, but the actual implementation of the announced measures is typically done later in time. The only measures for which I consider the effects on yields of the actual implementation are the SMP (because implementation immediately follows the announcements) and the LTROs with maturity of one or more years. It is necessary to point out that the actual implementation of an LTRO consists of three days: the first is the announcement day, the second is the allotment day (when the ECB receive all the bids) and the third is the settlement day (when the ECB allocates money to the bidders). For LTROs I consider both the days in which the ECB communicated the intention of implementing such measures, and the days in which the call for bids took place.

Another relevant issue is the timing of the announcements as this piece of information is necessary to correctly decide the size of the event window. I consider a 1-day event window for announcements made early in the trading day or after the market closure, while I consider a 2-day event windows when the announcement was made in a late time for the investment community to completely influence markets. To get these information I searched on the platform for financial and economic news Bloomberg. There, in the ECB news section, I found the timing of the snaps releases which I consider as indicative of the effective time in which financial markets got the news.

1.4.1 Data

For the analysis on bond yields I use series calculated by Thomson Reuters and available on Datastream.

The yield curves are calculated by Thomson Reuters using a cubic spline interpolation[6] based on data of a minimum of five bonds of the required currency/rating/sector/issuer combination. Since not all bonds quote ask prices, to be sure to have a liquid price, bid prices are used. Finally, no extrapolation is performed: if no assets are available beyond a certain maturity date, the curve ends with the last standard term available.

I have decided to consider government bonds' yields of countries with different ratings, namely: Austria, Belgium, Finland, France, Germany, Greece, Italy, Netherlands, Portugal and Spain. My aim is to give a stylized but detailed view of what happened along the yield curve and so the considered maturities are: 3 months, 6 months, 1 year, 2 years, 3 years, 5 years, 7 years, 10 years, 15 years, 20 years and 30 years. These data are not provided for all countries and in such a case I have integrated the dataset with the series of the closest maturities to the ones selected. However this has not always been possible (e.g. for Greece data on intermediate maturities are completely missing) and so my dataset is not complete from the point of view of maturities. Moreover some series are short, i.e. observations start after the 2007: I have not dropped these series from my dataset because I wanted to use all information available.

Each year is made up from 260 to 262 observations which correspond roughly to the number of working days in one year. When a national holiday happens to fall on a working day the value registered in the previous working day is applied. This smooths a little the variability of data but, on the other hand, it allows to have the same number of observations in each time series. This is one of the reasons that convinced me to use this dataset.

1.4.2 Econometric Methodology

In this part of my work I will apply the event-study methodology used by Swanson (2011). In particular, the econometric methodology is based on a two-sided t-test, by which the null hypothesis is rejected

[6] Spline interpolation is a form of interpolation where the interpolant is spline, a smooth polynomial function that is piecewise-defined (it has a different shape in different areas of the horizontal axis variable), and possesses a high degree of smoothness at the places where the polynomial pieces connect (knots). So the spline fit is a data analysis technique that uses the least squares criterion to estimate the parameters of the spline polynomial model.

when the value of the test statistic is either sufficiently small or sufficiently large, i.e. there are two alternative hypothesis, one positive and one negative. This contrasts with a one-sided t-test, in which there is only one alternative hypothesis that represents either the rejection region "sufficiently small" or "sufficiently large". Concerning the objectives of this work, I consider as null hypothesis the fact that bond yields remained unchanged after the announcements of unconventional monetary policy measures. By contrast, the alternative hypothesis is that those announcements had some kind of effects on bond yields and so the null hypothesis is rejected when the value of the test statistic is either sufficiently small or sufficiently large.

In particular, the t-statistic is distributed as a Student-$\mathcal{T}$ with $T-1$ degree of freedom (where T is the number of observation in the sample) and it is calculated as follows:

$$t_{cij} = \frac{v_{cij,tl} - v_0}{\text{sd}_{cij,l}} \sim \mathcal{T}(T-1)$$

Here $v_{cij,tl}$ is the variation in yields of bond i of country c in event j at time t, which can be a 1-day variation or a 2-day variation ($l = 1, 2$), depending on the timing of the announcement and v_0 is the value under the null hypothesis. The 1-day change is calculated as the difference between the yield in t and the yield in $t-1$, while the 2-day change is calculated as the difference between the yield in t and the yield in $t-2$. Concerning the objectives of my work, I consider as null hypothesis the fact that bond yields remained unchanged after the announcements of unconventional monetary policy measures. By contrast, the alternative hypothesis is that those announcements had some kind of effects on bond yields. So $v_{cij,tl} = y_{cij,t} - y_{cij,t-l}$ with $l = 1, 2$, $v_0 = 0$ and the statistics becomes:

$$t_{cij} = \frac{v_{cij,tl}}{\text{sd}_{cij,l}}$$

To reconcile this analysis with the general framework presented in Section 1.3.1, here the estimated variation is v_0 and the abnormal variation is $v_{cij,tl}$.

As I want to study the significance of the change in yields, the difference in yield variations is scaled on the standard deviation of 1- or 2-day changes of bond i in event j. The standard deviation is calculated on the 30 yield variations prior to the announcement day so it is not influenced by the variability caused by the announcement itself. A deeper explanation about the calculation of the standard deviation is needed. First of all I derived the series of 1- and 2-day changes, then the standard deviation is calculated as the square root of the yield changes' sample variance:

$$\text{sd}_{cij,l} = \sqrt{\frac{\sum_{t=1}^{n} \left(v_{cij,tl} - \bar{v}_{cij,l}\right)^2}{T-1}}$$

So T is equal to 30 and $\bar{v}_{cij,l} = \frac{1}{T}\sum_{t=1}^{T} v_{cij,tl}$ is the average variation in the time-window of event j. However, as I mentioned before, not all the time series are available for the sample period needed because they start after the beginning of 2007. If observations are not enough to calculate the 30-days standard deviation I cannot compute the t-statistics and so the related yield change is not evaluated. This however happens in very few cases and not much information is lost.

To evaluate the joint significance of yields' changes for the same announcement I use a Wald test which is distributed as a chi-squared with q degrees of freedom (where q is the number of restrictions). The most simple Wald statistic to test the significance of a single coefficient is given by:

$$W = \left(\frac{coefficient}{std.error\,(coefficient)} \right)^2$$

This is the square of the t-statistic and it is distributed as a chi-squared with 1 degree of freedom (because it tests only one restriction).

As I want to test the significance of q values, I can calculate the joint Wald statistic as the sum of q single Wald statistics which is asymptotically distributed as a chi-square with q degrees of freedom[7]:

$$W_{cj} = \sum_{i=1}^{q} \left(\frac{v_{cij,tl}}{\mathrm{sd}_{cij,l}} \right)^2 = \sum_{i=1}^{q} (t_{cij})^2 \rightarrow \chi^2 (q)$$

Such a formulation is valid under the assumption that the t-statistics are independent implying that also the variations in yields are independent. At a macroeconomic level this might seem a quite strong assumption, but for daily data we can apply the assumption coming from theoretical finance that prices evolve following a random walk, which makes variations in yields independent.

Summarizing, the procedure consists of shrinking the dimensionality of data to obtain the statistics of interest. I start from yields of different bonds (i) for different countries (c) in different events (j) and I aggregate yield variations by time (t) to obtain q t-statistics for each event. Then I aggregate t-statistics by bonds to obtain Wald statistics specific for country and events.

As regards results, following the theory I would expect that all the announcements brought a decline in bond yields for at least two reasons. First, the direct purchase of bonds by the ECB decreased the total supply of bonds in the market producing a rise in prices and a decline in returns. On the other hand, liquidity injections increased the banks' availability of funds which should in principle have raised the amount of funds invested in financial markets both because banks may have decided to directly invest in bonds but also through an increase in lending flows to the private sector. Moreover positive spillovers on sovereign debt can be due to the fact that if banks are less liquidity-constrained it is less likely that the government would have to intervene to sustain the credit sector. Indeed, evidence about the importance of the banking sector in determining the level of bond yield spreads is presented by Gerlach, Schulz, and Wolff (2010) and Acharya, Drechsler, and Schnabl (2011). Second, these unconventional measures may be interpreted as a serious engagement of the ECB to maintain stability in credit and financial markets. Therefore any announcement should have shaped expectations towards an improvement of market functioning and might be interpreted as a signal of the fact that the expansionary monetary policy would be longlasting in the future.

[7] This result is true asymptotically. Here the t-statistics have many degrees of freedom, they are asymptotically normally distributed, and then the sum of q normal distribution is a chi-square. To get the true distribution of this Wald statistics it would be necessary to sum q F-distributions as:

$$t^2 = \left(\frac{N^2}{\sqrt{\frac{\chi^2}{V}}} \right) = \frac{\chi^2/1}{\chi^2/v} = F(1, v) \, .$$

1.4.3 Results

Results are presented in tables 1.2 to 1.11.

The first event is the announcement on August 22nd 2007 of a supplementary LTRO with 3-month maturity and for an amount of 40 billion euros that, although conducted with the standard variable-rate tender procedure, represents the start of the ECB injection of liquidity to support markets. Most of the short- and medium-term yields experienced significant positive changes. The most significant effects occurred for Belgium, Finland and Germany, while there has been no significant change for Greek and Dutch bond yields. This implies that the investment community exited the government bond market. Probably investors interpreted the ECB action as a confirmation of their fears about financial market instability. The Wald test for the joint significance of the movements along the yield curve finds that changes in Austrian, German, Finnish ans Spanish yields are significant at a 1% level, changes in Belgian yields are significant at a 5% level while French yields' changes are significant at the 10% level.

One month after the Lehman's Brothers bankruptcy, on October 15th 2009, the ECB started to intervene on money markets more aggressively announcing several LTROs with 3/6-month maturity and fixed-rate full allotment procedure and the expansion of the list of eligible collaterals. This is the official beginning of the unconventional monetary policy measures. This event produced the expected effect, i.e. almost all bond yields declined on short and medium maturities. Changes are highly significant for Italy, Portugal and Spain. Yields of France, Austria and Germany have been affected with a lower significance. The Wald test finds significant changes at a 5% level for Italy and Portugal while overall changes in Spanish yields are significant at the 10% level.

On May 7th 2009 the ECB announced the Enhanced Credit Support programme and the first Covered Bond Purchase Programme. The first consisted of three LTROs with 12-month maturity and fixed-rate full allotment procedure to be conducted in June, September and December. Furthermore the European Investment Bank (EIB) became an eligible counterparty in the Eurosystem's monetary policy operations. With the the ECB engaged itself in directly purchasing of euro-denominated covered bonds for an amount of 60 billion euros. It must be also recalled that on the same day the Governing Council decided to cut interest rates by 25 basis points. The effects of these three interventions are difficult to disentangle as bond yields display changes of different sign and magnitude along the yield curve. In general, yields of bonds with shorter maturities (up to 10 years) declined, while the opposite happened in longer-term maturities. The most significant changes are for Belgian, French, German, Greek, Dutch and Spanish bonds. On the other hand, all Greek long-term yields declined significantly. Concerning the joint significance, changes for Belgium, France, Germany, Greece, Netherlands and Spain are significant at the 1% level. But why short-term yields decreased while long-term yields increased? This seems to be the opposite effect than the one produced by the Operation Twist implemented by the Federal Reserve (the Fed was selling short-term government bonds and buying long-term government bonds). These results are consistent with a shift in the investors' portfolio composition: they sold longer-term bonds for shorter-term ones. This can be justified by a lowering in short-term risk perception due to an improvement in liquidity conditions. Moreover, when the available liquidity in the credit and financial sector is increased, it is likely that a part of this liquidity will be invested also in government bonds. Also the reduction in interest rates should induce a decrease in the yield curve. Nevertheless data show a rise in long-term rates which represents an increase in bonds riskiness. The only way to explain this pattern is a flight to quality due to the CBPP1: as the ECB announced that it would buy covered bonds, investors might have switched to this type of assets. So the considered interventions had been able only to ease short-term market tensions, while concerns about long-term financial conditions remained high meaning that there was no positive spillovers on sovereign debt.

Details of the CBPP1 were published on June 4th 2009. The ECB revealed that it would directly buy covered bonds for an amount of 60 billion euros in both the primary and the secondary market, with rating not lower than BBB- or equivalent and with underlying assets that include exposure to private or public entities. Yields at all maturities and of all countries increased with very low p-values. Again, this piece of evidence suggests that there has been a flight to quality in investors' portfolio while no positive spillovers from the banking sector on expected government financial positions are detectable. However it is necessary to mention that in the same day the ECB left the interest rate unchanged after a three months of consecutive reductions. So there could have also been an expectation effect over the ECB decision: markets might have expected a further decrease in interest rates and the fact that this did not happened could have led to a perception of increased risk that translated into higher government bond yields.

On December 3rd 2009 the ECB published details of refinancing operations up to April 2010 announcing that from then on the MROs would be conducted as fixed rate tender procedure with full allotment for as long as is needed. This tender procedure would also continue to be used in the special-term refinancing operations[8] with a maturity of one maintenance period[9]. Both liquidity measures would be in place at least until April 13th 2010. This announcement is relevant because it was the first time that the ECB used the words "for as long as is needed", which is a quite binding claim and gave to the financial sector the feeling that the provision of extra liquidity would continue for long time. However, this does not appear to have had the desired effect on bond yields as most of them increased significantly. The same is confirmed by the Wald statistic. As before, it is necessary to point out that on this same day there had been the monthly meeting of the Governing Council that left the interest rates unchanged.

On May 10th 2010 the ECB established the Securities Markets Programme and implemented the first government bonds' purchases which led to a strong decrease in yields of Belgium, Greece, Italy, Portugal and Spain with t-statistics much higher than 3 in most of the cases. This is not however a pure announcement effect but the direct effect of national central banks purchases. Yields of the remaining countries display a mixed pattern with significance mostly concentrated on long-term yields increases. Furthermore the ECB decided to implement a supplementary LTRO with 6-months maturity and it reactivated the US dollar liquidity-providing operations. Overall this intervention had the expected effect of easing market tensions on riskier bonds.

In August 2011 the ECB started again to purchase government bonds. The statement of the President announcing the action in the late evening of August 7th 2011 was followed by the beginning of purchases on August 8th and this produced a significant decline in many of the considered bond yields.

[8]Special-term refinancing operations are additional open market operations with the aim to improve the overall liquidity position of the euro area banking system. Neither the schedule nor the maturity of this operations is fixed but they are usually short-term (7 or 28 days).

[9]The maintenance period is the period over which compliance with reserve requirements is calculated, i.e. the time-frame in which banks and other depository institutions must maintain a specified level of funds. The maintenance period begins on the settlement day of the first MRO following the monthly meeting of the Governing Council and usually it is a four-week period that begins on a Wednesday and ends on a Tuesday.

In particular a significant decline is shown for Austrian, Belgian, Finnish, Italian, Portuguese and Spanish bonds, except for very short maturities. In contrast Greek yields increased in the 3-months maturity with a t-statistic greater than 3 and declined on the long-medium term but not significantly. Unfortunately data on intermediate maturities are not available but these movements can be easily explained by an increase in the probability of default in the short term while, for longer horizons, perspectives remained relatively more benign. All these countries report very low p-values in the Wald test for the joint significance of changes.

On October 6th 2011 the ECB launched the second CBPP, whose technical details were published on November 3rd, and announced two supplementary LTROs of 12-month maturity. Moreover there had been the usual monthly meeting of the Governing Council that left interest rates unchanged. The evidence on yields is mixed and overall very few changes are statistically significant. As regards significant changes, Austria, Belgium, France, Greece and Netherlands recorded an increase in short-term yields while only Portuguese bonds at 6-months maturity declined. The Wald statistics is in line with these findings. Overall it seems that investors exited the bond market and it might be possible that they preferred to buy covered bonds. There is no evidence of positive spillovers from the credit sector to sovereign bonds.

On November 3rd the ECB published the details of the CBPP2 and lowered interest rates of 25 basis points. Again, in this situation the two events might have produced different effects in theory. This can also be seen in data because evidence is mixed and few results are significant, just like as two forces were pulling yields in different directions: in some cases the effect of lower interest rates prevailed and yields decreased, in other cases the flight to quality due to covered bond purchases prevailed and yields increased. In particular, yields of Austria, Belgium, Finland, France, Germany and Netherlands decreased and yields of Italy and Spain increased while Portugal display a mixed pattern. Few of these changes are significant. Significant movements happened only in Greek yields on medium- and long-term maturities with very low p-values. However this is in line with the high variability of November yields which I argue is due more to political events, namely the change of the Prime Minister and the connected high economic uncertainty, than to the ECB measures.

In the early afternoon of December 2nd some rumours about the future ECB monetary policy stance to be announced on December 8th spread into markets. Goldman Sachs predicted an interest rate cut of 25 basis point, the implementation of new LTROs with maturity of 2 years and the broadening of collateral accepted[10]. New rumours from several different sources came out on December 5th expecting new LTROs with 2- or 3-year maturity[11]. The effect of these rumours was that yields decreased all along the curve for almost all countries except for Finland, Germany and Netherlands. However significant declines apply only to Italy and Belgium in long-term yields and to all Spanish yields. The yield pattern is similar to the one presented at the implementation of the SMP. This is a relevant finding as it proves that it is not necessary for investors to physically have money in their pockets to invest, but the simple expectation of future liquidity is sufficient to move markets. It is interesting to notice that Finnish yields remained almost unchanged and German and Dutch yields increased significantly on short maturities.

[10] http://www.businessinsider.com/goldman-sachs-the-ecb-will-cut-rates-next-week-but-there-will-be-no-big-bazooka-2011-12?op=1

[11] Bloomberg ticker of the news: NSN LVQBV86K50XY. See also: http://www.thisislondon.co.uk/business/european-central-bank-expected-to-cut-interest-rates-6375411.html

This might signal that, thanks to the expected higher liquidity, investors left safer assets for riskier activities. This is the only case in which there had been positive spillovers from the banking sector to government debt.

Once the effects of rumours is taken into account it is not surprising to see that the formal announcement of the 36-months LTROs on December 8th led to significant changes only in long-term Greek yields which displayed a huge rise. Moreover the ECB cut the interest rate of 25 basis points, it extended the range of securities eligible for collateral in credit operations and reduced the reserve ratio to 1%. Evidence about yields of other countries is mixed, most of them increased but there is no significance. This lack of significance is due to the high yields volatility. So the most aggressive ECB liquidity intervention did not produce a big decrease in yields on impact just because the fall had already happened few days earlier.

To evaluate the impact of the supplementary LTROs I investigate also if the call for bids had any effects on yields., i.e. whether the fact that the ECB asked for bids for the subsequent day led to any change in yields.

In general, liquidity injections can affect government bond yields because they reduce the systemic banking risk with positive spillovers on sovereign debt, as it is less likely that governments would intervene to support the financial sector, leading to a decline in long-term rates, but also by increasing monetary aggregates and then inflation. For the call for bids of June 23rd 2009, September 29th 2009, December 15th 2009, December 20th 2011 and February 28th 2012 only very few yields show a significant change but no common pattern is identifiable and the Wald test finds no significant joint changes for any country. Most probably the market did not react to these type of announcements because they were expected. The only exception is the LTRO announced on the 25th of October 2011: yields fell significantly on longer-term bonds for Austria, Belgium, Finland, Netherlands and especially in France. Some positive and significant changes happened on Italian, Portuguese and Spanish medium-term maturity bonds.

The last three events of this event-study regard the Outright Monetary Transaction program. On the July 26th 2012 the President of the ECB declared that “Within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough.”. This statement referred to the ongoing tensions on sovereign debt markets and it had been followed by the official announcement of a new program called OMT on August 2nd 2012. The first declaration of the ECB President had a significant effect mainly on Italian and Spanish yields which decreased at all maturities while German yields increased. On the other hand, the official announcement of the OMT program led to very few significant changes in yields. The details of the program were announced on September 6th and they had been followed by an increase in yields of German and Dutch bond yields and by a decline in Italian, Portuguese and Spanish bond yields mainly at medium- and long-term maturities. Therefore announcement effects involved not only the government bonds that could be potentially bought by the ECB, i.e. bonds up to 3-year maturity, but also bonds with longer maturities meaning that this program led to positive spillovers all along the yield curve. These results are in line with the findings of Altavilla, Giannone, and Lenza (2014).

This event-study analysis highlights that overall the unconventional monetary policy measures of the ECB have been able to move market yields. However, the effects differ across countries and they are influenced by the general economic condition. Often ECB interventions led to a shift in the composition of investors' portfolios as some yields increased and some other decreased. Effects are almost always different between short- and long-term maturities and between speculative- and investment-grade countries. Moreover, the transmission mechanism is different and it depends on the nature of the ECB intervention. The SMP led to a decrease in yields for a direct supply effect that pushes up prices. On the other hand, announcements and implementations of the CBPP brought to an increase in yields consistent with a flight to quality effect. Liquidity injections through LTROs overall led to a decrease in yields which was always anticipated at the days of the announcement and so no significant yields' change is detectable on the implementation day. Significant announcement effects has been found also for the OMT program as yields of some highly indebted countries declined. These are relevant findings as they show the importance of expectations for markets' behaviour. Finally, interventions aimed at supporting banks' funding conditions, i.e. the CBPPs and the LTROs, had almost no spillovers on sovereign debt as they did not brought a decline in long-term yields.

1.5 Panel Analysis of Liquidity Injections

The previous sections found no relevant effects of actual LTRO implementation on government bond yields as in most cases markets anticipated the liquidity injection and yields moved on the announcement day. These anticipated movements in yields can be due to the action of many different types of investor, also the ones that would not receive directly the liquidity from the ECB. For example, after the announcement of a new LTRO to be implemented somewhere in the future, a private investor could decide to immediately buy government bonds if he thinks that the liquidity will ease market tensions pushing up prices. On the other hand, it is also likely that most of the banks asking for funds from the ECB would invest once they will have actually received the liquidity. As a matter of fact, if markets were efficient there would only be an announcement effects while if banks are liquidity constrained there would be also an implementation effect.

To go deeper into this matter, in this section I will focus on the actual implementation of long-term refinancing operations to assess the impact of liquidity injections by the European Central Bank. This will allow me to see if there have been any supply effect in markets, i.e. if actually banks invested the received liquidity in government bonds or if market participants did that because of an increase in lending from banks or because of a reduction in sovereign risk perception, as explained by Gerlach, Schulz, and Wolff (2010) and by Acharya, Drechsler, and Schnabl (2011). Therefore, the analysis of implementation effects will produce further evidence on whether positive spillovers from liquidity injections to sovereign debt exist. For this purpose I will consider a modified measure of yields, namely the cumulative percentage change.

As discussed before, there have been six main LTROs implemented by the ECB, four with a maturity of 12 months and two with a maturity of 36 months. It takes three days for the ECB to complete an LTRO: the first day it calls for bids, the second day bids are collected in the auction and the third day there is the settlement. These LTROs were unconventional not only for the maturity but also because they are conducted at fixed-rate tender and full-allotment procedure, meaning that the auction was not competitive and the ECB accommodated all bids.

For seek of simplicity I numbered the events chronologically so that in the following discussion:

- Event 1 refers to the 12-month maturity LTRO implemented in June 23rd - 25th 2009;
- Event 2 refers to the 12-month maturity LTRO implemented in September 29th - October 1st 2009;
- Event 3 refers to the 12-month maturity LTRO implemented in December 15th - 17th 2009;
- Event 4 refers to the 12-month maturity LTRO implemented in October 25th - 27th 2011;
- Event 5 refers to the 36-month maturity LTRO implemented in December 20th - 22nd 2011;
- Event 6 refers to the 36-month maturity LTRO implemented in February 28th - March 1st 2012.

The effects of the last two events have been already evaluated by Darracq Pariés and De Santis (2013) which uses a panel-VAR framework and identify the credit supply shock by means of the Bank Lending Survey using quarterly data. Their results show that the 3-year LTROs are expansionary over the short to the medium term as they led to an increase in GDP through the compression of lending rate spreads, the decrease of inter-bank risk and the increase of loan volume, therefore producing evidence about the importance of the bank lending channel in the transmission of these shocks.

1.5.1 Model Specification and Econometric Methodology

Concerning the econometric methodology, I keep on applying an event-study approach but here I shift the focus of the analysis from a single country to the aggregate effect. In order to do so I construct a panel where the dependent variables are bond yields of several different countries and the regressors are time-varying dummy variables capturing the changes in yields around LTROs implementations. In particular I consider a 21-day window around the auction day so that the LTROs implementation is perfectly centered and for each event I calculate the cumulative percentage change in yields:

$$y_{it} = \frac{Y_{it} - Y_{i0}}{Y_{i0}}$$

Therefore y_{it} is a series of 21 observations for each event but the first element is always zero. The aggregate vector Y has 126 observations for each country for a total of 1260 elements when considering the 10 Euro-area countries and 2016 elements when the panel is expanded with 6 extra Euro-area countries.

To reconcile the analysis with the general framework presented in section 1.3.1, here I consider as market expectations the change in the very first day of the event-window, i.e. zero. Therefore the test to evaluate whether the percentage yield growth rate is abnormal compares the actual cumulative change in yields with that measure of expectations leading to a t-test similar to the one in the previous section:

$$t = \frac{y_{it}}{\mathrm{sd}_{it}} \sim \mathcal{T}(n-1)$$

I decided to use a medium-size event-window for several reasons. First of all, and as before, I need to assume that the macroeconomic context is fixed. For this assumption to be valid the event-window cannot be too wide otherwise many other events could influence yields. On the other hand, the window cannot be too close to the implementation, otherwise I would not capture investment decisions that are shifted of few days. There is also a statistical reason for the event-window not to be too narrow: if this is the case, as I am considering cumulative changes, variations in data will be too low, reducing the power of significance tests. Moreover the choice of the 21-days window is in line with Dell'Erba (2012), which performs a similar analysis on the effects of rating changes on yield spreads.

The model I estimate is the following:

$$y_{itk} = \alpha_{ik} + \sum_{\tau=-s+1}^{s} \beta_m d_{i\tau k} + \varepsilon_{itk}$$

Here yields of each country are regressed over 20 time-varying dummies for each event, each one of them has a 1 on a different day along the 21-days window across countries and zero otherwise. In particular, the dummies capture the yield variations from the second day of the sample, which in the output tables presented below is labelled as T-9 and T is the central day of the window. The T-10 day has no dummy as it is taken as the reference day to calculate the significance of the variation and clearly including 21 dummies would lead to a perfect-collinearity problem. The model is estimated separately for each event k and so I run the estimation six times, each time including the 20 dummies of the event of interest and the sample consists of 126 observations.

The model has fixed effects because, as regressors are the same across countries, there should be correlation between individual heterogeneity and residuals. Moreover I used standard errors consistent to both autocorrelation and heteroskedasticity by clustering by individuals. Details about the econometric specification are reported in appendix A.

1.5.2 Euro-Area Countries

The first step of the analysis is to consider only the usual 10 European countries as dependent variables, namely Austria, Belgium, Finland, France, Germany, Greece, Italy, Netherlands, Portugal and Spain. Results are presented in table 1.12.

The events that produced more significant results are the LTROs of June 2009 and September 2009.

The very first 12-month maturity LTRO of June 2009 led to a significant decrease in bond yields across Europe starting from the 8th day preceding the auction meaning that investors anticipated the liquidity injection and they kept on buying bonds also for several days after: the effects of the LTRO had been persistent. Figure 1.3 shows that the decline has been progressive in time.

The second LTRO, implemented in September 2009, led to a similar decline in yields. In the first days of the window, yields increased significantly but then, from day T-4, changes become negative and highly significant. The highest declines are reached during the five days after the implementation, as can be seen also from figure 1.4.

The remaining four events do not seems to produce significant changes in yields' growth rates, however some interesting insights can be taken combining the output of the panel analysis with figures representing the evolution of single-country yields along the event windows.

The third event, i.e. the third 12-month LTRO of December 2009, produced an increase in yields which is the opposite of what one should expect if there would have been a supply effect. Significant changes are concentrated at the end of the window. Figure 1.5 confirms this pattern even though it shows some other interesting details. The growth rates remained for most of the time positive for all countries, but there were also days in which yields decreased slowing down the growth rate and also making it negative for Belgium, Finland, France, Germany and Netherlands. This is not highlighted by the panel analysis as it captures only the growth trend of yields, while it fails to evaluate changes in this growth rate from one day to the other. Moreover it stands out that Greece yield growth trend was nearly 10 times higher than the others and so this is the reason why the panel analysis always reports positive coefficients: Greece yields' changes dominates other bonds. This big difference in the magnitude of changes also justifies the big standard errors. Finally the most important thing to notice is that on December 15th (the day when the ECB called for bids) all growth rates declined and, except for Greece, Portugal and Spain, they went back to the previous levels after one week. This means that the bond markets tensions in December had been eased by the liquidity injection of the ECB.

The fourth event is characterized by aggregate positive changes in yield growth rates with almost no statistical significance. This outcome is the result of very different dynamics in single-countries yields, as depicted in figure 1.6. Two aspects are worth noting. First, countries can be divided into two groups, one that had negative changes in yields, and the other with positive changes in yields along the event window: the countries of the first group are the higher-rated ones, namely Germany, Netherlands and Finland, while the countries of the second group are Belgium, France, Italy, Portugal and Spain. Austrian yields fluctuated around the zero-growth while Greek yields remained almost unchanged in the first half of the window and then soared in the second half. This is probably due to the Greek internal political issues that increased the uncertainty around its future fiscal performance. Second, during the first ten days, yields moved almost in the same direction while after the injection of liquidity they diverged. Greece, Italy ad Spain record a sharp increase while Finland, Germany and Netherlands show a decline. This is captured by the increase in standard errors in the second half of the windows. Overall the positive changes dominated over negative ones and so panel coefficients are low but positive. So, in this case the ECB intervention led to the expected decrease in yields only for safer countries.

Event 5, the first 36-month maturity LTRO of December 20th 2011, did produce declines in bond yields all around the implementation days and after. However these changes are not statistically significant because of the high variability in yields, as can be seen from figure 1.7. Yields declined for all countries but Greece, Portugal and Italy and so the balancing between these two trends justifies the low magnitude of coefficients. These findings can be justified by the fact that markets anticipated the liquidity injections on December 2nd, when some rumours circulated about the decision of the ECB to implement two LTROs with 3-year maturity, as shown by the previous event-study analysis on single-country yields. So, this LTRO produced a decrease in yields only at announcements while the actual liquidity injection did not lead to significant supply effects.

The last LTRO displays positive coefficient for the first part of the window and then, 2 days before the implementation, they become negative but not significant. Figure 1.8 gives useful insights. All countries except Greece and Portugal exhibited a downward trend in yield changes that in most cases were negative. On the other hand, Greece and Portugal recorded growing positive changes in yields. The balancing of this different pattern explains the lack of significance of most coefficients. Figure 1.8 also shows that on March 8th there had been an abrupt decline in Greek yields which was due to the decisions taken at the monthly ECB meeting to reaccept Greek debt instruments as collateral in European credit operations and to activate a buyback scheme backed up by bonds issued by the European Financial Stability Facility (EFSF). Hence the ECB liquidity injection led to declining yields for all countries but Greece and Portugal.

Overall, from this first panel analysis, it is possible to conclude that these six LTROs produced only some of the expected supply effect on yields leading at least to a decline in growth rates and so the ECB had not always been able to mitigate bond market tensions. However, the most important thing to notice is that the effects of the first two LTROs were similar for all countries while for the following interventions it is not possible to identify a unique pattern in yields. This means that at the beginning of the crisis there was an actual lack of liquidity in markets and so the LTROs were fully effective but then the nature of the crisis changed leading to different responses in yields. This interpretation is supported by the papers of Arghyrou and Kontonikas (2012) and Afonso, Arghyrou, Bagdatoglou, and Kontonikas (2013) which find that the crisis can be divided into two main sub-periods, i.e. August 2007 - February 2010 and March 2010 onwards, in which both the determinants of spreads and their relationship were different.

To better understand this last intuition and to evaluate how the monetary policy transmission actually works inside a monetary union, in the following sections I will extend the analysis dividing the European countries into two subsets.

1.5.3 Greece and Portugal

The analysis of the effects of liquidity injections at the Euro-area level showed that during the last three LTROs yields variability has been high which might be due to differences in the evolution of yields across countries. To evaluate this hypothesis I replicate the analysis distinguishing between Greece and Portugal and the remaining eight Euro-area countries.

Results are presented in table 1.13, where, for simplicity, "NGP" stands for no Greece and Portugal, i.e. the other eight Euro-area countries, "GP" stands for Greece and Portugal and "diff" indicates the difference between the effect on the yields of the remaining eight countries and the effect on Greek and Portuguese yields.

The first LTRO, implemented at the end of June 2009, led to a decrease in all Euro-area yields that intensified after the actual settlement. The impact was however weaker on Greek and Portuguese yields as shown by the difference between the two coefficients, which in some days is highly significant. These findings complement the results displayed in table 1.12 showing that the decline in yields was actually uniform across countries.

For the second event, the LTRO implemented at the end of September 2009, the results are quite similar. In the very first days of the window, core-countries' yield growth increased significantly, then changes became negative few days before the LTRO and their magnitude increased. On the other hand, Greece and Portugal always report negative and significant changes in yields and the magnitude intensify after the implementation date. The difference between the coefficients is negative but not significant.

This yield decomposition adds some interesting insights regarding the third event, i.e. the LTRO implemented in mid December 2009. In the first half of the window all yields increased significantly. The growth was stronger for Greece and Portugal with coefficients that are more than double those of core countries. Starting from the day of implementation, changes became negative for the other Euro area countries but they are not significant.

For the fourth LTRO, implemented in the second half of October 2011, the current analysis does not add much to what obtained when we do not distinguish Greece and Portugal from other countries. Only few increases in Greece and Portugal yields are significant in the second half of the window. In this period core-countries' yields decreased but not significantly.

The results for the two LTROs with 36-month maturity show that, in both cases, Greek and Portuguese yields increased while other countries yields decreased. Coefficients are almost always highly significant and Greece and Portugal experienced the largest movements. So these LTRO produced supply effects only on core-countries' yields meaning that investors decided to sell risky bonds and purchased safer ones. Therefore, despite the high amount of liquidity injected, the ECB had not been able to reduce the spreads of debt distressed countries.

Overall, this analysis highlights that liquidity injections had the expected supply effect in most cases and especially during event 1, 2, 5 and 6, in line with what obtained from the aggregate analysis. However the distinction allows to understand that only during event 1 and 2 there had been a supply effect on all Euro-area bond yields while in the last two events supply effects only concerned core-countries' yields.

1.5.4 Sovereign Ratings

As several coefficients do not have the expected sign, to further understand the reasons behind yield changes I replicated the analysis distinguishing countries on the base of their investment category, i.e. investment grade or speculative grade. To obtain this classification I considered the sovereign credit ratings from the agency Standard & Poor's as they are publicly available on the official website. Table 1.14 shows the long-term local currency credit rating[12] of the 10 European countries considered for this analysis.

By dividing the European countries in two subsets I can evaluate the effects of the liquidity injections on the two investment category meaning that I can evaluate whether the monetary policy transmission mechanism is unique inside the monetary union.

Results are presented in table 1.15. For seek of simplicity, I used abbreviations: "INVEST" stands for investment grade countries, i.e. Austria, Belgium, Finland, France, Germany and Netherlands, "SPECUL" stands for speculative grade countries, i.e. Greece, Italy, Portugal and Spain, and "diff" indicates the difference between the effect on the yields of investment grade countries and of speculative grade countries.

The first two events, the LTROs implemented in June and September 2009, produced a significant decrease in the growth rate of both investment-grade and speculative-grade countries yields along all the time-window. The impact is higher for investment-grade countries and overall this does not add much to the previous analysis: the first LTRO led to the expected supply effect on bond yields.

The third event is the LTRO of December 2009. This analysis confirms the results reported in tables 1.12 and 1.13 as most of the coefficients are positive and significant changes occurred mainly in investment-grade countries yields. Therefore there had been no supply-effect on bond yields.

[12] The local currency international rating measures the likelihood of repayment in the currency of the jurisdiction in which the issuer is domiciled and hence does not take account of the possibility that it will not be possible to convert local currency into foreign currency, or make transfers between sovereign jurisdictions (transfer and convertibility risk).

Concerning the LTRO of October 2011, coefficients of investment-grade countries are almost always negative but not significant while the opposite happens for speculative-grade countries.

A similar evolution of yields characterizes the fifth event, i.e. the implementation of the first LTRO with 36-month maturity. Investment-grade countries display significant and negative changes all along the time-window while speculative-grade countries yields increased but significant changes apply in the first six days and in the fourth day after the LTRO implementation. The difference between changes in speculative- and investment-grade countries yields is significant all along the time window.

Also the second LTRO with 36-month maturity had the expected supply effects only on investment-grade countries. Coefficients of higher-rated bonds are significant in several days both before and after the LTRO implementation. Therefore during all these events there had been a substitution of riskier bonds for safer ones: the LTRO had been effective but not on the desired bonds because it actually increased spreads rather than mitigate market tensions.

To conclude, the LTROs that produced the desired supply-effects were only the first two (for all countries), while other supply effects were in wrong directions.

1.5.5 Italy and Spain

Section 1.5.3 shows that Greek and Portuguese yields often followed a very different pattern with respect to the other Euro-area countries, especially in the last four events. For this reason, in this section I drop yields of Greece and Portugal from the dataset and I distinguish the movements in Italian and Spanish yields from changes in the remaining six countries.

Results are presented in table 1.16, where, for simplicity, "NIS" stands for no Italy and Spain, i.e. the remaining six Euro-area countries, "IS" stands for Italy and Spain and "diff" indicates the difference between the effect on the yields of the remaining six countries and the effect on Italian and Spanish yields.

The first two LTRO led to substantial and highly significant decreases in both categories confirming the previous findings. Coefficients are always greater for the six core countries but the difference with respect to Italy and Spain coefficients is rarely significant.

Interesting results appear analysing the third event, i.e. the LTRO implemented in December 2009. Yields of Italian and Spanish bonds always increased and most changes are significant. On the other hand, yields of the remaining countries display a mixed pattern: they alternate some days in which they rose with some others in which they decreased. In general, increases are always significant while declines are significant only in two days right after the implementation. In this period bond market tensions were high and the liquidity injection produced only a temporary stop in yield growth trend of the core European countries.

During the fourth event yields of the two groups followed an opposite trend. Italian and Spanish yields increased with high significance while the other countries' yields declined but not significantly. The magnitude of changes is much greater for Italy and Spain meaning that in October 2011 investors exited from this bond market segment. Therefore this LTRO produced a flight to safety effect: investors sold riskier bonds for safer ones.

The fifth event, which refers to the first 36-month maturity LTRO implemented in December 20th 2011, produced significant declines in core countries yields with p-values that are almost always lower that 0.01. As before, Italian and Spanish yields rose but significance is present only in the first five changes. This is due to the high yields' variability, as shown by figure 1.7, which prevents from taking clear conclusions about the effects of this LTRO. Overall it seems reasonable to interpret these patterns as consistent with a flight to safety, even though effects are less clear than those of the previous event.

The last LTRO shows significant supply effects for all the bonds considered. More precisely, the event-window can be divided into two parts. The first part includes the first seven days and here Italian and Spanish coefficients are negative and significant while the others are positive but not significant. Starting from the day T-2 also coefficients of the six core countries become negative and after the LTRO they become also highly significant. Therefore, in the second half of the window all changes are negative and significant with Italian and Spanish yields experiencing the greatest movements.

Interesting insights can be deduced from this analysis. The first two events are confirmed to be the only cases in which supply effects involved all the considered yields. More relevant are the results of the last three events: during event 4 and 5 there is clear evidence of a flight to quality effect, i.e. only yields of higher-rated countries declined, while the last LTRO had been effective in easing market tensions also on Italian and Spanish bonds.

1.5.6 Extra Euro-Area Countries

After analysing the yield dynamics inside the Euro-area, in this last part I want to assess whether the ECB liquidity injections had any effect on bond yields outside the Euro area which is the usual area of influence of ECB actions.

For this purpose I expand the panel adding as dependent variables the 10-year government bond yields of Denmark, Japan, Sweden, Switzerland, United Kingdom and United States. The regressors are the usual 20 dummy variables for each event. By using categorical variables I am able to check whether the dummy variables have any significance for yields of extra-Euro countries and if the difference between the effect on Euro and extra-Euro countries yields is statistically significant. Moreover I compare variations in extra-Euro yields also with two subsets of European countries, namely Greece and Portugal and the remaining eight countries[13].

The results are presented in tables 1.17, 1.18 and 1.19. For seek of simplicity, I used the following abbreviations: "EURO" stands for the usual ten Euro-area countries, "EXEURO" stands for the six extra-Euro countries used as control variables, "NGP" stands for all countries but Greece and Portugal, "GP" stands for Greece and Portugal and "diff" indicates the difference between the previous two coefficients.

The coefficients for Euro-area countries are the same presented in tables 1.12 and 1.13 and so in the following I focus mainly on the coefficients of control variables, which capture the effects of LTROs on yields on extra-Euro countries, and on their magnitude and significance with respect to the effects on Euro countries. On the other hand, standard errors differ from the ones presented in previous tables since here the dimensionality of the panel has changed. However differences are negligible as almost all p-values remain in the same category of significance.

[13] In practice, I constructed several dummy variables: the first indicates Euro-area countries and is equal to one for Austria, Belgium, Finland, France, Germany, Greece, Italy, Netherlands, Portugal, Spain and it is zero otherwise; the second selects extra-Euro countries and so it is equal to one for Denmark, Japan, Sweden, Switzerland, UK, US while it is zero otherwise; the last two dummy variables split Euro-area countries into two subsets, i.e. Greece and Portugal and the core European countries.

During the first event, both yields of European and extra-Euro countries declined all along the time window and figure 1.9 confirms this pattern. P-values are always very low but the interesting point is that the magnitude of the decrease is higher for extra-Euro countries and also significant around the implementation date. The same is true with respect to the two subsets of Euro countries.

Also the second event is connected to a decline in yields growth rate outside the Euro-area with high statistical significance. In this case supply effects start from the fourth day before the auction. Figure 1.10 shows that yields followed a declining trend during the first fifteen days of the window and then the trend shifted upwards but still remained negative. Here the magnitude of changes is much higher for extra-Euro countries, with coefficients that in most of the days are more than double the change in European yields. As a matter of fact also the difference between coefficients is statistically significant.

So, these two LTROs had highly statistically significant effects both inside and outside the Euro-area meaning that investors actually used the liquidity to buy bonds and most of the purchases involved extra Euro-area countries bonds.

The LTRO of December 2009 led to significant increases in yields of both Euro-area and extra-Euro area countries. Here it is important to point out that increases are much higher for Greek and Portuguese bonds signalling rising market tensions connected to debt sustainability issues. On the other hand, extra-Euro countries' yields experienced greater movements with respect to core countries' yields, even though their difference is never significant. For extra Euro-area countries applies a reasoning similar to the one used for Euro-area countries. An increase in yields is the opposite of one would have expected after a liquidity injection. However figures 1.11 and 1.5 show that after the call for bids for the LTRO (on December 15th) yields growth rates declined for all countries. So it is possible to say that a little liquidity effect appeared just as a temporary stop in the increasing trend of growth rates.

The fourth event is the LTRO implemented in October 2011. From an aggregate point of view, during the first half of the window, there is some significance in both Euro-area yields, which always increased, and in extra-Euro yields, which decreased in most of the cases. The interesting thing here is that extra-Euro yields started to decrease significantly in the second half of the window, as it is also clear from figure 1.12. In contrast, Euro-area yields increased and so the difference between the coefficients of the two groups is statistically significant. By considering the breakdown of Euro-area countries it is possible to see that core countries yields have negative coefficients in the second part of the window, while Greek and Portuguese yields always increased. In particular, even though the magnitude of changes is relevant, coefficients of the two groups of Euro-area countries are never statistically significant because of the high variability in yields. Moreover, the difference between non-European countries coefficients and those of Greece and Portugal is much greater than the difference with respect to the core European countries. This seems to indicate that investors moved out from the European bond market (and especially from lower-rated bonds) and purchased non-Euro bonds. Finally, in contrast to what said for Euro-area yields, extra-Euro countries yields movements seem to be highly correlated (except for Japan). So, for this event, the supply effect can be found mainly on extra-Euro yields and once again this is evidence of a flight to safety.

For the fifth event the panel analysis finds no significant liquidity effects for the Euro countries as a whole but Greece and Portugal bond yields rose with very low p-values and the other eight countries yields declined from the fourth day before the implementation. On the other hand, extra Euro-area bond yields declined during all the time span with high statistical significance, as confirmed also by figure 1.13. Therefore we had a supply effect on both higher-rated Euro and non-Euro bonds meaning that most of the injected liquidity had been used to purchase safe securities.

The analysis of the last LTRO does not provide very interesting information as yields of extra-Euro countries almost always increased in several days at the beginning of the window with high statistical significance. This can be seen also in figure 1.14 that highlights that only the Swiss bonds followed a declining trend in their growth rate, while other countries yields fluctuated around the zero growth rate. Interesting movements happened in the two Euro-countries subsets as Greek and Portuguese yields always increased while yields of the core countries had been affected by a supply effect. So, in this case, investors preferred to buy higher-rated Euro bonds.

This last analysis has been useful to show some relevant evidence about the transmission of liquidity shocks outside the Euro-area. These channels fully worked during event 1, 2, 4 and 5.

1.5.7 Overall Effects of the LTROs

The panel analysis produced lots of evidence about the effects of the liquidity injections. Overall most of the considered events produced some decrease in bond yields meaning that banks during the crisis experienced some liquidity constraints and moreover there have been positive spillovers from the banking sector to government debt.

The first LTRO was implemented in June 23rd-25th 2009. All the bond yields considered declined in the event-window with very low p-values. The effect was much more prominent for investment-grade countries than for lower-rated ones. I also presented evidence about the decline in yields of extra-Euro countries meaning that there had been a transmission also outside the area of influence of the ECB. This event caused the strongest and broader supply effects suggesting that banks actually used the available liquidity to buy government bonds.

The second LTRO took place in September 29th-October 1st 2009. Yield growth rates declined for both investment-grade and speculative-grade countries starting from the fourth day before the auction. Concerning extra-Euro countries the decrease in yields started with the same timing as European yields. Overall supply effects are evident as investors anticipated the liquidity injection buying both Euro-area and non-Euro bonds.

It is necessary to notice that these first two LTRO had been conducted in a period of high stress for the banking sector. As a matter of fact, at the beginning of the financial crisis, banks experienced a liquidity crisis due to the lack of confidence which made the interbank market dysfunctional. Therefore banks actually used the received liquidity to invest in the bond market.

The third LTRO was implemented in December 15th-17th. All the analysis reported shows that no supply effects affected any of the bond yields considered. All the considered categories of bonds recorded an increase in yields which was more significant for higher-rated European bonds and extra-Euro bonds meaning that investors exited form the government bond market. The graphical analysis of Euro-area yields shows that the LTRO seems to have temporary eased the yield growth rate for some countries but this does not generate any statistically significant result.

The fourth LTRO was implemented in October 25th-27th. Yields of speculative grade countries increased during all the time-window and the significance is higher in the last days. Greek and Portuguese yields followed this trend but coefficients are not significant while Italian and Spanish yield changes are coupled with very low p-values. Core European countries' yields declined but not significantly. On the other hand, supply effects are evident for extra-Euro countries. This pattern indicates that investors sold risky bonds and purchased safer ones.

The fifth LTRO was the first one with 36-month maturity and it took place in December 20th-22nd 2011. Inside the Euro area investment-grade countries yields reduced significantly during most of the event-windows while Greek and Portuguese yields increased with high statistical significance. Italian and Spanish yields increased with low significance. Yields growth of extra Euro-area countries declined and changes are greater in the last days. Also in this case the liquidity injected was not used in the expected way and it did not help to ease bond market tensions as spreads of highly indebted countries increased.

The last LTRO was the second one with 36-month maturity and it took place in February 28th-March 1st 2012. The outcome of the empirical analysis is similar to the previous ones as the expected supply effects mostly concentrated on higher-rated Euro bonds after the auction day. Moreover, here there have been a significant increase in yields of Greek and Portuguese bonds exacerbating the yield spreads with respect to Germany. These yields declined only after the decisions taken by the ECB Governing Council to reaccept Greek debt instruments as collateral in European credit operations. On the contrary, Italian and Spanish bond yields decreased with high statistical significance. Finally, yields of extra Euro-area bonds reported some significant positive changes at the beginning of the window and some not-significant negative changes after the LTRO implementation.

Overall these last three LTROs did not produce the expected supply effect as investors only purchased higher-rated bonds and the spreads of Greece and Portugal increased making the ECB intervention detrimental for bond markets. Spreads of Italy and Spain increased during event 4 and 5 while they reduced during event 6. It must however recalled that the event-study analysis of policy announcements found that news about these last two interventions had significant effects on yields of almost all countries. In these cases there have been an announcement effect and a weaker supply effect once banks actually received the liquidity.

It is also important to notice that during event 1, 2, 4 and 5 non-European yields declined more than Euro-area ones. This can be explained using the uncovered interest parity. This relationship predicts that, when foreign interest rates decreases more than national ones, the national currency should depreciate, which is what actually happened to the Euro currency with respect to the Japanese yen, the Swedish krone and the Swiss franc. Figure 1.15 shows that the Euro exchange rate with respect to the UK sterling and the US dollar alternated periods in which it depreciated with periods in which it appreciated. In particular, it depreciated from mid October 2009 to mid June 2010 and from May 2011 on, while it appreciated from mid June 2010 to April 2011. These periods are consistent with event 1, 2, 4 and 5 and so it is possible to conclude that the uncovered interest parity fully explain the yields' evolution over these events. On the other hand this evidence is not consistent with the Dornbusch (1976) overshooting model which predicts that, after an expansionary monetary policy, national interest rates should decline more than foreign ones and the exchange rate overshoots, i.e. it depreciates a lot so to generate a subsequent appreciation.

Finally, the evidence supports also the idea that LTROs were effective as long as the crisis was due to a lack of liquidity. Since the autumn 2009 the crisis became debt-oriented and liquidity injections lost their effectiveness. Debt sustainability issues led to a differentiation between European countries which is the cause of the impaired transmission of monetary policy. Positive spillovers from the banking sector to sovereign debt affected only higher-rated countries. Therefore, inside a monetary union there can be situations in which the monetary policy transmission mechanism is not unique making the effects of unconventional interventions ambiguous. Moreover, in the last days of the event-window of the sixth LTRO the ECB announced to reaccept Greek bonds as collateral in European credit operations and this led to an abrupt decline in Greek yields suggesting that direct interventions on bonds are more effective in containing spreads than liquidity injections. What makes the effects of a monetary policy action difficult to forecast seems to be the lack of homogeneity between the single-countries macroeconomic fundamentals and the impaired functioning of financial markets. This finding raises some issues regarding the effectiveness of monetary policy during unconventional times.

1.6 Conclusion

In this work I focused on the effects of unconventional monetary policy measures implemented by the ECB on government bond yields. The aim was to evaluate whether banks actually invested the received liquidity and so if there had been positive spillovers from the banking to sovereign debt.

The first empirical analysis concerned the effects of announcements on single-countries bond yields to evaluate whether policy actions affected markets through investors' expectations. The findings, even though they are not all consistent with each-other, supports the effectiveness of the expectational channel in shaping market movements. The announcements that produced the most relevant effects were the ones about the Covered Bond Purchase Programmes, the Securities Markets Programme, the Outright Monetary Transaction programme and the rumours about the lengthening in the maturity of LTROs in early December 2011. On the other hand no significant changes in yields had been found in conjunction with the actual LTROs implementation.

For the second empirical analysis I constructed a panel of both Euro-area and extra Euro-area country yields and I analysed the direct effects of extraordinary liquidity injections by the ECB, namely six longer-term refinancing operations. The most interesting finding here is that the transmission mechanism of these liquidity injections was not unique. Indeed, the last three LTROs led to an increase in market spreads for lower-rated Euro-area countries due to a flight to safety effect. This can be justified by the change in the nature of the financial crisis. At the beginning the ECB had been successful in mitigate market tension because the crisis was due to a lack of confidence between banks that led to funding problems. All countries benefited from the liquidity injections because they improved funding conditions for both banks and firms and so there had been positive spillovers from the banking sector to sovereign debt. However, in 2009 the liquidity-crisis evolved into a debt-crisis and from then on the monetary policy effects differentiated across countries. In a context of increasing sovereign default risk for several European countries the monetary policy transmission started to be influenced by the differences in macroeconomic fundamentals and the impaired functioning of financial markets. Positive spillovers from liquidity to government debt involved only higher-rated countries. This finding raises some issues regarding the effectiveness of monetary policy during unconventional times especially when market tensions are not due to monetary issues like the lack of liquidity but rather they are caused by fiscal issues like debt sustainability. In this context liquidity injections had the effect of exacerbating rather than mitigating market tensions.

As a matter of fact, the first part of this work showed that the interventions that proved to be more effective in containing bond spreads during the debt crisis were the direct interventions on bonds, like the Securities Market Programme and the acceptance of bonds as collateral as they led to strong declines in yields. Therefore, even though liquidity injections in credit markets proved not to be effective during the debt-crisis to mitigate spreads, the ECB is not powerless: direct bond purchases are effective and it should keep on implementing that kind of actions if it wanted to reduce spreads.

Appendix A. Econometric Details of the Panel Model

In section 1.5 I specified the following model:

$$y_{itk} = \alpha_{ik} + \sum_{\tau=-s+1}^{s} \beta_m d_{i\tau k} + \varepsilon_{itk}$$

Here the subscript k capture the six events over which the model is estimated, while i and t represent, respectively, countries and time.

The regressors are 20 time-varying dummies for each event ($s = 10$), each one of them has a 1 on a different day along the 21-days window across countries and zero otherwise. In particular, the dummies capture the yield variations from the second day of the sample, which in the output tables presented below is labelled as T-9 and T is the central day of the window. The T-10 day has no dummy as it is taken as the reference day to calculate the significance of the variation and clearly including 21 dummies would lead to a perfect-collinearity problem. The model is estimated separately for each event and so I run the estimation six times, each time including the 20 dummies of the event of interest and the sample consists of 126 observations.

As this is not a structural model, it can suffer from different misspecification problems. In the following I analyse these problems and explain how I accounted for them.

Fixed Effects vs. Random Effects

In this context, regressors are the same across individuals and so there should be correlation between individual heterogeneity and residuals. To capture this heterogeneity I added the fixed effect to the model. Fixed effects are actually non-significant as estimation outputs always report a zero correlation between the matrix of regressors and individual heterogeneity meaning that the results from the fixed-effects model are very similar to the ones coming from a random-effects model. Moreover, the model had been estimated also with random effects and standard errors are equal to the ones in the fixed-effects case up to the 5th decimal so that the significance of coefficient does not change between the two specifications.

Overall, for the theoretical reason explained here, I preferred to use the fixed-effect model.

Robust Standard Errors

Following the classical assumptions, errors should be independent and identically distributed but in reality this is often not the case. When this assumption is violated the OLS standard errors are not consistent anymore and to obtain an accurate statistical inference it is necessary to take into account the structure of the variance-covariance matrix.

Here errors are both autocorrelated and heteroskedastic. Autocorrelation comes form the fact that the event-windows are the same for all the bonds considered, while heteroskedasticity is typical of financial data at high frequency.

Concerning the correlation structure, in a panel context there can be several levels of correlation which in general are referred to as “clustered errors”. “Clustered” refers to the fact that the correlation is grouped along different dimensions. The simplest case is when the clustering is along one dimension:

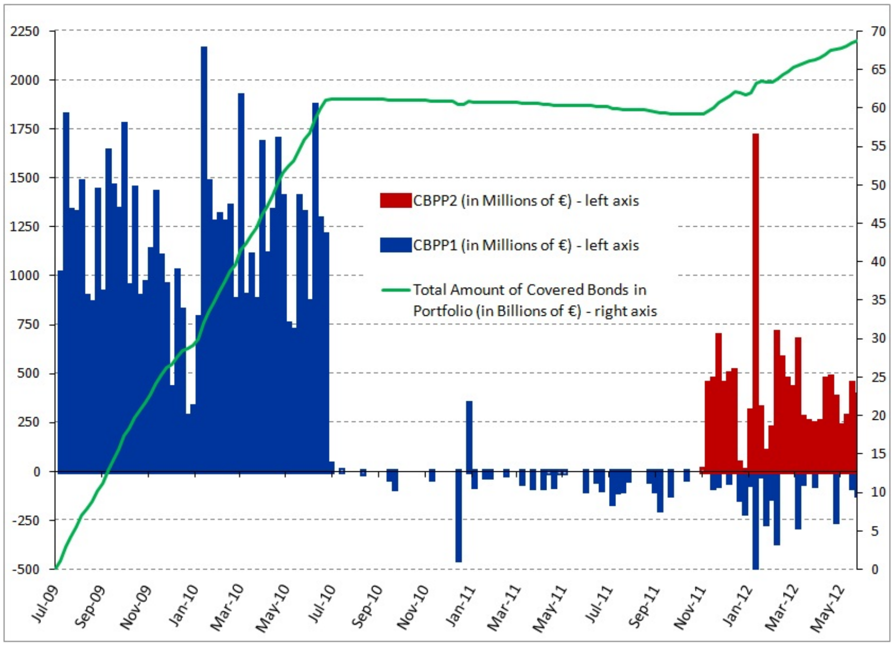
individuals or time. When errors are clustered within individuals it means that there are "individual effects", i.e. errors are correlated across time for each individual ($E\left(\varepsilon_{it}\varepsilon_{ik} \mid x_{it}, x_{ik}\right) \neq 0 \,\forall\, t \neq k$). When errors are clustered within time it means that there are "time effects", i.e. errors are correlated across individuals for each moment in time ($E\left(\varepsilon_{it}\varepsilon_{jt} \mid x_{it}, x_{jt}\right) \neq 0 \,\forall\, i \neq j$). The extended case is when the clustering involves multiple levels but only one dimension. For example the correlation can be through individuals and cities and in this case clusters are said to be nested. On the other hand, errors can be clustered by the two different dimensions of the panel: individuals and time. In this case clusters are said to be non-nested. If errors are correlated between different individuals in different time we have "persistent common shocks", meaning that shocks are common to all individuals and autocorrelated for L periods ($E\left(\varepsilon_{it}\varepsilon_{jk} \mid x_{it}, x_{jk}\right) \neq 0 \,\forall\, i \neq j$ and $|t-k| > L$). Of course errors can be clustered also by more than two dimensions and this would complicate the procedure. For each of this case the corrections needed to obtain robust errors are different.

In the present framework the regressors are independent of each other and of the errors because they are dummy variables. So, even though errors are correlated across individuals in each time because the event-windows are the same, $Cov\left(x_{it}\varepsilon_{it}, x_{jt}\varepsilon_{jt}\right) = 0$ and then I don't need to cluster by time. The only correction needed is to cluster by individual which can be easily done with STATA.

Heteroskedasticity implies that the variance of the error term is not constant over time. To account for this kind of misspecification it is necessary to use Huber-White standard errors. Stock and Watson (2008) prove that the heteroskedasticity-consistent estimator in case of fixed-effects and the autocorrelation-consistent estimator are asymptotically equivalent for $T = 3$ while if $T > 3$ the autocorrelation-consistent estimator should be used. For this reason, in STATA the command to cluster by individual produces a variance-covariance matrix which is consistent also to heteroskedasticity.

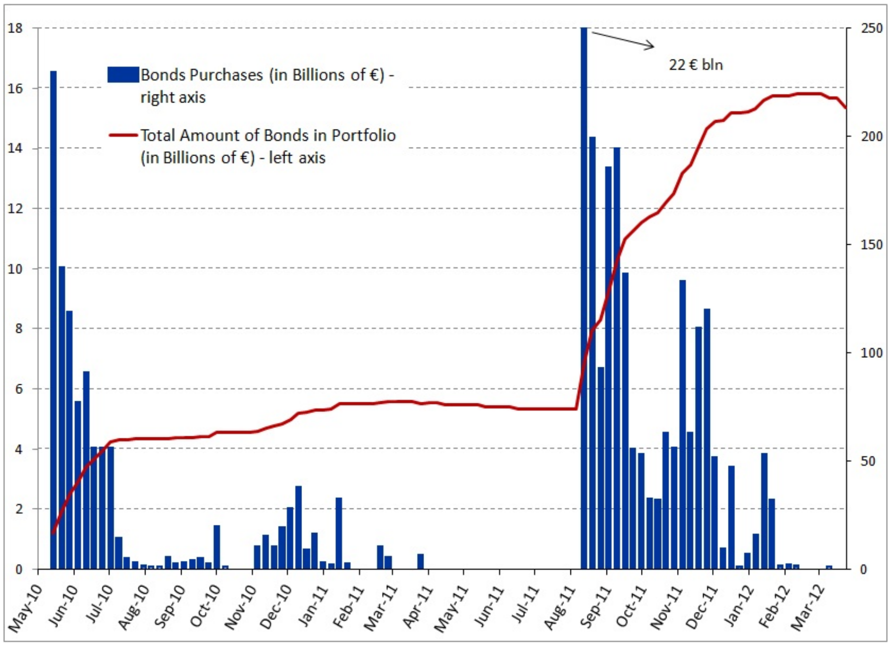
Appendix B. Figures

Figure 1.1: **ECB purchases of covered bonds under the two CBPPs**



Source: Datastream

Figure 1.2: **ECB purchases of bonds under the SMP**



Source: Bloomberg

Figure 1.3: **Event 1: cumulative percentage change in yields (11/06/09 - 08/07/09)**

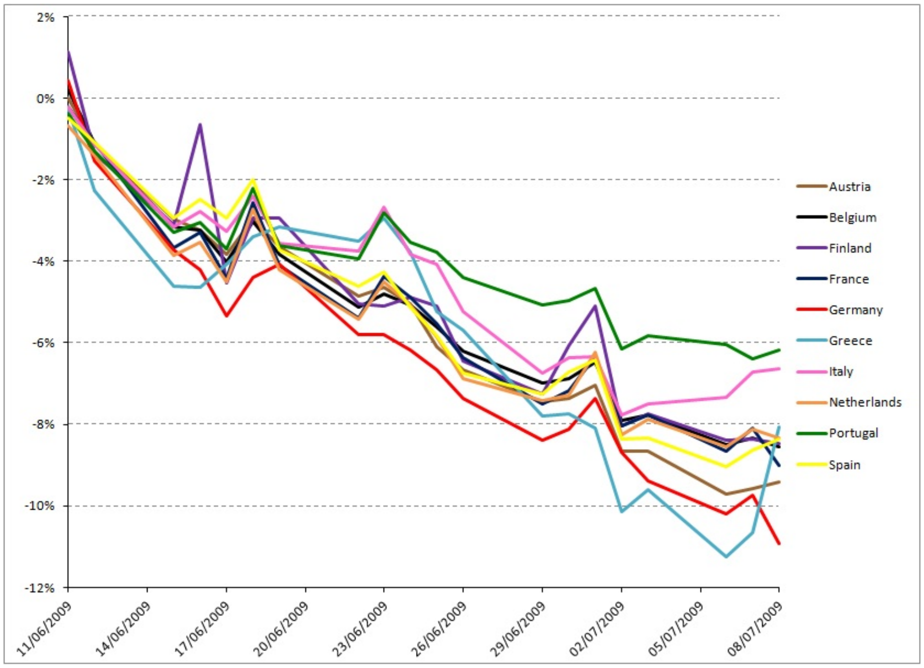


Figure 1.4: **Event 2: cumulative percentage change in yields (17/09/09 - 14/10/09)**

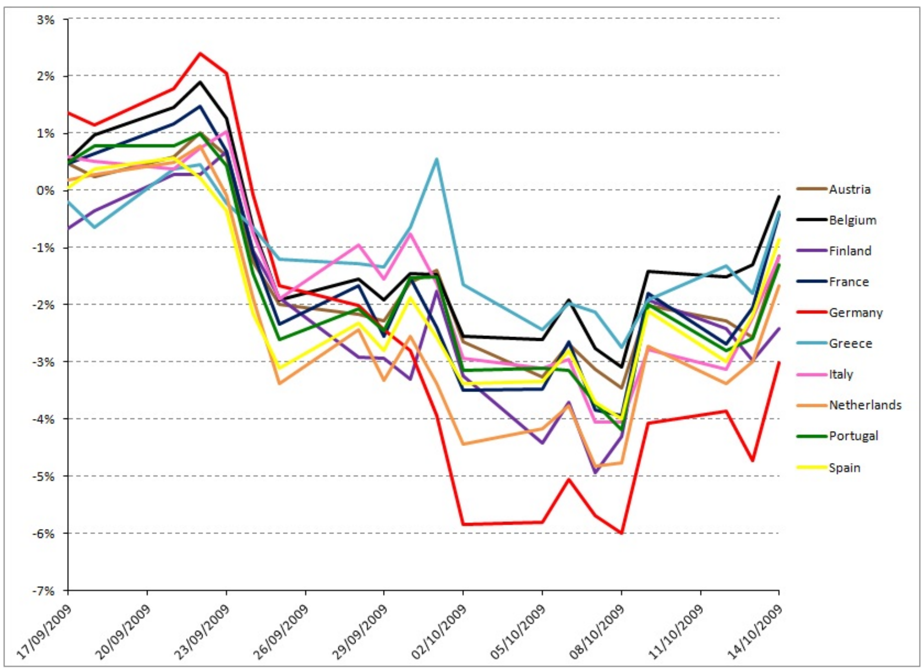


Figure 1.5: **Event 3: cumulative percentage change in yields (3/12/09 - 30/12/09)**

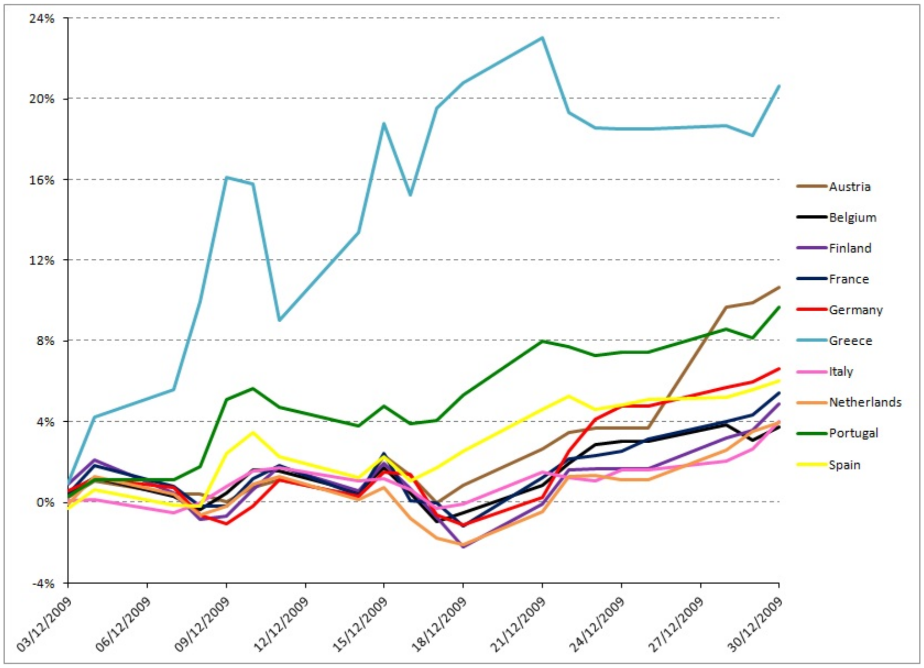


Figure 1.6: **Event 4: cumulative percentage change in yields (13/10/11 - 9/11/11)**

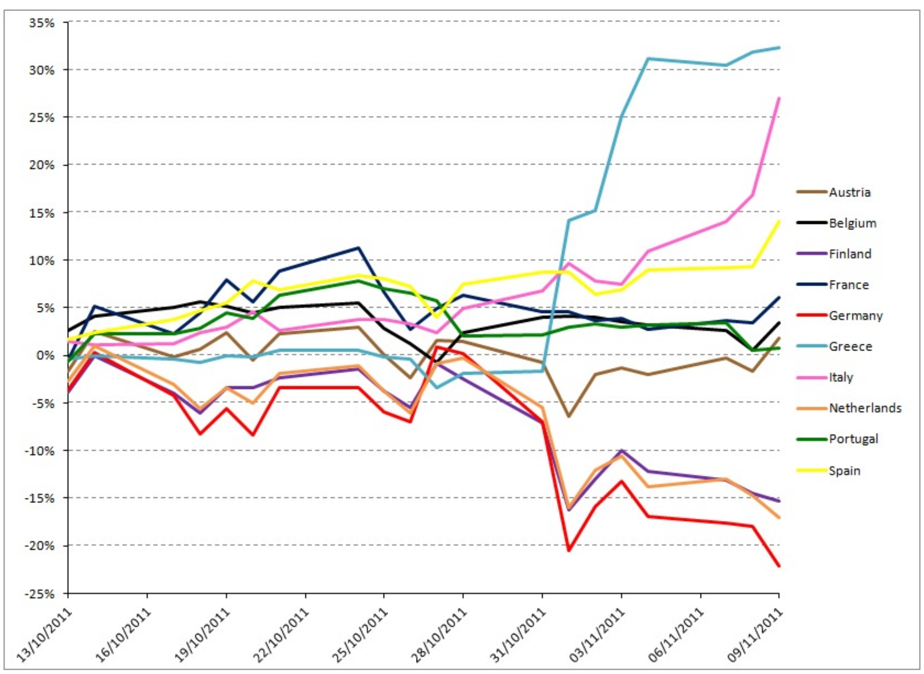


Figure 1.7: **Event 5: cumulative percentage change in yields (8/12/11 - 4/01/12)**

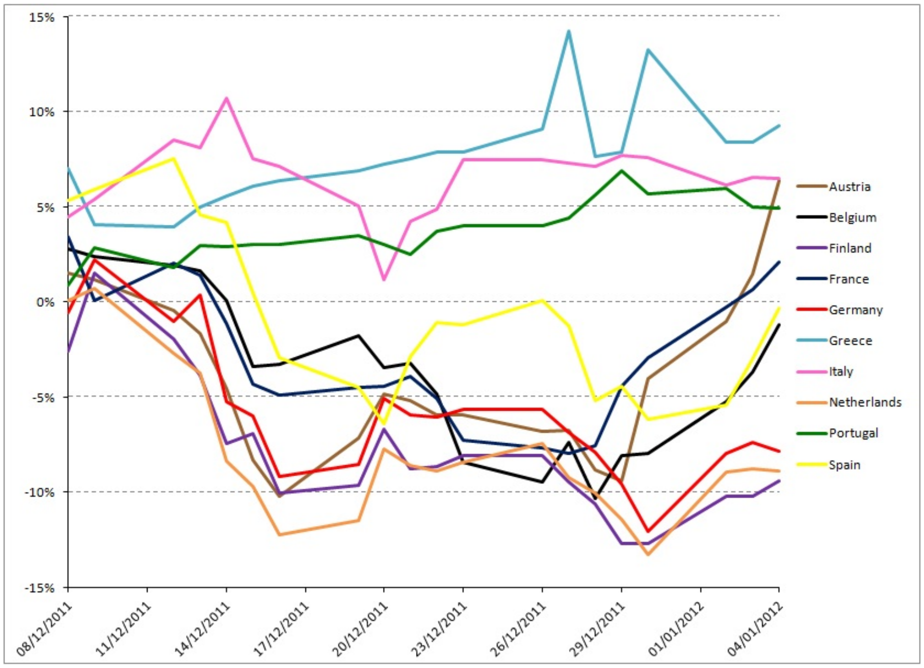


Figure 1.8: **Event 6: cumulative percentage change in yields (16/02/12 - 14/03/12)**

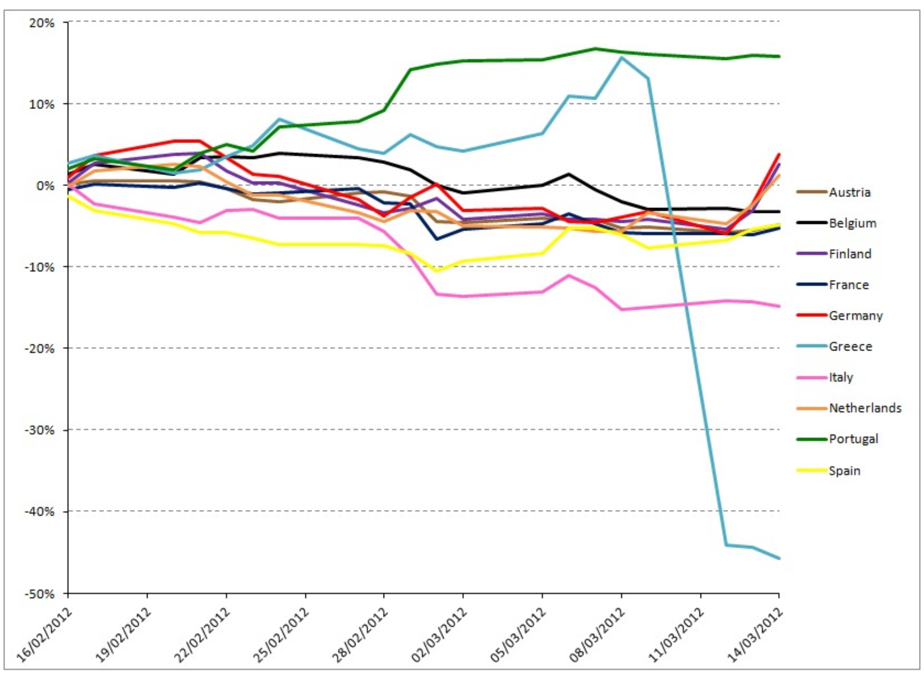


Figure 1.9: **Event 1: cumulative percentage change in yields (11/06/09 - 08/07/09)**

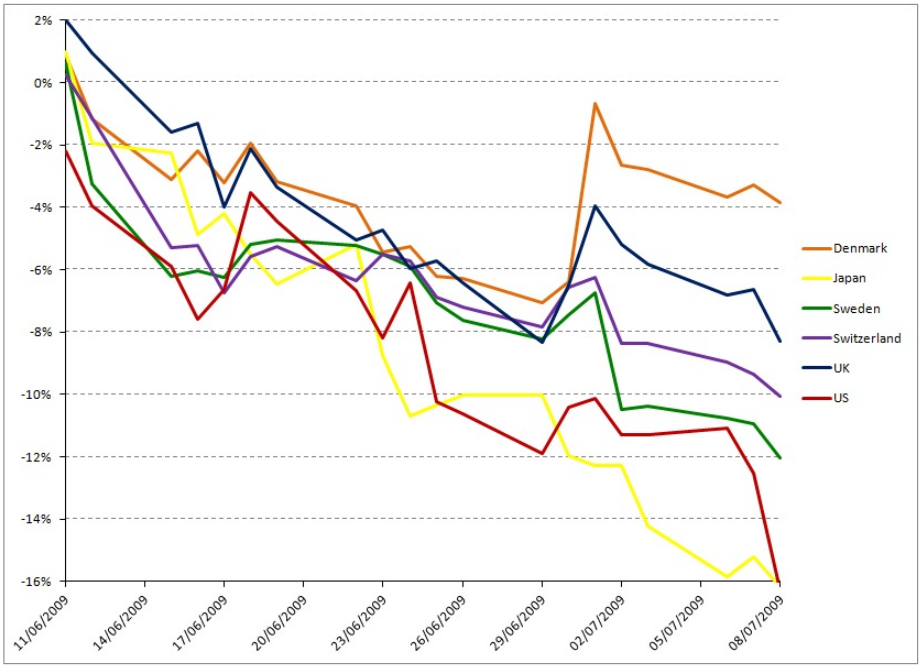


Figure 1.10: **Event 2: cumulative percentage change in yields (17/09/09 - 14/10/09)**

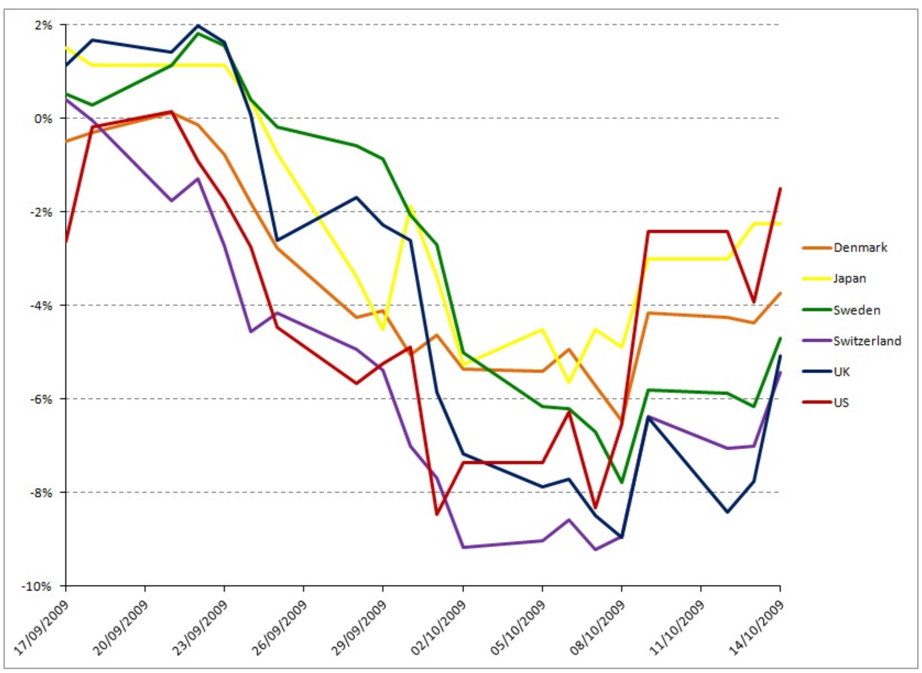


Figure 1.11: **Event 3: cumulative percentage change in yields (3/12/09 - 30/12/09)**

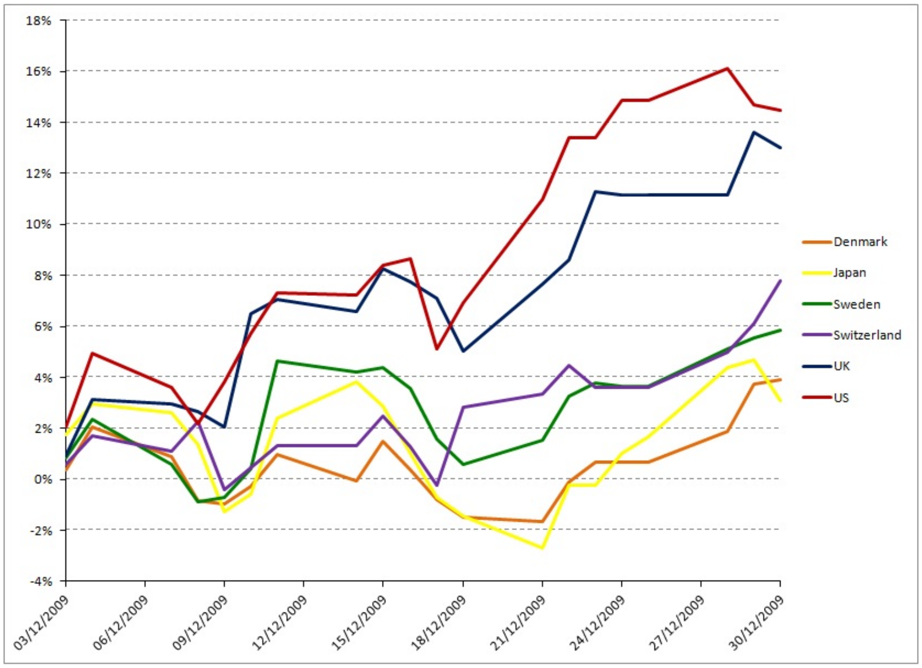


Figure 1.12: **Event 4: cumulative percentage change in yields (13/10/11 - 9/11/11)**

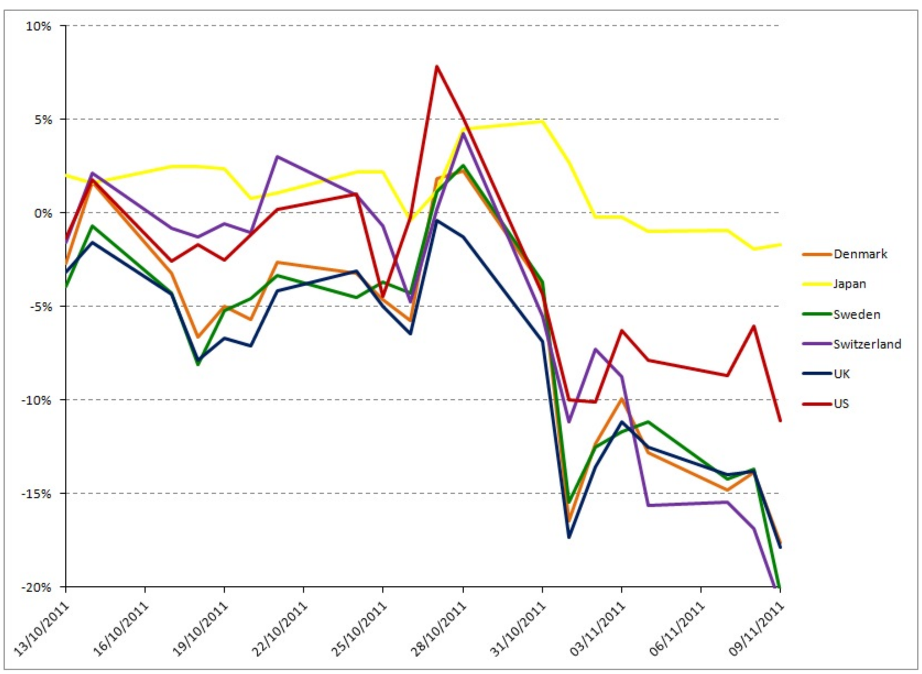


Figure 1.13: **Event 5: cumulative percentage change in yields (8/12/11 - 4/01/12)**

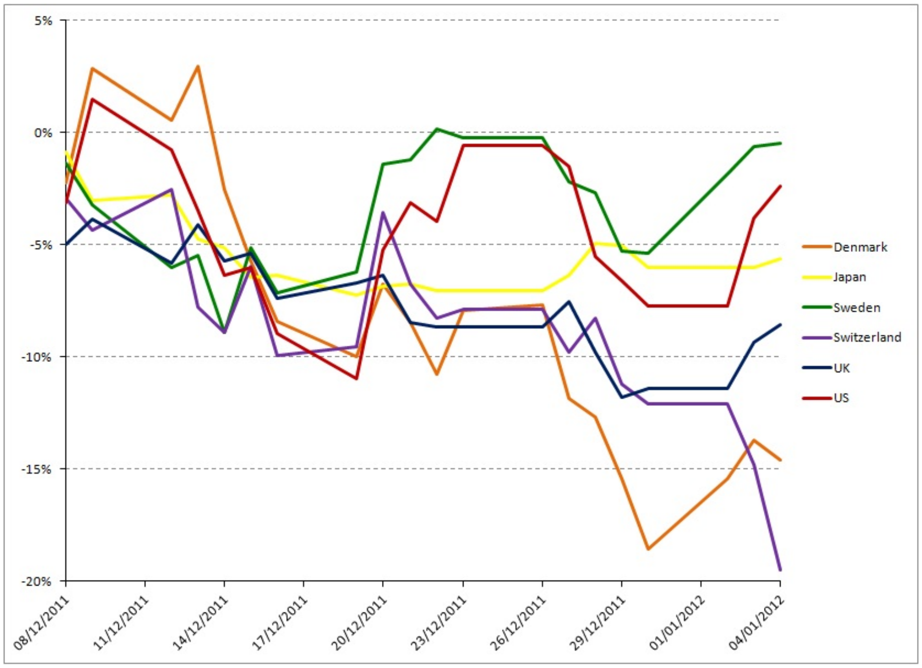


Figure 1.14: **Event 6: cumulative percentage change in yields (16/02/12 - 14/03/12)**

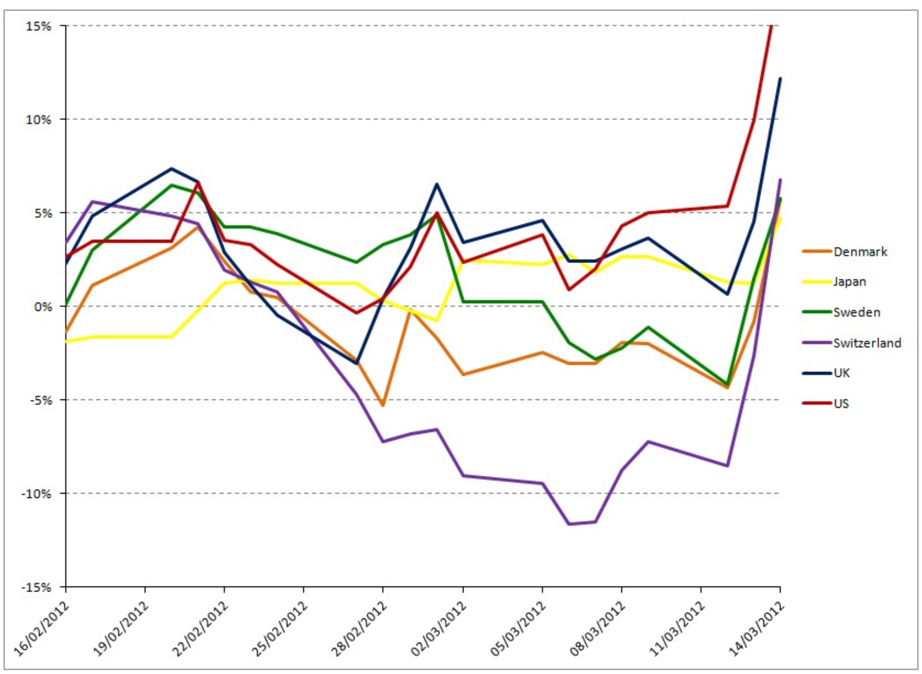
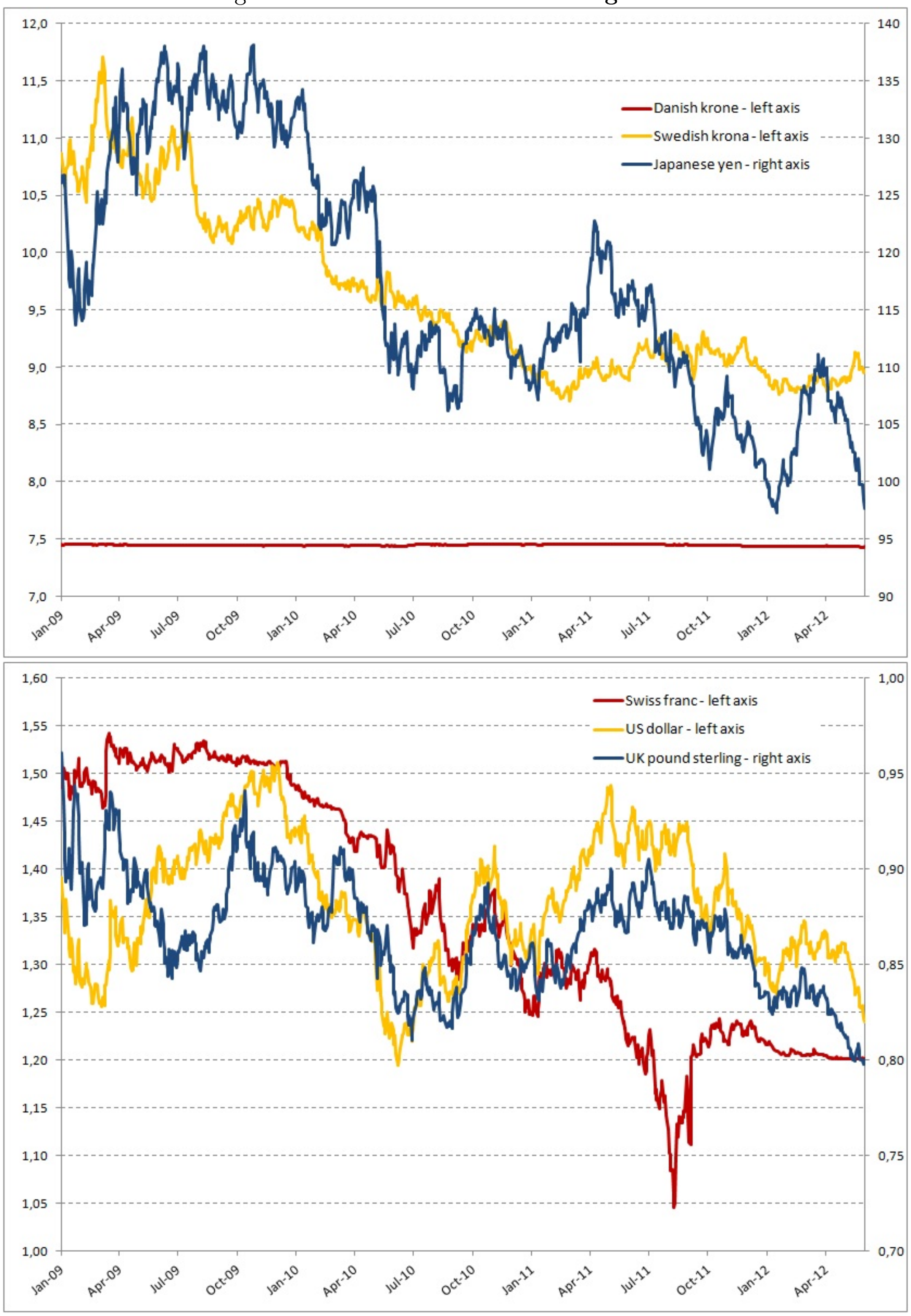


Figure 1.15: **Euro nominal exchange rates**



Source: ECB

*Nominal exchange rate is defined as the ratio between the foreign currency and the Euro currency

Appendix C. Tables

Table 1.1: **Main ECB announcements of unconventional monetary policy measures**

Date	Time	Description	Event Window
August 22, 2007	15.34	Announcement of the 1st supplementary LTRO (3-month maturity, standard procedure)	2 days (Aug. 21-23)
October 15, 2008	16.32	Announcement of several LTROs (3/6-month maturity, fixed-rate full allotment procedure) and expansion of the list of eligible collaterals	2 days (Oct. 14-16)
May 7, 2009	14.35	Announcement of the Enhanced Credit Support programme and of the Covered Bonds Purchase Programme 1	2 days (May 6-8)
June 4, 2009	14.30	Publication of the technical details of the Covered Bonds Purchase Programme 1	2 days (June 3-5)
June 23, 2009	15.35	Call for bids of a LTRO with 12-month maturity	2 days (June 22-24)
September 29, 2009	15.35	Call for bids of a LTRO with 12-month maturity	2 days (Sep. 28-30)
December 3, 2009	15.40	Announcement of details on refinancing operations (MROs conducted as fixed-rate and full-allotment procedure “for as long as is needed”)	2 days (Dec. 2-4)
December 15, 2009	15.35	Call for bids of a LTRO with 12-month maturity	2 days (Dec. 14-16)
May 10, 2010	3.15	Announcement of the Securities Markets Programme	1 days (May 9-10)
August 7, 2011	23.00	Statement about the active implementation of the Securities Markets Programme	1 day (Aug. 7-8)
October 6, 2011	14.45	Announcement of the Covered Bonds Purchase Programme 2 and of two LTROs with 12-month maturity	2 days (Oct. 5-7)
October 25, 2011	15.35	Call for bids of a LTRO with 12-month maturity	2 days (Oct. 24-26)
November 3, 2011	15.30	Publication of the technical details of the Covered Bonds Purchase Programme 2	2 days (Nov. 2-4)
December 2, 2011		Rumours about ECB’s LTROs with 36-month maturity	2 days (Dec. 1-5)
December 8, 2011	14.30	Announcement of two LTROs with 36-month maturity	2 days (Dec. 7-9)
December 20, 2011	15.35	Call for bids of a LTRO with 36-month maturity	2 days (Dec. 19-21)
February 28, 2012	15.35	Call for bids of a LTRO with 36-month maturity	2 days (Feb. 27-29)
July 26 2012	12.00	Statement about the commitment of the ECB to do whatever it takes to preserve the euro	2 days (Jul. 25-27)
August 2 2012	14.30	Announcement of the Outright Monetary Transactions program	2 days (Aug. 1-3)
September 6 2012	14.30	Publication of the details of the Outright Monetary Transactions program	2 days (Sep. 5-7)

Table 1.2: **Austria: effects of ECB announcements on government bond yields**

EVENTS	**RESPONSES TO ANNOUNCEMENTS**						**Joint Significance**
	1y	**2y**	**3y**	**5y**	**7y**	**10y**	
Aug. 22, 2007 (2d)	**0.106**	**0.151**	**0.146**	0.1	0.074		**0.577**
p-value	0.0007	0.0547	0.0562	0.1426	0.2047		0.0001
Oct. 15, 2008 (2d)	0.047	-0.029	**-0.263**	-0.161	-0.117	-0.058	-0.581
p-value	0.7747	0.8400	0.0921	0.2589	0.3212	0.5871	0.4454
May 7, 2009 (2d)	**-0.082**	-0.077	-0.088	-0.006	0.034	**0.097**	**-0.122**
p-value	0.0777	0.1246	0.2484	0.9326	0.5617	0.0680	0.0830
Jun. 4, 2009 (2d)	**0.152**	**0.253**	0.286	**0.309**	**0.267**	**0.213**	**1.48**
p-value	0.0914	0.0769	0.2261	0.0050	0.0063	0.0002	0.0000
Jun. 23, 2009 (2d)	-0.051	-0.065	-0.047	-0.033	-0.029	-0.008	-0.233
p-value	0.5804	0.6734	0.8439	0.7878	0.7911	0.9066	0.9947
Sept. 29, 2009 (2d)	0.021	0.041	0.038	0.033	0.018	0.021	0.172
p-value	0.3156	0.3009	0.3402	0.4915	0.7211	0.6634	0.6900
Dec. 3, 2009 (2d)	-0.052	0.042	**0.095**	**0.089**	0.081	0.038	**0.293**
p-value	0.1400	0.2219	0.0445	0.0710	0.1063	0.3888	0.0178
Dec. 15, 2009 (2d)	0.005	-0.024	-0.006	0.017	0.045	0.036	0.073
p-value	0.9347	0.4401	0.9016	0.7085	0.3006	0.3580	0.8382
May 10, 2010 (1d)	**-0.182**	0.064	**0.15**	0.047	**0.107**	**0.114**	**0.3**
p-value	0.0000	0.1194	0.0182	0.5149	0.0254	0.0245	0.0000
Aug. 7, 2011 (1d)	-0.052	**-0.143**	-0.099	**-0.11**	**-0.113**	**-0.087**	**-0.604**
p-value	0.3947	0.0231	0.1172	0.0665	0.0421	0.0592	0.0017
Oct. 6, 2011 (2d)	**0.166**	0.082	0.116	0.109	0.084	0.151	**0.708**
p-value	0.0621	0.3141	0.2111	0.2457	0.4141	0.1345	0.0912
Oct. 25, 2011 (2d)	-0.13	**-0.202**	**-0.168**	**-0.182**	-0.148	-0.161	**-0.991**
p-value	0.2000	0.0103	0.0556	0.0301	0.1060	0.1035	0.0005
Nov. 3, 2011 (2d)	**-0.222**	-0.138	-0.022	-0.048	-0.055	0.001	-0.484
p-value	0.0336	0.1355	0.8066	0.5734	0.5626	0.9927	0.2335
Dec. 2, 2011 (2d)	0.022	-0.012	-0.091	-0.125	-0.168	-0.066	-0.44
p-value	0.8652	0.9575	0.6997	0.6034	0.4680	0.7179	0.9800
Dec. 8, 2011 (2d)	0.094	0.048	0.072	0.045	-0.007	0.039	0.291
p-value	0.4630	0.8334	0.7629	0.8538	0.9762	0.8322	0.9928
Dec. 20, 2011 (2d)	-0.008	-0.044	-0.08	-0.043	0.057	0.064	-0.054
p-value	0.9468	0.8446	0.7482	0.8641	0.8098	0.7309	0.9992
Feb. 28, 2012 (2d)	-0.056	0.048	-0.009	-0.037	0.001	-0.011	-0.064
p-value	0.2431	0.6143	0.8596	0.6074	0.9888	0.8660	0.9188
Jul. 26, 2012 (2d)	0.092	-0.033	-0.096	-0.097	-0.086	-0.064	-0.284
p-value	0.1234	0.6125	0.2472	0.2785	0.3366	0.4358	0.3233
Aug. 2, 2012 (2d)	0.032	0.026	0.032	0.021	0.008	0.004	0.123
p-value	0.6069	0.6972	0.6821	0.8092	0.9245	0.9576	0.9952
Sep. 6, 2012 (2d)	-0.003	0.07	0.053	0.055	0.034	0.047	0.256
p-value	0.9449	0.1606	0.2790	0.2821	0.4670	0.2756	0.3932

Significant changes are in bold font.

Table 1.3: **Belgium: effects of ECB announcements on government bond yields**

EVENTS	**RESPONSES TO ANNOUNCEMENTS**											**Joint**
	3m	**6m**	**1y**	**2y**	**3y**	**5y**	**7y**	**10y**	**15y**	**20y**	**30y**	**Significance**
Aug. 22, 2007 (2d)	**0.062**		**0.123**	**0.148**	**0.13**	**0.107**	0.067	0.037	0.02		0.009	**0.703**
p-value	0.0947		0.0613	0.0412	0.0670	0.0928	0.2416	0.4766	0.6843		0.8454	0.0171
Oct. 15, 2008 (2d)	-0.202		0.101	-0.164	-0.226	-0.193	-0.128	-0.087	-0.006		0.076	-0.829
p-value	0.3066		0.6495	0.2977	0.1269	0.1918	0.2923	0.4299	0.9593		0.5936	0.4597
May 7, 2009 (2d)	-0.042		-0.053	-0.042	-0.027	0.024	0.065	**0.135**	**0.162**		**0.189**	**0.411**
p-value	0.6475		0.3446	0.6082	0.6924	0.6211	0.2005	0.0096	0.0014		0.0009	0.0000
Jun. 4, 2009 (2d)	0.048		**0.149**	**0.283**	**0.296**	**0.291**	**0.204**	**0.142**	**0.12**		0.077	**1.61**
p-value	0.3560		0.0013	0.0000	0.0000	0.0185	0.0001	0.0058	0.0319		0.2086	0.0000
Jun. 23, 2009 (2d)	**-0.197**		0.022	-0.035	-0.066	-0.061	-0.023	0.002	0.01		0.016	-0.332
p-value	0.0343		0.7341	0.7107	0.4498	0.6588	0.7486	0.9737	0.8584		0.7612	0.7188
Sept. 29, 2009 (2d)	0.009	0.027	0.059	0.049	0.003	0.029	0.002	0.004	0.016	-0.014	-0.027	0.157
p-value	0.8808	0.3795	0.1936	0.2185	0.9414	0.5072	0.9660	0.9362	0.7373	0.7930	0.6425	0.9291
Dec. 3, 2009 (2d)	-0.074	-0.033	-0.001	0.036	0.074	**0.089**	0.07	0.043	0.046	0.007	0.028	0.285
p-value	0.1500	0.6775	0.9857	0.3580	0.1205	0.0537	0.1150	0.3080	0.2975	0.8884	0.5666	0.1807
Dec. 15, 2009 (2d)	0.006	**0.124**	-0.028	-0.012	-0.025	-0.011	-0.009	-0.002	-0.035	-0.038	-0.021	-0.051
p-value	0.8833	0.0755	0.6084	0.7681	0.6050	0.8237	0.8490	0.9611	0.4055	0.4273	0.6459	0.8916
May 10, 2010 (1d)	-0.050	**-0.040**	**0.303**	**-0.188**	**-0.177**	**-0.090**	-0.046	**-0.068**	-0.025	**0.108**	**0.110**	**-0.163**
p-value	0.1327	0.0693	0.0001	0.0001	0.0001	0.0247	0.2044	0.0719	0.4642	0.0077	0.0024	0.0000
Aug. 7, 2011 (1d)	**-0.095**	-0.109	**-0.233**	**-0.238**	**-0.217**	**-0.255**	**-0.260**	**-0.199**	**-0.250**	**-0.192**	**-0.165**	**-2.213**
p-value	0.0111	0.3831	0.0012	0.0156	0.0138	0.0001	0.0001	0.0016	0.0000	0.0000	0.0002	0.0000
Oct. 6, 2011 (2d)	**0.153**	0.009	0.008	0.004	0.063	0.011	-0.013	-0.033	0.003	0.005	0.017	0.227
p-value	0.0555	0.8976	0.9322	0.9797	0.7142	0.9438	0.9298	0.8046	0.9789	0.9650	0.8666	0.9621
Oct. 25, 2011 (2d)	**-0.167**	-0.037	-0.134	-0.215	-0.266	-0.265	-0.252	-0.182	-0.216	**-0.242**	**-0.216**	**-2.192**
p-value	0.0812	0.6153	0.2981	0.2690	0.1583	0.1228	0.1106	0.2021	0.1188	0.0558	0.0715	0.0091
Nov. 3, 2011 (2d)	**-0.241**	-0.092	-0.091	-0.069	-0.062	-0.025	-0.016	-0.032	-0.046	-0.023	-0.04	-0.737
p-value	0.0160	0.2278	0.4351	0.7205	0.7305	0.8724	0.9129	0.8130	0.7072	0.8445	0.7147	0.5889
Dec. 2, 2011 (2d)	-0.345	-0.323	-0.554	-0.417	-0.499	-0.463	-0.495	**-0.509**	**-0.44**	**-0.479**	**-0.426**	**-4.950**
p-value	0.1136	0.1470	0.1577	0.3455	0.2386	0.2262	0.1548	0.0875	0.0631	0.0536	0.0632	0.0036
Dec. 8, 2011 (2d)	-0.005	0.132	0.249	-0.066	-0.005	-0.001	0.016	0.106	0.036	0.039	-0.007	0.494
p-value	0.9833	0.5804	0.5565	0.8825	0.9907	0.9980	0.9647	0.7406	0.8902	0.8861	0.9774	1.0000
Dec. 20, 2011 (2d)	-0.211	-0.32	-0.167	-0.15	-0.179	-0.026	-0.117	-0.065	-0.077	-0.081	-0.05	-1.443
p-value	0.4266	0.2836	0.7219	0.7451	0.6906	0.9489	0.7507	0.8413	0.7737	0.7718	0.8439	0.9950
Feb. 28, 2012 (2d)	0.01	0.043	-0.105	-0.075	-0.078	-0.069	-0.055	-0.055	-0.071	-0.053	-0.039	-0.547
p-value	0.9158	0.5856	0.2680	0.3801	0.4588	0.4273	0.4940	0.4754	0.2810	0.4379	0.5042	0.8085
Jul. 26, 2012 (2d)	0.011	0.008	-0.01	-0.08	-0.142	-0.114	-0.092	-0.066	-0.05	-0.059	-0.064	-0.658
p-value	0.8067	0.8840	0.8559	0.4708	0.2741	0.4272	0.4773	0.5740	0.6395	0.5681	0.5104	0.9573
Aug. 2, 2012 (2d)	**-0.078**	0.027	0.021	-0.04	-0.079	-0.102	-0.089	-0.102	-0.039	-0.074	-0.059	-0.614
p-value	0.0883	0.6631	0.7090	0.7206	0.5432	0.4725	0.4807	0.3645	0.7106	0.4495	0.5219	0.7996
Sep. 6, 2012 (2d)	0.005	0.035	0	-0.016	-0.061	-0.067	-0.04	-0.025	-0.039	-0.043	-0.033	-0.284
p-value	0.9278	0.2905	1.0000	0.6862	0.2398	0.2639	0.4579	0.6406	0.4856	0.4205	0.5365	0.8440

Table 1.4: **Finland: effects of ECB announcements on government bond yields**

EVENTS	**RESPONSES TO ANNOUNCEMENTS**							**Joint**
	2m	**2y**	**3y**	**5y**	**8y**	**10y**	**15y**	**Significance**
Aug. 22, 2007 (2d)		**0.214**	**0.181**	**0.143**		0.075		**0.613**
p-value		0.0062	0.0182	0.0491		0.1817		0.0003
Oct. 15, 2008 (2d)	-0.06	-0.282	-0.269	-0.172		0.008		-0.775
p-value	0.3974	0.1243	0.1128	0.2587		0.9468		0.2027
May 7, 2009 (2d)	-0.01	-0.036	0.084	0.04	0.107	**0.215**		**0.4**
p-value	0.5395	0.6414	0.2674	0.6611	0.1324	0.0100		0.0602
Jun. 4, 2009 (2d)	0.01	**0.303**	**0.248**	**0.34**	**0.17**	0.149		**1.22**
p-value	0.6085	0.0001	0.0025	0.0005	0.0714	0.1389		0.0000
Jun. 23, 2009 (2d)	-0.03	-0.14	-0.036	-0.104	-0.004	0.007		-0.307
p-value	0.1847	0.1519	0.7146	0.3472	0.9670	0.9490		0.5352
Sept. 29, 2009 (2d)	0	0.044	0.013	0.052	0.032	-0.014		0.127
p-value	1.0000	0.3088	0.8256	0.3698	0.5649	0.7944		0.8837
Dec. 3, 2009 (2d)	**-0.05**	0.014	**0.093**	**0.09**	**0.087**	0.071	0.017	**0.322**
p-value	0.0492	0.7733	0.0347	0.0829	0.0712	0.1635	0.7368	0.0115
Dec. 15, 2009 (2d)	0	-0.02	**-0.088**	-0.028	-0.029	0.004	-0.015	-0.176
p-value	1.0000	0.6765	0.0894	0.6319	0.5986	0.9396	0.7375	0.7907
May 10, 2010 (1d)	0.000	0.018	0.016	0.067	**0.166**	**0.117**	0.063	**0.447**
p-value	1.0000	0.7381	0.7549	0.2883	0.0002	0.0168	0.1425	0.0002
Aug. 7, 2011 (1d)	**-0.051**	**-0.159**	**-0.179**	**-0.187**	**-0.163**	**-0.201**	**-0.143**	**-1.083**
p-value	0.0667	0.0443	0.0052	0.0063	0.0120	0.0011	0.0071	0.0000
Oct. 6, 2011 (2d)	0.083	0.068	0.05	0.098	0.124	0.127	0.097	0.647
p-value	0.2891	0.3473	0.6045	0.3677	0.2541	0.2548	0.3508	0.4507
Oct. 25, 2011 (2d)	-0.015	**-0.142**	**-0.155**	**-0.177**	-0.13	-0.106	-0.159	**-0.884**
p-value	0.8882	0.0676	0.0631	0.0751	0.2201	0.3347	0.1338	0.0282
Nov. 3, 2011 (2d)	0.079	-0.023	-0.046	-0.021	-0.012	0.02	-0.002	-0.005
p-value	0.5098	0.7919	0.6317	0.8613	0.9282	0.8808	0.9877	0.9973
Dec. 2, 2011 (2d)	0.02	0.056	0.034	-0.025	0	0.005	-0.02	0.07
p-value	0.8530	0.6242	0.7776	0.8568	1.0000	0.9731	0.8867	0.9997
Dec. 8, 2011 (2d)	0.017	0.05	0.021	0.047	0.06	0.04	0.084	0.319
p-value	0.8752	0.6532	0.8574	0.7295	0.6897	0.7921	0.5591	0.9953
Dec. 20, 2011 (2d)	-0.016	0.005	0.021	0.033	0.024	0.023	0.047	0.137
p-value	0.8754	0.9616	0.8434	0.7811	0.8529	0.8625	0.7154	0.9998
Feb. 28, 2012 (2d)	0.002	-0.023	-0.015	0.01	-0.02	-0.009	0.002	-0.053
p-value	0.9358	0.7718	0.9037	0.9463	0.8221	0.9048	0.9824	1.0000
Jul. 26, 2012 (2d)	0	0.025	0.005	0.036	0.069	0.057	0.083	0.275
p-value	1.0000	0.6199	0.9309	0.6467	0.4434	0.5292	0.3500	0.9355
Aug. 2, 2012 (2d)	0	0.03	0.047	0.092	0.053	0.045	0.011	0.278
p-value	1.0000	0.4676	0.3127	0.1878	0.5132	0.5719	0.8900	0.7563
Sep. 6, 2012 (2d)	0	0.06	0.07	0.031	0.06	0.056	0.12	0.397
p-value	1.0000	0.0299	0.0851	0.6719	0.4074	0.5192	0.1003	0.0828

Table 1.5: **France: effects of ECB announcements on government bond yields**

EVENTS	**RESPONSES TO ANNOUNCEMENTS**											**Joint**
	3m	**6m**	**1y**	**2y**	**3y**	**5y**	**7y**	**10y**	**15y**	**20y**	**30y**	**Significance**
Aug. 22, 2007 (2d)	-0.011	**0.076**	**0.149**	0.127	0.121	0.079	0.052	0.017	0.001	0.008	-0.004	**0.615**
p-value	0.7724	0.0890	0.0068	0.1344	0.1325	0.2858	0.4185	0.7608	0.9857	0.8761	0.9374	0.0726
Oct. 15, 2008 (2d)	-0.092	**0.482**	-0.194	**-0.35**	-0.241	-0.25	-0.151	-0.069	0.004	0.036	0.031	-0.794
p-value	0.8278	0.0473	0.1542	0.0705	0.2079	0.1417	0.3045	0.5590	0.9757	0.8056	0.8421	0.1611
May 7, 2009 (2d)	-0.016	-0.063	-0.054	-0.064	0.018	0.124	**0.132**	**0.191**	**0.17**	**0.19**	**0.201**	**0.829**
p-value	0.7236	0.3615	0.3490	0.5802	0.8611	0.1406	0.0824	0.0015	0.0036	0.0021	0.0017	0.0000
Jun. 4, 2009 (2d)	**0.087**	0.082	**0.162**	**0.277**	**0.37**	**0.284**	**0.202**	**0.157**	**0.121**	0.073	0.057	**1.872**
p-value	0.0774	0.1724	0.0014	0.0535	0.0000	0.0009	0.0055	0.0242	0.0523	0.2578	0.3675	0.0000
Jun. 23, 2009 (2d)	**-0.11**	-0.089	-0.074	-0.095	-0.049	-0.04	0.006	0.021	0.031	0.006	0.009	-0.384
p-value	0.0392	0.1535	0.2664	0.5309	0.7024	0.6908	0.9401	0.7619	0.6051	0.9100	0.8631	0.6012
Sept. 29, 2009 (2d)	0.01	**0.039**	-0.006	0.036	-0.012	0.007	0.017	0.005	-0.007	-0.029	-0.045	0.015
p-value	0.6190	0.0692	0.8442	0.4277	0.8473	0.8954	0.7414	0.9273	0.9016	0.6315	0.4589	0.9052
Dec. 3, 2009 (2d)	**-0.048**	-0.049	-0.008	**0.089**	**0.088**	0.078	**0.092**	0.063	0.035	0.026	0.033	**0.399**
p-value	0.0176	0.1804	0.7898	0.0437	0.0877	0.1567	0.0722	0.2177	0.4388	0.6034	0.5316	0.0113
Dec. 15, 2009 (2d)	**0.04**	-0.029	-0.028	-0.042	-0.035	-0.016	-0.025	-0.01	-0.04	-0.036	-0.006	-0.227
p-value	0.0676	0.4044	0.3885	0.4220	0.6082	0.7715	0.6403	0.8349	0.3621	0.4633	0.9097	0.7316
May 10, 2010 (1d)	-0.002	-0.020	0.002	0.049	-0.009	0.077	0.066	0.059	**0.076**	**0.122**	**0.125**	**0.545**
p-value	0.8691	0.5449	0.9304	0.2805	0.8606	0.1423	0.1430	0.1344	0.0461	0.0063	0.0048	0.0011
Aug. 7, 2011 (1d)	-0.009	0.003	**-0.138**	-0.043	0.061	0.059	-0.044	-0.029	-0.021	-0.013	-0.032	-0.206
p-value	0.8168	0.9492	0.0518	0.4931	0.3525	0.3654	0.3676	0.4866	0.6395	0.7925	0.5532	0.6789
Oct. 6, 2011 (2d)	**0.113**	0.082	0.103	0.045	0.102	0.092	0.111	0.105	0.102	0.112	0.115	1.082
p-value	0.0812	0.2027	0.1580	0.5854	0.1914	0.2928	0.2653	0.2455	0.3133	0.2550	0.2209	0.1088
Oct. 25, 2011 (2d)	-0.109	-0.008	-0.049	**-0.271**	**-0.299**	**-0.357**	**-0.303**	**-0.255**	**-0.277**	**-0.287**	**-0.276**	**-2.491**
p-value	0.1048	0.8754	0.5354	0.0006	0.0002	0.0001	0.0017	0.0087	0.0086	0.0071	0.0094	0.0000
Nov. 3, 2011 (2d)	**-0.155**	-0.07	-0.071	-0.028	-0.067	-0.074	-0.06	-0.029	-0.041	0.011	0.048	-0.536
p-value	0.0554	0.1947	0.3724	0.7451	0.4935	0.5123	0.5854	0.7851	0.7220	0.9242	0.6722	0.6864
Dec. 2, 2011 (2d)	-0.073	0.054	0.011	-0.082	-0.031	-0.021	-0.013	-0.017	-0.054	-0.034	-0.056	-0.316
p-value	0.4184	0.5834	0.9226	0.6582	0.8760	0.9191	0.9428	0.9169	0.7549	0.8323	0.7085	0.9996
Dec. 8, 2011 (2d)	-0.006	0.048	0.003	-0.085	0	0	0.038	0.002	-0.042	-0.04	-0.042	-0.124
p-value	0.9407	0.6200	0.9770	0.6356	1.0000	1.0000	0.8244	0.9898	0.7956	0.7860	0.7573	1.0000
Dec. 20, 2011 (2d)	0.015	-0.04	-0.035	0.04	0.039	0.005	-0.005	0.02	0.048	0.065	0.067	0.219
p-value	0.9031	0.6853	0.7639	0.8288	0.8404	0.9799	0.9777	0.9027	0.7723	0.6773	0.6451	1.0000
Feb. 28, 2012 (2d)	**-0.048**	-0.04	-0.035	-0.12	-0.064	-0.059	-0.041	-0.06	-0.045	-0.025	-0.027	-0.564
p-value	0.0785	0.2152	0.3060	0.2014	0.5879	0.5202	0.6142	0.3989	0.4283	0.6431	0.6229	0.4813
Jul. 26, 2012 (2d)	-0.008	0.006	**0.118**	**-0.141**	-0.138	-0.115	-0.086	-0.072	-0.073	-0.079	-0.056	**-0.644**
p-value	0.8747	0.8868	0.0048	0.0641	0.1202	0.2267	0.3661	0.4240	0.4054	0.3345	0.4899	0.0353
Aug. 2, 2012 (2d)	-0.011	-0.019	**-0.105**	-0.006	-0.009	-0.019	-0.006	-0.006	-0.026	-0.026	-0.011	-0.244
p-value	0.8282	0.6533	0.0607	0.9371	0.9179	0.8345	0.9468	0.9440	0.7549	0.7335	0.8824	0.9577
Sep. 6, 2012 (2d)	0.001	0.008	0.011	0.054	0.009	-0.011	-0.031	-0.029	-0.023	-0.012	-0.024	-0.047
p-value	0.9223	0.5937	0.8047	0.1793	0.8424	0.8361	0.5524	0.5670	0.6776	0.8283	0.6760	0.9835

Table 1.6: **Germany: effects of ECB announcements on government bond yields**

EVENTS	RESPONSES TO ANNOUNCEMENTS										Joint
	3m	**6m**	**1y**	**2y**	**3y**	**5y**	**7y**	**10y**	**20y**	**30y**	**Significance**
Aug. 22, 2007 (2d)	-0.005	0.074	**0.166**	**0.155**	**0.142**	**0.118**	0.077	0.052	0.028	0.017	**0.824**
p-value	0.9481	0.1407	0.0046	0.0447	0.0482	0.0787	0.1965	0.3200	0.5645	0.7238	0.0027
Oct. 15, 2008 (2d)	**-0.530**	-0.27	0.054	**-0.288**	-0.258	-0.164	-0.089	-0.011	0.055	0.055	-1.446
p-value	0.0924	0.1954	0.7812	0.0928	0.1282	0.3003	0.5312	0.9250	0.7156	0.7123	0.2762
May 7, 2009 (2d)	-0.044	**-0.131**	-0.068	-0.016	0.029	0.143	**0.181**	**0.206**	**0.182**	**0.216**	**0.698**
p-value	0.3146	0.0558	0.2274	0.8642	0.7733	0.1363	0.0601	0.0076	0.0171	0.0027	0.0000
Jun. 4, 2009 (2d)	0.062	0.082	**0.154**	**0.317**	**0.297**	**0.262**	**0.213**	0.103	0.113	0.085	**1.688**
p-value	0.1749	0.1482	0.0049	0.0002	0.0002	0.0019	0.0093	0.1376	0.1182	0.2543	0.0000
Jun. 23, 2009 (2d)	0.000	0.031	-0.015	-0.063	-0.04	-0.038	-0.014	-0.014	0.045	0.046	-0.062
p-value	1.0000	0.5543	0.8211	0.5794	0.6849	0.6979	0.8696	0.8420	0.4820	0.4652	0.9949
Sept. 29, 2009 (2d)	0.000	0.036	**0.049**	0.047	0.01	-0.012	-0.032	-0.026	-0.019	-0.052	0.001
p-value	1.0000	0.1140	0.0817	0.4905	0.8833	0.8331	0.5691	0.6192	0.7578	0.4090	0.6439
Dec. 3, 2009 (2d)	-0.044	**-0.05**	0.005	**0.113**	**0.105**	**0.119**	**0.1**	0.038	0.029	0.038	**0.453**
p-value	0.1332	0.0399	0.8839	0.0425	0.0225	0.0394	0.0819	0.4795	0.5848	0.4920	0.0031
Dec. 15, 2009 (2d)	-0.013	-0.021	-0.03	-0.026	-0.035	0.006	0.008	0.034	-0.016	-0.011	-0.104
p-value	0.6802	0.5255	0.2966	0.6744	0.5238	0.9248	0.8937	0.5023	0.7440	0.8382	0.9825
May 10, 2010 (1d)	-0.005	-0.017	-0.027	0.052	**0.083**	0.092	**0.119**	**0.186**	**0.149**	**0.185**	**0.817**
p-value	0.8708	0.6555	0.5453	0.3047	0.0949	0.1316	0.0298	0.0000	0.0032	0.0004	0.0000
Aug. 7, 2011 (1d)	-0.048	-0.055	-0.027	-0.072	-0.080	-0.087	-0.085	-0.088	-0.047	-0.065	-0.654
p-value	0.7162	0.4906	0.6641	0.3319	0.2586	0.2641	0.2422	0.1952	0.4790	0.3299	0.5232
Oct. 6, 2011 (2d)	0.131	0.087	0.102	0.122	0.120	0.146	0.161	0.165	0.160	0.143	**1.337**
p-value	0.2246	0.3846	0.1302	0.1982	0.2300	0.2375	0.1807	0.1798	0.1745	0.1979	0.0770
Oct. 25, 2011 (2d)	-0.007	-0.023	-0.064	-0.132	-0.140	-0.149	-0.107	-0.080	-0.090	-0.099	-0.891
p-value	0.9115	0.6617	0.2477	0.1178	0.1239	0.1864	0.3580	0.4948	0.4373	0.3989	0.3388
Nov. 3, 2011 (2d)	**-0.262**	-0.087	-0.074	-0.050	-0.050	-0.059	-0.046	-0.023	-0.033	-0.031	**-0.715**
p-value	0.0001	0.1190	0.2012	0.6002	0.6438	0.6763	0.7589	0.8808	0.8177	0.8274	0.0038
Dec. 2, 2011 (2d)	**0.298**	0.022	**0.112**	-0.002	-0.005	-0.030	-0.039	-0.034	-0.113	-0.117	**0.092**
p-value	0.0000	0.6575	0.0693	0.9801	0.9590	0.8243	0.7843	0.8206	0.4262	0.3871	0.0012
Dec. 8, 2011 (2d)	0.040	0.076	0.060	0.003	0.026	-0.001	0.015	0.046	0.061	0.051	0.377
p-value	0.6841	0.1414	0.3700	0.9685	0.7792	0.9939	0.9142	0.7625	0.6809	0.7149	0.9568
Dec. 20, 2011 (2d)	-0.027	-0.022	-0.010	0.009	0.021	0.039	0.035	0.053	0.067	0.068	0.233
p-value	0.7459	0.6438	0.8702	0.8752	0.7537	0.6961	0.7284	0.6413	0.5690	0.5297	0.9981
Feb. 28, 2012 (2d)	**-0.147**	0.007	-0.017	0.005	-0.004	0.027	0.011	0.006	0.024	0.023	-0.065
p-value	0.0459	0.7940	0.7408	0.8641	0.9398	0.6722	0.8744	0.9355	0.7368	0.7509	0.8912
Jul. 26, 2012 (2d)	**0.143**	0.011	**0.095**	0.034	0.055	0.091	0.110	**0.131**	0.107	0.107	**0.884**
p-value	0.0025	0.7846	0.0029	0.3697	0.2538	0.2058	0.1484	0.0882	0.2042	0.2010	0.0002
Aug. 2, 2012 (2d)	0.006	0.041	0.010	0.034	0.038	0.052	0.032	0.017	0.001	0.006	0.237
p-value	0.9275	0.4288	0.7986	0.2549	0.3132	0.3809	0.6255	0.8022	0.9889	0.9287	0.9364
Sep. 6, 2012 (2d)	-0.084	**0.083**	0.019	**0.070**	**0.075**	**0.097**	0.096	0.115	**0.124**	**0.142**	**0.737**
p-value	0.3871	0.0547	0.6480	0.0035	0.0339	0.0939	0.1497	0.1278	0.0934	0.0714	0.0002

Table 1.7: **Greece: effects of ECB announcements on government bond yields**

EVENTS	**RESPONSES TO ANNOUNCEMENTS**				**Joint Significance**
	3m	**10y**	**15y**	**30y**	
Aug. 22, 2007 (2d)		0.006	-0.018	-0.014	-0.026
p-value		0.9576	0.8764	0.9228	0.9981
Oct. 15, 2008 (2d)		-0.032	0.007	-0.003	-0.028
p-value		0.7763	0.9517	0.9835	0.9934
May 7, 2009 (2d)		**-0.13**	**-0.135**	**-0.145**	**-0.41**
p-value		0.0185	0.0617	0.0106	0.0006
Jun. 4, 2009 (2d)		0.147	0.144	**0.191**	**0.482**
p-value		0.1219	0.1183	0.0417	0.0216
Jun. 23, 2009 (2d)		-0.016	0.064	0.07	0.118
p-value		0.8763	0.4473	0.4027	0.7198
Sept. 29, 2009 (2d)		0.029	0.02	-0.024	0.025
p-value		0.6375	0.7060	0.7238	0.9191
Dec. 3, 2009 (2d)		**0.205**	0.147	0.146	**0.498**
p-value		0.0877	0.2349	0.1101	0.0626
Dec. 15, 2009 (2d)		0.089	0.188	-0.01	0.267
p-value		0.6270	0.2354	0.9386	0.6335
May 10, 2010 (1d)		**-4.009**	**-1.979**	**-0.665**	**-6.653**
p-value		0.0000	0.0000	0.0003	0.0000
Aug. 7, 2011 (1d)	**5.543**	-0.412	-0.163	-0.198	**4.770**
p-value	0.0002	0.3786	0.5715	0.4109	0.0005
Oct. 6, 2011 (2d)	**4.925**	0.946	0.144	-0.108	**5.907**
p-value	0.0002	0.5583	0.9194	0.8883	0.0009
Oct. 25, 2011 (2d)	0.103	-0.235	-0.207	0.802	0.463
p-value	0.9725	0.8772	0.8722	0.1738	0.7365
Nov. 3, 2011 (2d)	-0.187	**3.948**	**4.86**	**1.359**	**9.980**
p-value	0.9468	0.0019	0.0000	0.0257	0.0000
Dec. 2, 2011 (2d)	-0.004	-0.679	0.739	-0.608	-0.552
p-value	0.9991	0.7965	0.7173	0.4379	0.9357
Dec. 8, 2011 (2d)	0.014	1.283	1.314	**2.001**	4.612
p-value	0.9969	0.6279	0.5230	0.0240	0.1758
Dec. 20, 2011 (2d)	-1.683	0.203	0.21	-0.551	-1.821
p-value	0.7244	0.9317	0.9074	0.4161	0.9346
Feb. 28, 2012 (2d)	0.019	0.589	0.185	-0.122	0.671
p-value	0.9924	0.6614	0.8949	0.9060	0.9940
Jul. 26, 2012 (2d)	-0.02	-0.938	-0.996	-1.535	-3.489
p-value	0.9675	0.3107	0.3500	0.1089	0.3189
Aug. 2, 2012 (2d)	-0.25	-0.88	-1.247	-1.376	-3.753
p-value	0.6098	0.3245	0.2162	0.1513	0.2831
Sep. 6, 2012 (2d)	0.13	-0.188	-0.257	-0.184	-0.499
p-value	0.5436	0.7616	0.6660	0.7646	0.9446

Table 1.8: **Italy: effects of ECB announcements on government bond yields**

EVENTS	**RESPONSES TO ANNOUNCEMENTS**										**Joint**
	3m	**6m**	**1y**	**2y**	**3y**	**5y**	**7y**	**10y**	**15y**	**30y**	**Significance**
Aug. 22, 2007 (2d)				**0.133**	**0.126**	0.071	0.018	0.012		-0.033	0.312
p-value				0.0794	0.0933	0.2694	0.7336	0.7966		0.4771	0.2102
Oct. 15, 2008 (2d)				**-0.275**	**-0.328**	**-0.299**	-0.215	-0.057		-0.01	**-1.237**
p-value				0.0802	0.0492	0.0511	0.1118	0.5658		0.9378	0.0208
May 7, 2009 (2d)				**-0.165**	-0.038	0.051	0.073	0.039		0.049	0.043
p-value				0.0915	0.6604	0.5547	0.1650	0.4095		0.2791	0.2324
Jun. 4, 2009 (2d)				**0.294**	**0.287**	**0.254**	**0.178**	**0.14**		**0.144**	**1.47**
p-value				0.0009	0.0020	0.0031	0.0009	0.0168		0.0127	0.0000
Jun. 23, 2009 (2d)				-0.083	-0.106	-0.079	-0.048	-0.005		0.058	-0.234
p-value				0.3746	0.3170	0.3367	0.4587	0.9394		0.3136	0.5917
Sept. 29, 2009 (2d)	0.006	0.016	0.029	-0.075	0.024	0.078	0.019	0.008	0	-0.041	0.064
p-value	0.9448	0.2291	0.4534	0.5253	0.5841	0.1414	0.6826	0.8681	1.0000	0.4414	0.8231
Dec. 3, 2009 (2d)	-0.032	**-0.073**	-0.027	0.056	0.084	0.059	0.013	0.006	-0.014	-0.025	0.047
p-value	0.7641	0.0038	0.5925	0.3727	0.2631	0.3222	0.8209	0.9293	0.7539	0.5525	0.1751
Dec. 15, 2009 (2d)	-0.001	-0.036	-0.035	-0.061	**-0.096**	-0.05	-0.051	-0.018	-0.035	-0.039	-0.422
p-value	0.9925	0.2723	0.5126	0.4120	0.0967	0.3615	0.3283	0.7665	0.4347	0.3209	0.5399
May 10, 2010 (1d)	0.004	**-0.296**	**-0.349**	**-0.554**	**-0.718**	**-0.507**	**-0.441**	**-0.280**	**-0.237**	**-0.169**	**-3.547**
p-value	0.9631	0.0008	0.0053	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001	0.0000
Aug. 7, 2011 (1d)	-0.093	-0.250	**-0.544**	**-0.946**	**-0.969**	**-0.929**	**-0.869**	**-0.811**	**-0.528**	**-0.405**	**-6.344**
p-value	0.6998	0.2730	0.0217	0.0001	0.0002	0.0000	0.0000	0.0000	0.0001	0.0010	0.0000
Oct. 6, 2011 (2d)	0.144	-0.159	-0.04	-0.135	-0.089	-0.109	-0.054	-0.002	0.025	-0.033	-0.452
p-value	0.6792	0.5294	0.8736	0.5958	0.7179	0.6136	0.7610	0.9898	0.8750	0.8440	0.9991
Oct. 25, 2011 (2d)	**0.37**	**0.573**	**0.619**	0.082	-0.005	-0.025	0.001	-0.027	-0.099	-0.065	**1.424**
p-value	0.0471	0.0055	0.0167	0.6011	0.9746	0.8827	0.9939	0.7957	0.2799	0.4839	0.0160
Nov. 3, 2011 (2d)	**0.713**	0.105	0.307	**0.398**	**0.362**	0.26	**0.218**	**0.18**	**0.151**	0.053	**2.747**
p-value	0.0002	0.6606	0.3687	0.0427	0.0492	0.1256	0.0903	0.0827	0.0867	0.5304	0.0000
Dec. 2, 2011 (2d)	0.247	**-1.062**	-0.698	-0.857	-0.838	**-0.956**	**-0.888**	-0.284	**-0.507**	-0.38	**-6.223**
p-value	0.8150	0.0441	0.5240	0.1184	0.1514	0.0530	0.0329	0.3767	0.0883	0.1065	0.0046
Dec. 8, 2011 (2d)	0.095	0.345	0.742	0.404	0.293	0.531	0.432	0.35	0.345	0.148	3.685
p-value	0.9305	0.5650	0.4998	0.5056	0.6487	0.3492	0.3737	0.3151	0.2995	0.5567	0.8385
Dec. 20, 2011 (2d)	0.005	-0.295	0.251	-0.083	0.02	-0.042	-0.064	-0.055	-0.065	-0.058	-0.386
p-value	0.9965	0.6484	0.8185	0.8875	0.9749	0.9414	0.8941	0.8773	0.8487	0.8152	1.0000
Feb. 28, 2012 (2d)	-0.246	-0.253	**-0.334**	**-0.55**	**-0.389**	**-0.371**	**-0.307**	**-0.269**	-0.203	-0.191	**-3.113**
p-value	0.1096	0.1292	0.0470	0.0065	0.0336	0.0651	0.0872	0.0755	0.1291	0.1040	0.0000
Jul. 26, 2012 (2d)	-0.041	**-0.706**	**-0.738**	**-1.135**	**-0.965**	**-0.765**	**-0.637**	**-0.495**	**-0.426**	**-0.354**	**-6.262**
p-value	0.9206	0.0008	0.0296	0.0028	0.0028	0.0047	0.0038	0.0060	0.0067	0.0179	0.0000
Aug. 2, 2012 (2d)	0.224	-0.301	**-0.752**	-0.577	-0.496	-0.267	-0.093	0.144	0.104	0.159	-1.855
p-value	0.5460	0.4696	0.0926	0.2826	0.3144	0.5145	0.7819	0.5768	0.6298	0.3952	0.6292
Sep. 6, 2012 (2d)	0.028	-0.145	-0.065	-0.213	-0.274	-0.391	**-0.406**	**-0.43**	**-0.326**	**-0.29**	**-2.512**
p-value	0.8810	0.4506	0.8416	0.5449	0.3621	0.1283	0.0540	0.0153	0.0334	0.0489	0.0070

Table 1.9: **Netherlands: effects of ECB announcements on government bond yields**

EVENTS	**RESPONSES TO ANNOUNCEMENTS**										**Joint Significance**
	3m	**6m**	**1y**	**2y**	**3y**	**5y**	**7y**	**10y**	**20y**	**30y**	
Aug. 22, 2007 (2d)			0.07	0.126	0.107	0.064	0.044	0.02	-0.014	-0.016	0.401
p-value			0.7806	0.2244	0.1863	0.3667	0.4671	0.7203	0.7898	0.7541	0.7426
Oct. 15, 2008 (2d)			0.33	0	**-0.342**	-0.226	-0.12	-0.057	0.049	0.041	-0.325
p-value			0.1052	1.0000	0.0859	0.1680	0.4078	0.6396	0.7132	0.7912	0.3343
May 7, 2009 (2d)			-0.044	-0.073	-0.02	0.044	0.105	**0.193**	**0.177**	**0.149**	**0.531**
p-value			0.4648	0.4835	0.8219	0.5608	0.1065	0.0013	0.0142	0.0300	0.0003
Jun. 4, 2009 (2d)			**0.157**	**0.276**	**0.275**	**0.304**	**0.231**	**0.161**	0.095	0.078	**1.577**
p-value			0.0201	0.0006	0.0002	0.0002	0.0023	0.0262	0.1575	0.2384	0.0000
Jun. 23, 2009 (2d)			-0.104	-0.084	-0.047	-0.045	-0.024	0.015	0.03	0.026	-0.233
p-value			0.1424	0.4056	0.6039	0.6323	0.7668	0.8318	0.5979	0.6465	0.8452
Sept. 29, 2009 (2d)			0.012	0.025	0.035	-0.004	0.034	-0.004	-0.024	-0.056	0.018
p-value			0.7030	0.6635	0.4812	0.9409	0.5213	0.9423	0.6855	0.3779	0.9723
Dec. 3, 2009 (2d)			**-0.043**	0.038	**0.093**	0.087	0.058	0.044	0.043	0.037	**0.357**
p-value			0.0734	0.3229	0.0250	0.1148	0.2568	0.3536	0.3967	0.5077	0.0409
Dec. 15, 2009 (2d)			-0.031	-0.025	**-0.123**	-0.028	-0.034	-0.03	-0.029	-0.032	-0.332
p-value			0.1708	0.5360	0.0252	0.6323	0.4906	0.5052	0.5512	0.5632	0.2782
May 10, 2010 (1d)			0.015	0.000	0.019	0.104	0.086	0.083	**0.149**	**0.145**	**0.601**
p-value			0.7345	1.0000	0.7725	0.1690	0.1938	0.1464	0.0136	0.0188	0.0134
Aug. 7, 2011 (1d)	**-0.087**	-0.101	**-0.134**	-0.084	-0.068	-0.082	**-0.102**	-0.084	-0.125	-0.066	**-0.933**
p-value	0.0457	0.4371	0.0078	0.1918	0.2446	0.1791	0.0809	0.1106	0.0467	0.3124	0.0010
Oct. 6, 2011 (2d)	**0.151**	**0.113**	**0.112**	0.098	0.088	0.117	0.147	0.158	0.169	0.14	**1.293**
p-value	0.0130	0.0702	0.0955	0.2275	0.3156	0.2235	0.1476	0.1221	0.1406	0.1836	0.0031
Oct. 25, 2011 (2d)	-0.053	-0.051	-0.065	**-0.138**	**-0.146**	**-0.177**	-0.162	-0.13	-0.111	-0.093	**-1.126**
p-value	0.4278	0.4591	0.3327	0.0873	0.0778	0.0660	0.1247	0.2320	0.3303	0.4202	0.0559
Nov. 3, 2011 (2d)	-0.045	-0.049	-0.058	-0.089	-0.083	-0.091	-0.067	-0.043	-0.072	-0.041	-0.638
p-value	0.4763	0.4507	0.3850	0.3256	0.3927	0.4619	0.6156	0.7556	0.6063	0.7635	0.8970
Dec. 2, 2011 (2d)	**0.077**	**0.11**	0.056	0.001	-0.031	-0.067	-0.027	-0.013	-0.077	-0.112	-0.083
p-value	0.0872	0.0697	0.4190	0.9932	0.8135	0.6538	0.8440	0.9199	0.5761	0.3822	0.5538
Dec. 8, 2011 (2d)	-0.008	-0.001	-0.032	-0.018	0.003	-0.001	0.02	0.018	0.049	0.04	0.070
p-value	0.8846	0.9885	0.6713	0.8756	0.9812	0.9945	0.8818	0.8886	0.7308	0.7638	1.0000
Dec. 20, 2011 (2d)	-0.043	-0.025	-0.005	0.032	0.047	0.061	0.077	0.072	0.073	0.079	0.368
p-value	0.3865	0.7006	0.9412	0.7588	0.6908	0.6255	0.4905	0.4762	0.5239	0.4424	0.9684
Feb. 28, 2012 (2d)	0.001	0.006	0.009	-0.008	0.003	0.033	0.015	0.005	0.003	0.017	0.084
p-value	0.9493	0.6609	0.5442	0.8746	0.9730	0.6912	0.8374	0.9406	0.9657	0.8091	0.9999
Jul. 26, 2012 (2d)	0.029	-0.006	0	-0.015	-0.038	-0.004	0.016	0.031	0.033	0.046	0.092
p-value	0.1213	0.6234	1.0000	0.6866	0.4915	0.9591	0.8467	0.7129	0.7129	0.5892	0.9445
Aug. 2, 2012 (2d)	0.013	**0.028**	0.01	0.028	0.03	0.036	0.029	0.017	0.018	-0.018	0.191
p-value	0.4757	0.0340	0.6435	0.4247	0.5309	0.6155	0.6882	0.8191	0.8221	0.8136	0.6938
Sep. 6, 2012 (2d)	0	0.011	0.021	**0.042**	**0.07**	0.083	0.078	0.07	0.055	0.112	**0.542**
p-value	1.0000	0.3240	0.1096	0.0821	0.0533	0.1288	0.2166	0.3018	0.4519	0.1129	0.0351

Table 1.10: **Portugal: effects of ECB announcements on government bond yields**

EVENTS	RESPONSES TO ANNOUNCEMENTS								Joint
	6m	2y	3y	5y	7y	10y	15y	30y	Significance
Aug. 22, 2007 (2d)		**0.152**	0.117	0.094	0.053	0.009	-0.004		0.421
p-value		0.0392	0.1539	0.1337	0.3647	0.8510	0.9365		0.1214
Oct. 15, 2008 (2d)		**-0.239**	**-0.378**	**-0.261**	-0.133	-0.109	-0.03		**-1.15**
p-value		0.0930	0.0207	0.0733	0.3208	0.3234	0.8087		0.0241
May 7, 2009 (2d)		-0.104	-0.031	0.037	0.04	0.077	**0.112**		0.131
p-value		0.1537	0.7425	0.5850	0.5611	0.2108	0.0307		0.1375
Jun. 4, 2009 (2d)		**0.328**	**0.388**	**0.253**	**0.226**	**0.196**	**0.162**		**1.553**
p-value		0.0000	0.0001	0.0036	0.0006	0.0083	0.0091		0.0000
Jun. 23, 2009 (2d)		-0.059	-0.1	-0.05	-0.045	0.019	0.043		-0.192
p-value		0.5428	0.4165	0.5774	0.5495	0.8019	0.5033		0.8936
Sept. 29, 2009 (2d)		0.006	0.043	0.069	0.054	0.021	0.007	-0.007	0.193
p-value		0.8695	0.4824	0.1491	0.3120	0.6940	0.9041	0.9107	0.7827
Dec. 3, 2009 (2d)		0.036	**0.102**	0.055	0.053	0.042	-0.024	-0.008	0.256
p-value		0.3604	0.0741	0.2593	0.2294	0.4042	0.6222	0.8702	0.3222
Dec. 15, 2009 (2d)		-0.031	-0.046	0.027	-0.019	0.003	-0.013	-0.028	-0.107
p-value		0.4665	0.4471	0.6406	0.7639	0.9582	0.8043	0.6049	0.9704
May 10, 2010 (1d)		**-3.218**	**-2.710**	**-1.381**	**-1.784**	**-1.739**	**-1.356**	**-0.236**	**-12.424**
p-value		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0202	0.0000
Aug. 7, 2011 (1d)	0.321	**-1.798**	**-2.001**	**-1.417**	**-1.500**	-0.415	-0.438	-0.050	**-7.298**
p-value	0.7042	0.1000	0.0933	0.0633	0.0353	0.3976	0.3179	0.8314	0.0362
Oct. 6, 2011 (2d)	**-1.423**	-0.163	0.067	-0.053	0.026	-0.056	0.138	-0.025	-1.489
p-value	0.0022	0.8571	0.9248	0.9287	0.9540	0.8774	0.4793	0.8997	0.1577
Oct. 25, 2011 (2d)	-0.017	0.924	**0.959**	0.458	0.259	-0.16	-0.159	0.143	2.407
p-value	0.9822	0.1401	0.0439	0.1714	0.3908	0.5964	0.4825	0.4896	0.2162
Nov. 3, 2011 (2d)	-0.22	-0.733	0.356	0.155	0.143	-0.02	-0.087	-0.007	-0.413
p-value	0.8225	0.2560	0.5443	0.7663	0.7255	0.9486	0.7604	0.9754	0.9783
Dec. 2, 2011 (2d)	-0.434	-0.434	**-2.186**	-0.837	-0.707	-0.406	-0.171	-0.211	-5.386
p-value	0.7211	0.7069	0.0477	0.3268	0.3366	0.4228	0.6932	0.3804	0.4226
Dec. 8, 2011 (2d)	0.02	0.647	0.72	-0.212	0.69	0.366	0.061	-0.018	2.274
p-value	0.9864	0.6080	0.5568	0.8076	0.3825	0.5071	0.8882	0.9359	0.9826
Dec. 20, 2011 (2d)	-0.12	-0.353	-0.302	-0.015	-0.072	-0.122	-0.008	-0.016	-1.008
p-value	0.9012	0.7608	0.7959	0.9847	0.9239	0.8212	0.9840	0.9362	1.0000
Feb. 28, 2012 (2d)	0.103	-0.616	0.896	0.315	0.937	0.775	0.565	0.182	3.157
p-value	0.8670	0.7486	0.6002	0.8266	0.4502	0.4225	0.5121	0.7021	0.9704
Jul. 26, 2012 (2d)	0.121	-0.417	**1.092**	0.243	0.184	-0.13	-0.149	-0.304	0.64
p-value	0.4619	0.4967	0.0276	0.6307	0.6675	0.6776	0.5987	0.0597	0.1939
Aug. 2, 2012 (2d)	-0.093	-0.235	-0.128	-0.406	-0.279	-0.217	0	-0.146	-1.504
p-value	0.6719	0.6798	0.7919	0.4064	0.5287	0.5022	1.0000	0.3829	0.9468
Sep. 6, 2012 (2d)	-0.186	**-0.971**	-0.993	**-1.124**	**-0.877**	**-1.025**	0	**-0.509**	**-5.685**
p-value	0.3814	0.0629	0.1325	0.0259	0.0163	0.0007	1.0000	0.0037	0.0000

Table 1.11: **Spain: effects of ECB announcements on government bond yields**

EVENTS	RESPONSES TO ANNOUNCEMENTS											Joint
	3m	**6m**	**1y**	**2y**	**3y**	**5y**	**7y**	**10y**	**15y**	**20y**	**30y**	**Significance**
Aug. 22, 2007 (2d)				0.14	**0.186**	0.073	0.048	0.024	0.02		0.009	**0.5**
p-value				0.1341	0.0000	0.1036	0.2792	0.5284	0.5536		0.8066	0.0000
Oct. 15, 2008 (2d)				**-0.405**	-0.238	**-0.277**	**-0.241**	-0.132	-0.026	0.041	-0.002	**-1.28**
p-value				0.0406	0.1086	0.0771	0.0867	0.2491	0.9054	0.7846	0.9897	0.0533
May 7, 2009 (2d)				-0.048	-0.039	0.014	0.09	**0.124**	**0.169**	**0.196**	**0.175**	**0.681**
p-value				0.5946	0.5233	0.8188	0.1515	0.0198	0.0036	0.0070	0.0141	0.0000
Jun. 4, 2009 (2d)				**0.293**	**0.29**	**0.271**	**0.219**	**0.136**	**0.119**	0.123	0.077	**1.528**
p-value				0.0004	0.0000	0.0007	0.0026	0.0517	0.0944	0.1256	0.3113	0.0000
Jun. 23, 2009 (2d)				-0.002	-0.071	-0.106	-0.084	-0.022	0.03	0.03	0.033	-0.192
p-value				0.9842	0.4215	0.2554	0.2954	0.7672	0.6215	0.6230	0.5982	0.8557
Sept. 29, 2009 (2d)				0.012	-0.009	0.036	0.047	0.017	0.021	0.018	0	0.142
p-value				0.9010	0.8471	0.5174	0.3794	0.7782	0.7248	0.7838	1.0000	0.9916
Dec. 3, 2009 (2d)				0.068	0.046	0.026	0.077	0.023	0.023	0.035	0.021	0.319
p-value				0.3495	0.3028	0.6644	0.1567	0.6473	0.6104	0.5280	0.6844	0.7178
Dec. 15, 2009 (2d)				**-0.139**	0.013	0.046	-0.01	-0.006	-0.024	-0.032	-0.025	-0.177
p-value				0.0442	0.7799	0.4217	0.8573	0.9127	0.6315	0.5717	0.6608	0.6503
May 10, 2010 (1d)				**-1.035**	**-0.797**	**-0.919**	**-0.681**	**-0.507**	**-0.349**	**-0.261**	**-0.174**	**-4.723**
p-value				0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Aug. 7, 2011 (1d)	**-0.429**	**-0.458**	**-0.654**	**-1.194**	**-1.202**	**-1.129**	**-1.157**	**-1.056**	**-0.863**	**-0.732**	**-0.696**	**-9.57**
p-value	0.0053	0.0242	0.0129	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oct. 6, 2011 (2d)	-0.194	-0.123	-0.17	-0.055	-0.072	-0.024	-0.068	-0.086	-0.063	-0.054	-0.036	-0.945
p-value	0.1208	0.3565	0.3559	0.7519	0.6327	0.8724	0.5915	0.4914	0.6320	0.6614	0.7826	0.8759
Oct. 25, 2011 (2d)	0.127	**0.232**	-0.153	-0.166	-0.165	-0.108	-0.074	-0.057	-0.056	-0.058	-0.07	-0.548
p-value	0.3297	0.0715	0.3102	0.2285	0.2248	0.3401	0.5180	0.5856	0.5664	0.5079	0.4387	0.3884
Nov. 3, 2011 (2d)	0.267	0.102	0.127	**0.354**	**0.319**	**0.214**	0.15	0.131	0.112	0.107	0.082	**1.965**
p-value	0.1218	0.3920	0.4036	0.0246	0.0330	0.0677	0.2163	0.2577	0.3081	0.2918	0.4092	0.0123
Dec. 2, 2011 (2d)	-0.7	**-0.981**	**-0.856**	**-0.981**	**-0.863**	**-0.758**	**-0.741**	**-0.607**	**-0.651**	**-0.522**	**-0.456**	**-8.116**
p-value	0.2740	0.0283	0.0093	0.0019	0.0060	0.0046	0.0022	0.0092	0.0070	0.0168	0.0347	0.0000
Dec. 8, 2011 (2d)	0.178	0.682	0.125	0.389	0.297	0.345	0.319	0.322	0.364	0.379	0.284	3.684
p-value	0.7955	0.1743	0.7433	0.3462	0.4602	0.3247	0.3330	0.2890	0.2330	0.1616	0.2767	0.4016
Dec. 20, 2011 (2d)	-0.091	-0.171	0.131	0.324	0.223	0.076	0.097	0.088	0.06	0.053	0.038	0.828
p-value	0.8981	0.7590	0.7548	0.4893	0.6223	0.8431	0.7859	0.7909	0.8588	0.8602	0.8964	0.9999
Feb. 28, 2012 (2d)	-0.048	-0.058	-0.193	-0.202	-0.182	-0.075	-0.063	-0.056	-0.075	-0.057	-0.059	-1.068
p-value	0.7331	0.6937	0.1455	0.2407	0.2602	0.5906	0.6320	0.7295	0.5728	0.6759	0.6554	0.8285
Jul. 26, 2012 (2d)	-0.819	**-1.008**	**-1.562**	**-1.133**	**-1.104**	**-0.915**	**-0.762**	**-0.671**	**-0.536**	**-0.465**	**-0.494**	**-9.469**
p-value	0.2056	0.0893	0.0034	0.0576	0.0450	0.0398	0.0459	0.0444	0.0400	0.0462	0.0226	0.0000
Aug. 2, 2012 (2d)	-0.218	-0.283	-0.224	-1.002	-0.742	-0.247	0.02	0.192	0.252	0.218	0.235	-1.799
p-value	0.7393	0.6529	0.6893	0.1389	0.2346	0.6198	0.9618	0.5947	0.3813	0.3980	0.3297	0.7723
Sep. 6, 2012 (2d)	-0.032	-0.201	-0.092	-0.262	-0.459	**-0.61**	**-0.695**	**-0.707**	**-0.582**	**-0.574**	**-0.554**	**-4.768**
p-value	0.9035	0.4779	0.7861	0.5714	0.2772	0.0816	0.0194	0.0088	0.0142	0.0066	0.0082	0.0000

Table 1.12: **Effects of LTROs on Euro-area 10-year government bond yields**

Time	**Event 1**	**Event 2**	**Event 3**	**Event 4**	**Event 5**	**Event 6**
T-9	-0.0004	0.0033*	0.0036**	-0.0076	0.0226**	0.0057
	[0.00176]	[0.00178]	[0.00134]	[0.00746]	[0.00974]	[0.00405]
T-8	-0.0133***	0.0040*	0.0148***	0.0190***	0.0263***	0.0131
	[0.00121]	[0.00185]	[0.00369]	[0.00587]	[0.00649]	[0.00802]
T-7	-0.0345***	0.0079***	0.0092	0.0029	0.0198	0.0084
	[0.00175]	[0.0017]	[0.00568]	[0.01072]	[0.0126]	[0.01047]
T-6	-0.0311***	0.0103***	0.0092	-0.0001	0.0149	0.0115
	[0.00358]	[0.00236]	[0.01082]	[0.01664]	[0.01286]	[0.01227]
T-5	-0.0406***	0.0061**	0.0228	0.0161	-0.0033	0.0080
	[0.00229]	[0.00244]	[0.01727]	[0.01501]	[0.0206]	[0.01123]
T-4	-0.0286***	-0.0109***	0.0313*	0.0091	-0.0214	0.0007
	[0.00227]	[0.00207]	[0.01579]	[0.01743]	[0.02025]	[0.01169]
T-3	-0.0368***	-0.0220***	0.0264**	0.0249	-0.0362	0.0051
	[0.00135]	[0.00223]	[0.00825]	[0.01414]	[0.02352]	[0.016]
T-2	-0.0474***	-0.0194***	0.0217	0.0343*	-0.0320	-0.0045
	[0.0026]	[0.00193]	[0.0136]	[0.016]	[0.02144]	[0.01491]
T-1	-0.0419***	-0.0236***	0.0377*	0.0149	-0.0270	-0.0115
	[0.00348]	[0.00205]	[0.01792]	[0.01652]	[0.01623]	[0.01692]
T	-0.0474***	-0.0180***	0.0240	-0.0004	-0.0241	-0.0057
	[0.00266]	[0.00284]	[0.01553]	[0.01705]	[0.0182]	[0.02256]
T+1	-0.0538***	-0.0195***	0.0210	0.0138	-0.0239	-0.0197
	[0.00293]	[0.0041]	[0.02107]	[0.00967]	[0.01976]	[0.02643]
T+2	-0.0619***	-0.0333***	0.0223	0.0203	-0.0255	-0.0265
	[0.0029]	[0.00379]	[0.02301]	[0.01118]	[0.02207]	[0.02604]
T+3	-0.0719***	-0.0357***	0.0414*	0.0042	-0.0244	-0.0196
	[0.00289]	[0.0033]	[0.02362]	[0.01905]	[0.02328]	[0.02629]
T+4	-0.0687***	-0.0306***	0.0466**	-0.0147	-0.0228	-0.0094
	[0.003]	[0.0031]	[0.01846]	[0.04113]	[0.02738]	[0.02746]
T+5	-0.0641***	-0.0388***	0.0474**	-0.0024	-0.0400	-0.0141
	[0.00331]	[0.00355]	[0.01728]	[0.034]	[0.0254]	[0.02861]
T+6	-0.0820***	-0.0406***	0.0493**	0.0148	-0.0377	-0.0163
	[0.00328]	[0.003]	[0.01705]	[0.03746]	[0.02727]	[0.03296]
T+7	-0.0804***	-0.0227***	0.0502**	0.0155	-0.0326	-0.0181
	[0.00354]	[0.00249]	[0.01695]	[0.04708]	[0.03072]	[0.03111]
T+8	-0.0877***	-0.0264***	0.0635***	0.0196	-0.0185	-0.0798
	[0.00481]	[0.00263]	[0.01658]	[0.04781]	[0.02257]	[0.04894]
T+9	-0.0846***	-0.0254***	0.0649***	0.0139	-0.0109	-0.0704
	[0.00434]	[0.00309]	[0.01568]	[0.05113]	[0.02178]	[0.05023]
T+10	-0.0839***	-0.0125***	0.0756***	0.0311	0.0016	-0.0551
	[0.00444]	[0.00305]	[0.01717]	[0.06009]	[0.02291]	[0.05388]

Significance levels: * for 10%, ** for 5%, *** for 1%.

Standard errors in brackets.

Table 1.13: **Effects of LTROs on 10-year government bond yields of Greece-Portugal and of other Euro-area countries**

Time	Subject	Event 1	Event 2	Event 3	Event 4	Event 5	Event6
T-9	NGP	0.0003	0.0038	0.0030*	-0.0084	0.0183	0.0012
	GP	-0.0031***	0.0014	0.0064**	-0.0046***	0.0397	0.0237***
	diff	0.0034	0.0023	-0.0034	-0.0038	-0.0215	-0.0226***
T-8	NGP	-0.0122***	0.0048**	0.0118***	0.0209**	0.0242**	0.0077
	GP	-0.0177***	0.0008	0.0268*	0.0115	0.0347***	0.0346***
	diff	0.0055	0.0040	-0.0150	0.0094	-0.0105	-0.0269**
T-7	NGP	-0.0332***	0.0084***	0.0030	0.0013	0.0175	0.0063
	GP	-0.0396***	0.0058***	0.0336	0.0094	0.0289***	0.0166***
	diff	0.0064	0.0025	-0.0306	-0.0081	-0.0114	-0.0103
T-6	NGP	-0.0292***	0.0110***	-0.0031*	-0.0028	0.0087	0.0071
	GP	-0.0384***	0.0073***	0.0585	0.0108	0.0398***	0.0293***
	diff	0.0092	0.0037	-0.0617	-0.0136	-0.0311	-0.0222
T-5	NGP	-0.0410***	0.0074**	0.0020	0.0146	-0.0147	-0.0007
	GP	-0.0388***	0.0011	0.1062**	0.0225	0.0424***	0.0429***
	diff	-0.0022	0.0063	-0.1042**	-0.0079	-0.0572*	-0.0437**
T-4	NGP	-0.0287***	-0.0110***	0.0124**	0.0067	-0.0381	-0.0105
	GP	-0.0281***	-0.0105**	0.1070**	0.0188	0.0456***	0.0454***
	diff	-0.0006	-0.0006	-0.0946*	-0.0121	-0.0838***	-0.0559***
T-3	NGP	-0.0376***	-0.0227***	0.0158***	0.0225	-0.0570	-0.0127
	GP	-0.0339***	-0.0191***	0.0688***	0.0342	0.0471***	0.0764***
	diff	-0.0037	-0.0036	-0.0530**	-0.0117	-0.1041***	-0.0891***
T-2	NGP	-0.0500***	-0.0201***	0.0057***	0.0324	-0.0530**	-0.0210
	GP	-0.0371***	-0.0167***	0.0861*	0.0423	0.0519***	0.0617***
	diff	-0.0129***	-0.0033	-0.0805*	-0.0100	-0.1049***	-0.0827***
T-1	NGP	-0.0452***	-0.0248***	0.0177***	0.0101	-0.0466***	-0.0309**
	GP	-0.0287***	-0.0190***	0.1178*	0.0341	0.0512**	0.0659**
	diff	-0.0165***	-0.0058	-0.1001	-0.0241	-0.0978***	-0.0967***
T	NGP	-0.0501***	-0.0198***	0.0061*	-0.0082	-0.0427**	-0.0328**
	GP	-0.0365***	-0.0109**	0.0957*	0.0307	0.0504**	0.1024**
	diff	-0.0136***	-0.0090*	-0.0896*	-0.0389	-0.0931***	-0.1351***
T+1	NGP	-0.0559***	-0.0232***	-0.0033	0.0143	-0.0444**	-0.0492**
	GP	-0.0451***	-0.0048	0.1180*	0.0117	0.0581***	0.0983**
	diff	-0.0108	-0.0184*	-0.1213*	0.0026	-0.1025***	-0.1474**
T+2	NGP	-0.0648***	-0.0357***	-0.0048	0.0252*	-0.0468*	-0.0574***
	GP	-0.0504***	-0.0240***	0.1307*	0.0007	0.0595***	0.0971*
	diff	-0.0144**	-0.0117	-0.1355*	0.0245	-0.1063***	-0.1545**
T+3	NGP	-0.0737***	-0.0377***	0.0131*	0.0046	-0.0469*	-0.0517***
	GP	-0.0643***	-0.0278***	0.1550**	0.0022	0.0655**	0.1089**
	diff	-0.0094	-0.0100*	-0.1419*	0.0024	-0.1124***	-0.1605***
T+4	NGP	-0.0700***	-0.0319***	0.0244***	-0.0398	-0.0519**	-0.0455***
	GP	-0.0635***	-0.0256***	0.1353**	0.0857*	0.0933**	0.1348***
	diff	-0.0065	-0.0063	-0.1110**	-0.1256*	-0.1452**	-0.1803***
T+5	NGP	-0.0641***	-0.0412***	0.0270***	-0.0262	-0.0666**	-0.0519***
	GP	-0.0638***	-0.0293***	0.1291**	0.0926*	0.0665***	0.1369***
	diff	-0.0003	-0.0119	-0.1021*	-0.1188*	-0.1331***	-0.1887***
T+6	NGP	-0.0822***	-0.0420***	0.0292***	-0.0167	-0.0656**	-0.0604***
	GP	-0.0814***	-0.0347***	0.1295**	0.1408	0.0739***	0.1598***
	diff	-0.0008	-0.0073	-0.1003*	-0.1575	-0.1395***	-0.2202***
T+7	NGP	-0.0813***	-0.0236***	0.0303***	-0.0236	-0.0644**	-0.0591***
	GP	-0.0771***	-0.0195***	0.1295**	0.1718	0.0947**	0.1460***
	diff	-0.0041	-0.0040	-0.0992*	-0.1954	-0.1590***	-0.2052***
T+8	NGP	-0.0880***	-0.0278***	0.0453***	-0.0181	-0.0411	-0.0640***
	GP	-0.0864***	-0.0206***	0.1362***	0.1700	0.0719	-0.1426
	diff	-0.0016	-0.0072	-0.0909*	-0.1881	-0.1130	0.0785
T+9	NGP	-0.0844***	-0.0263***	0.0482***	-0.0231	-0.0304	-0.0525***
	GP	-0.0852***	-0.0219***	0.1316**	0.1618	0.0670	-0.1422
	diff	0.0008	-0.0044	-0.0834*	-0.1849	-0.0974	0.0897
T+10	NGP	-0.0871***	-0.0135***	0.0567***	-0.0025	-0.0158	-0.0316
	GP	-0.0711***	-0.0084*	0.1514***	0.1655	0.0711	-0.1491
	diff	-0.0160	-0.0051	-0.0947*	-0.1680	-0.0869	0.1175

Table 1.14: **Credit ratings of European countries from S&P**

Country	Local Currency Rating	Grade
Austria	AA+	Investment
Belgium	AA	Investment
Finland	AAA	Investment
France	AA+	Investment
Germany	AAA	Investment
Greece	CCC	Speculative
Italy	BBB+	Speculative
Netherlands	AAA	Investment
Portugal	BB	Speculative
Spain	BBB+	Speculative

Table 1.15: **Effects of LTROs on investment- and speculative-grade 10-year government bond yields**

Time	Subject	Event 1	Event 2	Event 3	Event 4	Event 5	Event6
T-9	INVEST	0.0015	0.0040	0.0044**	-0.0164	0.0079	0.0036
	SPECUL	-0.0033***	0.0023	0.0026	0.0055	0.0445***	0.0089
	diff	0.0048	0.0016	0.0018	-0.0219	-0.0365*	-0.0053
T-8	INVEST	-0.0126***	0.0049*	0.0145***	0.0221**	0.0135***	0.0191**
	SPECUL	-0.0143***	0.0026	0.0153	0.0144**	0.0456***	0.0040
	diff	0.0018	0.0022	-0.0008	0.0077	-0.0321***	0.0150
T-7	INVEST	-0.0341***	0.0096***	0.0051***	-0.0067	-0.0034	0.0227**
	SPECUL	-0.0350***	0.0053***	0.0152	0.0173*	0.0546***	-0.0132
	diff	0.0009	0.0043	-0.0101	-0.0240	-0.0580***	0.0359
T-6	INVEST	-0.0302***	0.0131***	-0.0038*	-0.0155	-0.0096	0.0265**
	SPECUL	-0.0323***	0.0061***	0.0287	0.0231*	0.0517***	-0.0110
	diff	0.0021	0.0070*	-0.0324	-0.0386	-0.0613***	0.0375
T-5	INVEST	-0.0444***	0.0087*	-0.0027	0.0052	-0.0444**	0.0139
	SPECUL	-0.0349***	0.0022	0.0612	0.0326**	0.0584***	-0.0008
	diff	-0.0095**	0.0065	-0.0639	-0.0274	-0.1028***	0.0147
T-4	INVEST	-0.0310***	-0.0099***	0.0082**	-0.0117	-0.0642***	0.0018
	SPECUL	-0.0250***	-0.0124***	0.0660*	0.0404**	0.0429**	-0.0010
	diff	-0.0060	0.0025	-0.0578	-0.0521	-0.1072***	0.0027
T-3	INVEST	-0.0380***	-0.0219***	0.0144***	0.0140	-0.0829***	0.0020
	SPECUL	-0.0352***	-0.0221***	0.0443**	0.0411**	0.0340	0.0098
	diff	-0.0028	0.0002	-0.0299	-0.0271	-0.1170***	-0.0078
T-2	INVEST	-0.0528***	-0.0213***	0.0037***	0.0230	-0.0717***	-0.0092
	SPECUL	-0.0395***	-0.0166***	0.0488	0.0514**	0.0275	0.0026
	diff	-0.0133***	-0.0047	-0.0450	-0.0283	-0.0992***	-0.0118
T-1	INVEST	-0.0486***	-0.0257***	0.0179***	-0.0063	-0.0535***	-0.0194
	SPECUL	-0.0317***	-0.0204***	0.0674	0.0466**	0.0127	0.0004
	diff	-0.0169***	-0.0054	-0.0494	-0.0529	-0.0662*	-0.0198
T	INVEST	-0.0518***	-0.0221***	0.0054	-0.0284	-0.0593***	-0.0153*
	SPECUL	-0.0407***	-0.0120***	0.0520	0.0416**	0.0287	0.0085
	diff	-0.0112**	-0.0100*	-0.0466	-0.0700**	-0.0879***	-0.0238
T+1	INVEST	-0.0581***	-0.0239***	-0.0067**	0.0084	-0.0656***	-0.0258*
	SPECUL	-0.0473***	-0.0129*	0.0626	0.0219	0.0386*	-0.0106
	diff	-0.0108*	-0.0110	-0.0693	-0.0135	-0.1042***	-0.0152
T+2	INVEST	-0.0665***	-0.0370***	-0.0104*	0.0129	-0.0728***	-0.0383***
	SPECUL	-0.0552***	-0.0277***	0.0714	0.0314	0.0454*	-0.0088
	diff	-0.0113*	-0.0093	-0.0818	-0.0185	-0.1182***	-0.0295
T+3	INVEST	-0.0749***	-0.0396***	0.0073	-0.0198	-0.0751***	-0.0333***
	SPECUL	-0.0672***	-0.0300***	0.0926*	0.0400	0.0516**	0.0011
	diff	-0.0077	-0.0096	-0.0853	-0.0598	-0.1267***	-0.0344
T+4	INVEST	-0.0715***	-0.0329***	0.0217***	-0.0839	-0.0793***	-0.0334**
	SPECUL	-0.0645***	-0.0272***	0.0839*	0.0891***	0.0618*	0.0265
	diff	-0.0071	-0.0057	-0.0622	-0.1730***	-0.1411***	-0.0599
T+5	INVEST	-0.0642***	-0.0420***	0.0266***	-0.0587	-0.0921***	-0.0396**
	SPECUL	-0.0638***	-0.0341***	0.0787*	0.0820***	0.0382	0.0241
	diff	-0.0005	-0.0079	-0.0521	-0.1407**	-0.1302***	-0.0637
T+6	INVEST	-0.0827***	-0.0426***	0.0282***	-0.0461	-0.0928***	-0.0450***
	SPECUL	-0.0810***	-0.0375***	0.0809*	0.1063*	0.0451	0.0267
	diff	-0.0016	-0.0051	-0.0527	-0.1524**	-0.1379***	-0.0717
T+7	INVEST	-0.0820***	-0.0232***	0.0292***	-0.0647	-0.0882***	-0.0412***
	SPECUL	-0.0782***	-0.0220***	0.0816*	0.1358*	0.0509	0.0166
	diff	-0.0038	-0.0012	-0.0524	-0.2006**	-0.1390**	-0.0578
T+8	INVEST	-0.0901***	-0.0269***	0.0483***	-0.0629	-0.0560**	-0.0508***
	SPECUL	-0.0841***	-0.0256***	0.0862**	0.1433**	0.0378	-0.1233
	diff	-0.0059	-0.0013	-0.0379	-0.2062**	-0.0938**	0.0725
T+9	INVEST	-0.0870***	-0.0277***	0.0506***	-0.0745*	-0.0465*	-0.0373***
	SPECUL	-0.0809***	-0.0220***	0.0864**	0.1465*	0.0425	-0.1202
	diff	-0.0061	-0.0057	-0.0358	-0.2210**	-0.0890**	0.0829
T+10	INVEST	-0.0912***	-0.0146**	0.0588***	-0.0718	-0.0313	-0.0093
	SPECUL	-0.0731***	-0.0092***	0.1008**	0.1855**	0.0510**	-0.1238
	diff	-0.0181**	-0.0054	-0.0420	-0.2573**	-0.0823**	0.1145

Table 1.16: **Effects of LTROs on 10-year government bond yields of Italy and Spain and of other Euro-area countries (ex Greece and Portugal)**

Time	Subject	Event 1	Event 2	Event 3	Event 4	Event 5	Event6
T-9	NIS	0.0015	0.0040	0.0044**	-0.0164	0.0079	0.0036
	IS	-0.0035**	0.0032	-0.0012	0.0155***	0.0492***	-0.0060
	diff	0.0051	0.0008	0.0056**	-0.0319**	-0.0413***	0.0096
T-8	NIS	-0.0126***	0.0049*	0.0145***	0.0221*	0.0135**	0.0191**
	IS	-0.0110***	0.0045***	0.0038*	0.0173**	0.0564***	-0.0265***
	diff	-0.0016	0.0003	0.0107***	0.0048	-0.0429***	0.0456***
T-7	NIS	-0.0341***	0.0096***	0.0051***	-0.0067	-0.0034	0.0227**
	IS	-0.0304***	0.0047***	-0.0032*	0.0252*	0.0803***	-0.0431***
	diff	-0.0037*	0.0049	0.0083***	-0.0319	-0.0837***	0.0658***
T-6	NIS	-0.0302***	0.0131***	-0.0038	-0.0155	-0.0096	0.0265**
	IS	-0.0262***	0.0049*	-0.0012*	0.0353***	0.0635***	-0.0513***
	diff	-0.0040	0.0082*	-0.0026	-0.0509	-0.0731***	0.0778***
T-5	NIS	-0.0444***	0.0087**	-0.0027	0.0052	-0.0444**	0.0139
	IS	-0.0309***	0.0034	0.0161*	0.0427***	0.0744**	-0.0446***
	diff	-0.0135***	0.0053	-0.0189**	-0.0375	-0.1188***	0.0585***
T-4	NIS	-0.0310***	-0.0099***	0.0082**	-0.0117	-0.0642***	0.0018
	IS	-0.0220***	-0.0144**	0.0250**	0.0621***	0.0402	-0.0473**
	diff	-0.0090**	0.0045	-0.0168*	-0.0738**	-0.1044**	0.0491**
T-3	NIS	-0.0380***	-0.0219***	0.0144***	0.0140	-0.0829***	0.0020
	IS	-0.0364***	-0.0251***	0.0199***	0.0481**	0.0209	-0.0568***
	diff	-0.0015	0.0032	-0.0054*	-0.0341	-0.1039*	0.0588**
T-2	NIS	-0.0528***	-0.0213***	0.0037***	0.0230	-0.0717***	-0.0092
	IS	-0.0418***	-0.0164**	0.0114***	0.0604**	0.0031	-0.0565***
	diff	-0.0110**	-0.0049	-0.0077***	-0.0374	-0.0748	0.0473**
T-1	NIS	-0.0486***	-0.0257***	0.0179***	-0.0063	-0.0535***	-0.0194
	IS	-0.0347***	-0.0218***	0.0170***	0.0591**	-0.0258	-0.0651***
	diff	-0.0139*	-0.0040	0.0010	-0.0654*	-0.0277	0.0457**
T	NIS	-0.0518***	-0.0221***	0.0054	-0.0284	-0.0593***	-0.0153
	IS	-0.0448***	-0.0132**	0.0083***	0.0525**	0.0069	-0.0853***
	diff	-0.0070	-0.0088	-0.0030	-0.0809**	-0.0662*	0.0700***
T+1	NIS	-0.0581***	-0.0239***	-0.0067*	0.0084	-0.0656***	-0.0258*
	IS	-0.0495***	-0.0210***	0.0071	0.0320***	0.0191	-0.1194***
	diff	-0.0086	-0.0029	-0.0139	-0.0236*	-0.0847**	0.0937***
T+2	NIS	-0.0665***	-0.0370***	-0.0104*	0.0129	-0.0728***	-0.0383***
	IS	-0.0599***	-0.0315***	0.0122	0.0621***	0.0313	-0.1146***
	diff	-0.0066	-0.0055	-0.0226	-0.0493**	-0.1041**	0.0764***
T+3	NIS	-0.0749***	-0.0396***	0.0073	-0.0198	-0.0751***	-0.0333***
	IS	-0.0701***	-0.0322***	0.0303*	0.0779***	0.0376	-0.1067***
	diff	-0.0049	-0.0073	-0.0230	-0.0976***	-0.1127**	0.0734**
T+4	NIS	-0.0715***	-0.0329***	0.0217***	-0.0839	-0.0793***	-0.0334**
	IS	-0.0654***	-0.0288***	0.0324	0.0924***	0.0303	-0.0818**
	diff	-0.0062	-0.0041	-0.0107	-0.1764***	-0.1096**	0.0484
T+5	NIS	-0.0642***	-0.0420***	0.0266***	-0.0587	-0.0921***	-0.0396***
	IS	-0.0637***	-0.0388***	0.0283	0.0713***	0.0098	-0.0887**
	diff	-0.0006	-0.0032	-0.0017	-0.1300**	-0.1019*	0.0491
T+6	NIS	-0.0827***	-0.0426***	0.0282***	-0.0461	-0.0928***	-0.0450***
	IS	-0.0807***	-0.0403***	0.0323*	0.0717***	0.0162	-0.1064**
	diff	-0.0020	-0.0023	-0.0041	-0.1179**	-0.1091*	0.0614
T+7	NIS	-0.0820***	-0.0232***	0.0292***	-0.0647	-0.0882***	-0.0412***
	IS	-0.0792***	-0.0245***	0.0337*	0.0998***	0.0071	-0.1129***
	diff	-0.0028	0.0012	-0.0045	-0.1645***	-0.0952	0.0716*
T+8	NIS	-0.0901***	-0.0269***	0.0483***	-0.0629	-0.0560**	-0.0508***
	IS	-0.0818***	-0.0306***	0.0363**	0.1165***	0.0037	-0.1039**
	diff	-0.0082	0.0037	0.0121	-0.1795***	-0.0597	0.0532
T+9	NIS	-0.0870***	-0.0277***	0.0506***	-0.0745	-0.0465*	-0.0373***
	IS	-0.0766***	-0.0220***	0.0412**	0.1312***	0.0179	-0.0982**
	diff	-0.0104	-0.0057	0.0095	-0.2056***	-0.0644	0.0610
T+10	NIS	-0.0912***	-0.0146***	0.0588***	-0.0718	-0.0313	-0.0093
	IS	-0.0750***	-0.0100***	0.0502***	0.2054***	0.0308	-0.0985*
	diff	-0.0162	-0.0046	0.0086	-0.2772***	-0.0621	0.0892*

Table 1.17: **Effects of LTROs on Euro-area and non Euro-area 10-year govenment bond yields**

Time	Subject	Event 1	Event 2	Event 3	Event 4	Event 5	Event6
T-9	EURO	-0.0004	0.0033*	0.0036**	-0.0076	0.0226**	0.0057
	EXEURO	0.0043	0.0008	0.0109***	-0.0178*	-0.0257***	0.0089
	diff	-0.0047	0.0025	-0.0073**	0.0101	0.0483***	-0.0032
T-8	EURO	-0.0133***	0.0040**	0.0148***	0.0190***	0.0263***	0.0131
	EXEURO	-0.0175**	0.0043	0.0286***	0.0082	-0.0169	0.0275**
	diff	0.0042	-0.0003	-0.0138*	0.0108	0.0432***	-0.0144
T-7	EURO	-0.0345***	0.0079***	0.0092	0.0029	0.0198	0.0084
	EXEURO	-0.0406***	0.0037	0.0196***	-0.0212*	-0.0290**	0.0394***
	diff	0.0062	0.0042	-0.0104	0.0241	0.0487***	-0.0310*
T-6	EURO	-0.0311***	0.0103***	0.0092	-0.0001	0.0149	0.0115
	EXEURO	-0.0453***	0.0043	0.0113	-0.0383**	-0.0377**	0.0465***
	diff	0.0142	0.0060	-0.0021	0.0382	0.0526**	-0.0350**
T-5	EURO	-0.0406***	0.0061**	0.0228	0.0161	-0.0033	0.0080
	EXEURO	-0.0517***	-0.0015	0.0041	-0.0293*	-0.0626***	0.0272***
	diff	0.0111	0.0076	0.0187	0.0455**	0.0594**	-0.0192
T-4	EURO	-0.0286***	-0.0109***	0.0313*	0.0091	-0.0214	0.0007
	EXEURO	-0.0398***	-0.0137	0.0205	-0.0312**	-0.0578***	0.0204***
	diff	0.0112	0.0028	0.0108	0.0404*	0.0364*	-0.0198
T-3	EURO	-0.0368***	-0.0220***	0.0264***	0.0249*	-0.0362	0.0051
	EXEURO	-0.0462***	-0.0249***	0.0395***	-0.0097	-0.0804***	0.0138**
	diff	0.0094*	0.0029	-0.0131	0.0345*	0.0442*	-0.0086
T-2	EURO	-0.0474***	-0.0194***	0.0217	0.0343**	-0.0320	-0.0045
	EXEURO	-0.0541***	-0.0342***	0.0386***	-0.0111	-0.0845***	-0.0123
	diff	0.0066	0.0148*	-0.0169	0.0454**	0.0525**	0.0078
T-1	EURO	-0.0419***	-0.0236***	0.0377*	0.0149	-0.0270	-0.0115
	EXEURO	-0.0634***	-0.0373***	0.0465***	-0.0271**	-0.0503***	-0.0134
	diff	0.0216**	0.0137*	-0.0088	0.0419*	0.0232	0.0019
T	EURO	-0.0474***	-0.0180***	0.0240	-0.0004	-0.0241	-0.0057
	EXEURO	-0.0666***	-0.0391***	0.0378**	-0.0365***	-0.0579***	0.0032
	diff	0.0192**	0.0211**	-0.0138	0.0361*	0.0338	-0.0090
T+1	EURO	-0.0538***	-0.0195***	0.0210	0.0138	-0.0239	-0.0197
	EXEURO	-0.0774***	-0.0545***	0.0202	0.0197	-0.0641***	0.0125
	diff	0.0237**	0.0350***	0.0008	-0.0059	0.0403	-0.0322
T+2	EURO	-0.0619***	-0.0333***	0.0223	0.0203*	-0.0255	-0.0265
	EXEURO	-0.0803***	-0.0655***	0.0207	0.0290***	-0.0539***	-0.0069
	diff	0.0183**	0.0322***	0.0016	-0.0087	0.0283	-0.0196
T+3	EURO	-0.0719***	-0.0357***	0.0414*	0.0042	-0.0244	-0.0196
	EXEURO	-0.0889***	-0.0672***	0.0320	-0.0324*	-0.0535***	-0.0015
	diff	0.0171**	0.0315***	0.0094	0.0365	0.0290	-0.0181
T+4	EURO	-0.0687***	-0.0306***	0.0466**	-0.0147	-0.0228	-0.0094
	EXEURO	-0.0821***	-0.0655***	0.0490**	-0.1129***	-0.0655***	-0.0175
	diff	0.0134	0.0349***	-0.0025	0.0982*	0.0427	0.0081
T+5	EURO	-0.0641***	-0.0388***	0.0474**	-0.0024	-0.0400	-0.0141
	EXEURO	-0.0667***	-0.0716***	0.0542**	-0.0933***	-0.0731***	-0.0185
	diff	0.0026	0.0327***	-0.0067	0.0909**	0.0331	0.0044
T+6	EURO	-0.0820***	-0.0406***	0.0493**	0.0148	-0.0377	-0.0163
	EXEURO	-0.0838***	-0.0726***	0.0584**	-0.0799***	-0.0923***	-0.0048
	diff	0.0018	0.0320***	-0.0091	0.0948**	0.0546	-0.0116
T+7	EURO	-0.0804***	-0.0227***	0.0502***	0.0155	-0.0326	-0.0181
	EXEURO	-0.0882***	-0.0469***	0.0594**	-0.1016***	-0.1019***	0.0018
	diff	0.0077	0.0242***	-0.0093	0.1171**	0.0693*	-0.0199
T+8	EURO	-0.0877***	-0.0264***	0.0635***	0.0196	-0.0185	-0.0798
	EXEURO	-0.0953***	-0.0517***	0.0728***	-0.1133***	-0.0908***	-0.0160
	diff	0.0076	0.0253***	-0.0093	0.1329**	0.0724**	-0.0637
T+9	EURO	-0.0846***	-0.0254***	0.0649***	0.0139	-0.0109	-0.0704
	EXEURO	-0.0966***	-0.0525***	0.0807***	-0.1103***	-0.0804***	0.0230
	diff	0.0120	0.0271***	-0.0158	0.1242**	0.0694**	-0.0934*
T+10	EURO	-0.0839***	-0.0125***	0.0756***	0.0311	0.0016	-0.0551
	EXEURO	-0.1112***	-0.0378***	0.0802***	-0.1491***	-0.0852**	0.0882***
	diff	0.0272	0.0254***	-0.0045	0.1802**	0.0868**	-0.1432**

Table 1.18: **Effects of LTROs on Euro-area (ex Greece and Portugal) and non Euro-area 10-year government bond yields**

Time	Subject	Event 1	Event 2	Event 3	Event 4	Event 5	Event6
T-9	EURO (NGP)	0.0003	0.0038*	0.0030*	-0.0084	0.0183*	0.0012
	EXEURO	0.0043	0.0008	0.0109***	-0.0178*	-0.0257***	0.0089
	diff	-0.0040	0.0030	-0.0079**	0.0094	0.0440***	-0.0077
T-8	EURO (NGP)	-0.0122***	0.0048**	0.0118***	0.0209***	0.0242***	0.0077
	EXEURO	-0.0175**	0.0043	0.0286***	0.0082	-0.0169	0.0275**
	diff	0.0053	0.0005	-0.0168***	0.0127	0.0411**	-0.0198
T-7	EURO (NGP)	-0.0332***	0.0084***	0.0030*	0.0013	0.0175	0.0063
	EXEURO	-0.0406***	0.0037	0.0196***	-0.0212*	-0.0290**	0.0394**
	diff	0.0075	0.0047	-0.0165***	0.0225	0.0464**	-0.0331*
T-6	EURO (NGP)	-0.0292***	0.0110***	-0.0031*	-0.0028	0.0087	0.0071
	EXEURO	-0.0453***	0.0043	0.0113	-0.0383*	-0.0377**	0.0465***
	diff	0.0160	0.0067	-0.0144*	0.0355	0.0464**	-0.0395*
T-5	EURO (NGP)	-0.0410***	0.0074**	0.0020	0.0146	-0.0147	-0.0007
	EXEURO	-0.0517***	-0.0015	0.0041	-0.0293*	-0.0626***	0.0272***
	diff	0.0107	0.0089	-0.0022	0.0439*	0.0479*	-0.0279**
T-4	EURO (NGP)	-0.0287***	-0.0110***	0.0124***	0.0067	-0.0381*	-0.0105
	EXEURO	-0.0398***	-0.0137	0.0205	-0.0312**	-0.0578***	0.0204***
	diff	0.0111	0.0027	-0.0081	0.0380	0.0197	-0.0309**
T-3	EURO (NGP)	-0.0376***	-0.0227***	0.0158***	0.0225	-0.0570**	-0.0127
	EXEURO	-0.0462***	-0.0249***	0.0395***	-0.0097	-0.0804***	0.0138**
	diff	0.0087	0.0022	-0.0237*	0.0322	0.0234	-0.0265*
T-2	EURO (NGP)	-0.0500***	-0.0201***	0.0057***	0.0324	-0.0530**	-0.0210*
	EXEURO	-0.0541***	-0.0342***	0.0386***	-0.0111	-0.0845***	-0.0123
	diff	0.0040	0.0141	-0.0330**	0.0435*	0.0315	-0.0087
T-1	EURO (NGP)	-0.0452***	-0.0248***	0.0177***	0.0101	-0.0466***	-0.0309**
	EXEURO	-0.0634***	-0.0373***	0.0465***	-0.0271**	-0.0503***	-0.0134
	diff	0.0183**	0.0125	-0.0288**	0.0371	0.0037	-0.0175
T	EURO (NGP)	-0.0501***	-0.0198***	0.0061**	-0.0082	-0.0427**	-0.0328**
	EXEURO	-0.0666***	-0.0391***	0.0378**	-0.0365***	-0.0579***	0.0032
	diff	0.0165*	0.0193*	-0.0317*	0.0283	0.0152	-0.0360
T+1	EURO (NGP)	-0.0559***	-0.0232***	-0.0033	0.0143	-0.0444**	-0.0492**
	EXEURO	-0.0774***	-0.0545***	0.0202	0.0197	-0.0641***	0.0125
	diff	0.0215**	0.0313***	-0.0234	-0.0054	0.0197	-0.0617**
T+2	EURO (NGP)	-0.0648***	-0.0357***	-0.0048	0.0252*	-0.0468**	-0.0574***
	EXEURO	-0.0803***	-0.0655***	0.0207	0.0290***	-0.0539***	-0.0069
	diff	0.0155*	0.0299***	-0.0255	-0.0038	0.0071	-0.0505*
T+3	EURO (NGP)	-0.0737***	-0.0377***	0.0131*	0.0046	-0.0469**	-0.0517***
	EXEURO	-0.0889***	-0.0672***	0.0320	-0.0324*	-0.0535***	-0.0015
	diff	0.0152*	0.0295***	-0.0189	0.0370	0.0066	-0.0502*
T+4	EURO (NGP)	-0.0700***	-0.0319***	0.0244***	-0.0398	-0.0519**	-0.0455***
	EXEURO	-0.0821***	-0.0655***	0.0490**	-0.1129***	-0.0655***	-0.0175
	diff	0.0121	0.0336***	-0.0247	0.0730	0.0136	-0.0280
T+5	EURO (NGP)	-0.0641***	-0.0412***	0.0270***	-0.0262	-0.0666***	-0.0519***
	EXEURO	-0.0667***	-0.0716***	0.0542**	-0.0933***	-0.0731***	-0.0185
	diff	0.0026	0.0304***	-0.0271	0.0671	0.0065	-0.0333
T+6	EURO (NGP)	-0.0822***	-0.0420***	0.0292***	-0.0167	-0.0656**	-0.0604***
	EXEURO	-0.0838***	-0.0726***	0.0584**	-0.0799***	-0.0923***	-0.0048
	diff	0.0016	0.0306***	-0.0292	0.0633	0.0267	-0.0556**
T+7	EURO (NGP)	-0.0813***	-0.0236***	0.0303***	-0.0236	-0.0644**	-0.0591***
	EXEURO	-0.0882***	-0.0469***	0.0594**	-0.1016***	-0.1019***	0.0018
	diff	0.0069	0.0234**	-0.0291	0.0780	0.0375	-0.0610**
T+8	EURO (NGP)	-0.0880***	-0.0278***	0.0453***	-0.0181	-0.0411*	-0.0640***
	EXEURO	-0.0953***	-0.0517***	0.0728**	-0.1133***	-0.0908***	-0.0160
	diff	0.0073	0.0239**	-0.0274	0.0953*	0.0498	-0.0480*
T+9	EURO (NGP)	-0.0844***	-0.0263***	0.0482***	-0.0231	-0.0304	-0.0525***
	EXEURO	-0.0966***	-0.0525***	0.0807***	-0.1103***	-0.0804***	0.0230
	diff	0.0122	0.0262**	-0.0325	0.0872	0.0500	-0.0755***
T+10	EURO (NGP)	-0.0871***	-0.0135***	0.0567***	-0.0025	-0.0158	-0.0316
	EXEURO	-0.1112***	-0.0378***	0.0802***	-0.1491***	-0.0852**	0.0882***
	diff	0.0240	0.0244***	-0.0235	0.1466*	0.0694*	-0.1198***

Table 1.19: **Effects of LTROs on Euro-area (Greece and Portugal) and non Euro-area 10-year government bond yields**

Time	Subject	Event 1	Event 2	Event 3	Event 4	Event 5	Event6
	EURO (GP)	-0.0031***	0.0014	0.0064*	-0.0046***	0.0397	0.0237***
T-9	EXEURO	0.0043	0.0008	0.0109***	-0.0178	-0.0257***	0.0089
	diff	-0.0074	0.0006	-0.0045	0.0132	0.0655**	0.0149
	EURO (GP)	-0.0177***	0.0008	0.0268*	0.0115	0.0347***	0.0346***
T-8	EXEURO	-0.0175*	0.0043	0.0286***	0.0082	-0.0169	0.0275
	diff	-0.0002	-0.0035	-0.0018	0.0033	0.0516**	0.0071
	EURO (GP)	-0.0396***	0.0058**	0.0336	0.0094	0.0289**	0.0166***
T-7	EXEURO	-0.0406***	0.0037	0.0196**	-0.0212	-0.0290**	0.0394**
	diff	0.0010	0.0021	0.0140	0.0306	0.0579***	-0.0228
	EURO (GP)	-0.0384***	0.0073**	0.0585	0.0108	0.0398***	0.0293**
T-6	EXEURO	-0.0453***	0.0043	0.0113	-0.0383*	-0.0377*	0.0465***
	diff	0.0069	0.0030	0.0473	0.0491*	0.0775***	-0.0173
	EURO (GP)	-0.0388***	0.0011	0.1062*	0.0225	0.0424***	0.0429***
T-5	EXEURO	-0.0517***	-0.0015	0.0041	-0.0293	-0.0626***	0.0272***
	diff	0.0129	0.0026	0.1020*	0.0518*	0.1051***	0.0158*
	EURO (GP)	-0.0281***	-0.0105**	0.1070**	0.0188	0.0456***	0.0454***
T-4	EXEURO	-0.0398***	-0.0137	0.0205	-0.0312*	-0.0578***	0.0204**
	diff	0.0117	0.0033	0.0865	0.0500*	0.1034***	0.0250***
	EURO (GP)	-0.0339***	-0.0191**	0.0688***	0.0342	0.0471**	0.0764***
T-3	EXEURO	-0.0462***	-0.0249**	0.0395**	-0.0097	-0.0804***	0.0138*
	diff	0.0124*	0.0058	0.0293	0.0439	0.1275***	0.0627***
	EURO (GP)	-0.0371***	-0.0167***	0.0861*	0.0423	0.0519***	0.0617***
T-2	EXEURO	-0.0541***	-0.0342***	0.0386**	-0.0111	-0.0845***	-0.0123
	diff	0.0169***	0.0174	0.0475	0.0534	0.1364***	0.0740***
	EURO (GP)	-0.0287***	-0.0190***	0.1178*	0.0341	0.0512**	0.0659**
T-1	EXEURO	-0.0634***	-0.0373***	0.0465**	-0.0271*	-0.0503***	-0.0134
	diff	0.0348***	0.0183*	0.0713	0.0612	0.1015***	0.0793**
	EURO (GP)	-0.0365***	-0.0109**	0.0957*	0.0307	0.0504*	0.1024**
T	EXEURO	-0.0666***	-0.0391***	0.0378*	-0.0365**	-0.0579***	0.0032
	diff	0.0301**	0.0283**	0.0579	0.0672*	0.1083***	0.0991**
	EURO (GP)	-0.0451***	-0.0048	0.1180	0.0117	0.0581**	0.0983*
T+1	EXEURO	-0.0774***	-0.0545***	0.0202	0.0197	-0.0641***	0.0125
	diff	0.0323**	0.0497***	0.0979	-0.0079	0.1223***	0.0857
	EURO (GP)	-0.0504***	-0.0240***	0.1307*	0.0007	0.0595***	0.0971*
T+2	EXEURO	-0.0803***	-0.0655***	0.0207	0.0290**	-0.0539**	-0.0069
	diff	0.0299**	0.0416***	0.1100	-0.0283	0.1134***	0.1040*
	EURO (GP)	-0.0643***	-0.0278***	0.1550**	0.0022	0.0655**	0.1089**
T+3	EXEURO	-0.0889***	-0.0672***	0.0320	-0.0324	-0.0535**	-0.0015
	diff	0.0246	0.0394***	0.1229	0.0346	0.1190***	0.1104**
	EURO (GP)	-0.0635***	-0.0256***	0.1353**	0.0857	0.0933*	0.1348***
T+4	EXEURO	-0.0821***	-0.0655***	0.0490*	-0.1129**	-0.0655***	-0.0175
	diff	0.0186	0.0399***	0.0863	0.1986**	0.1588**	0.1523***
	EURO (GP)	-0.0638***	-0.0293***	0.1291**	0.0926	0.0665***	0.1369***
T+5	EXEURO	-0.0667***	-0.0716***	0.0542*	-0.0933***	-0.0731***	-0.0185
	diff	0.0029	0.0423***	0.0750	0.1859**	0.1396***	0.1554***
	EURO (GP)	-0.0814***	-0.0347***	0.1295**	0.1408	0.0739***	0.1598***
T+6	EXEURO	-0.0838***	-0.0726***	0.0584*	-0.0799***	-0.0923***	-0.0048
	diff	0.0024	0.0379***	0.0712	0.2208*	0.1662***	0.1646***
	EURO (GP)	-0.0771***	-0.0195***	0.1295**	0.1718	0.0947**	0.1460***
T+7	EXEURO	-0.0882***	-0.0469***	0.0594*	-0.1016***	-0.1019***	0.0018
	diff	0.0110	0.0274**	0.0701	0.2735*	0.1965***	0.1442***
	EURO (GP)	-0.0864***	-0.0206**	0.1362**	0.1700	0.0719***	-0.1426
T+8	EXEURO	-0.0953***	-0.0517***	0.0728**	-0.1133***	-0.0908***	-0.0160
	diff	0.0089	0.0310**	0.0635	0.2833**	0.1628***	-0.1265
	EURO (GP)	-0.0852***	-0.0219***	0.1316**	0.1618	0.0670***	-0.1422
T+9	EXEURO	-0.0966***	-0.0525***	0.0807***	-0.1103***	-0.0804**	0.0230
	diff	0.0114	0.0305**	0.0509	0.2720*	0.1474***	-0.1652
	EURO (GP)	-0.0711***	-0.0084*	0.1514**	0.1655	0.0711***	-0.1491
T+10	EXEURO	-0.1112***	-0.0378***	0.0802***	-0.1491***	-0.0852**	0.0882***
	diff	0.0400	0.0294***	0.0712	0.3146*	0.1563***	-0.2372

Chapter 2

The Conduct of Monetary Policy in the Euro Area: Evidence from Time-Varying Parameters Reaction Functions

2.1 Introduction

The beginning of the European Monetary Union (EMU) in 1999 has brought several new issues to the attention of economists. At that time the main interest was to analyse the economic effects of the monetary policy unification in the Euro-area. Then, in subsequent years, researchers started to study the conduct of monetary policy by the European Central Bank (ECB henceforth) mainly by estimating Taylor-type monetary policy rules. This chapter aims at contributing to this strand of literature by producing further evidence on the conduct of monetary policy in the Euro area. In particular, I am going to estimate monetary policy reaction functions for the ECB with time varying coefficients from 1999 until the end of 2013 considering monthly data.

The reason why I consider time-varying coefficients is that assuming constant coefficients is a too strong restriction since policymakers can react differently to changes in economic variables depending on the actual economic conditions. The importance of allowing for some degree of discretion in the application of a monetary policy rule is stressed, beyond others, by Taylor (1993) that, besides formulating the well-known Taylor rule, critically deal with the practical aspects of taking policy decisions. In particular he pointed out that "(..) in my view, a policy rule need not be a mechanical formula (...). A policy rule can be implemented and operated more informally by policymakers who recognize the general instrument responses that underlie the policy rule, but who also recognize that operating the rule requires judgment and cannot be done by computer".

The change in policy can take the form of a gradual change or a sudden shift to another regime. These two different views require different model specifications and so it is important to clarify that in this work time variation is assumed to occur smoothly over time. As a matter of fact, the problem with models considering discrete breaks is that they cannot properly account for gradual policy changes leading to problematic interpretations when the actual policy changes do not exactly fit the specified model regimes. On the contrary, considering smooth transitions appears to be the most suited approach to deal with monetary policy. It must however be noted that, even though the model is well-suited for capturing gradual time variation, it can also capture jumps in coefficients as shown in appendix C.

In general a change in behaviour can be due either to a shift in the preferences of the central bank or to a structural shift in the economic relations. As shown by Svensson (1997), the coefficients in the monetary policy reaction function are a convolution of the central bank's preferences and other parameters describing the structure of the economy. Therefore the parameters coming from the estimation of the monetary policy rule will just represents the weight assigned by the central bank to the variables considered and conclusions on the source of their variation would need a further investigation in line with Castelnuovo and Surico (2003) and Assenmacher-Wesche (2006).

To better understand the behaviour of the ECB, this work considers several different specifications for the monetary policy reaction function. The baseline specification is a Taylor rule where the monetary authority is considered to target the current annual inflation rate and the output gap, which are however not known at the time of the policy decision but with at least one- or two-month lag. Assuming rational expectations, the current variables are instrumented in the first stage of the analysis taking the fitted values from a BVAR model with time-varying coefficient. This allows to avoid the endogeneity problem related to the use of their contemporaneous values. In order to correct for the generated-regressor bias the two models are estimated in the same simulation exercise. This procedure amounts at estimating a VAR model for inflation, the output gap and the monetary policy instrument and focusing only on the last equation of the model in which some exogenous variables are added. This formulation is consistent with Bernanke and Blinder (1992) and Bernanke and Mihov (1998) but also with a large part of the literature on the estimation of monetary policy rules where the generalized method of moments is applied after instrumenting the endogenous variables with their lags, as in Clarida, Galí, and Gertler (1998).

Then, the monetary policy reaction function is extended by adding other variables that might have been considered by the ECB. Indeed, one of the purposes of this work is to test the explanatory power of additional variables itself but also to see whether the inflation and the output gap coefficients are affected.

Another contribution is the consideration of the post-2008 period, which will be simply referred to as the "crisis period". The aim is to evaluate whether relevant changes in the conduct of monetary policy can be detected along the sample and if they can be attributed to the financial-credit crisis and sovereign debt sustainability issues that arose from 2008 on.

Results show that the sensitivity of the ECB towards inflation and output gap changed along the time span and mainly after 2008 as it also started to respond to new variables like bank loans and sovereign bond yield spreads.

Finally, also the variance-covariance matrix of the residuals is assumed to have a time-varying component. Errors' heteroskedasticity is important to correctly identify parameter time variation as assuming a constant variance-covariance matrix could induce to identify a change in the conduct of monetary policy while in fact what is occurring is just an unaccounted change in the characteristics of the monetary policy shock[1]. As a matter of fact, the residuals of the monetary policy reaction function can be interpreted as monetary policy shocks if the so-called recursiveness assumption is valid, i.e. the policy shocks are orthogonal to the regressors and to the other contemporaneous economic disturbances. This is one of the several methodologies used in literature to identify monetary policy shocks and it is extensively reviewed by Christiano, Eichenbaum, and Evans (1999). The two-step procedure applied in this paper allows to correctly estimate exogenous monetary policy shocks without necessarily having to identify the entire model structure as the sufficient assumption is that the policy instrument does not influence the given macro variables in the current period.

From an econometric point of view, the model has a state-space representation to which the Kalman filter and smoother can be applied and the estimation is possible through Bayesian simulation techniques. This choice is motivated by the fact that allowing time-variation in coefficients greatly increases the number of parameters to estimate bringing about an overfitting problem. Bayesian inference is an efficient solution to this kind of problems because it allows to shrink the dimensionality of the problem by letting parameters comes from *posterior* distributions defined by a narrow set of hyperparameters.

The structure of the chapter is as follows. Section 2.2 summarizes the monetary policy strategy adopted by the ECB since 1999. Section 2.3 reviews the literature about monetary policy rules both for what concerns their theoretical specification and the econometric applications with a focus on the Euro area. Section 2.4 defines the theoretical and econometric specification of the monetary policy reaction function. Section 2.5 shows the estimation results from different monetary policy reaction functions and section 2.6 concludes.

2.2 The ECB Strategy

For the purpose of this work it would be useful to identify which are the macroeconomic variables that are considered by the ECB in its decision process. This section reviews the monetary policy strategy of the ECB in the period 1999-2013 and it is based on information coming from official ECB documents like Monthly Bulletins and speeches of the President, usually after the Governing Council monthly meeting.

The policy strategy of the ECB has been announced in October 1998 and its main objective is the price stability in the Euro-area (ECB, 1998). The rationale behind this target is that a monetary policy that credibly maintains price stability is assumed to give the best possible contribution to the economic objectives of the European Union by creating an environment in which other policies can be most effective (ECB, 1999b). However, the ECB recognizes that it cannot directly control the price level, but it faces a complex transmission mechanism based on several different channels. This makes it difficult for the ECB to predict the effects of its policy actions as they are also likely to change in response to an evolving economic environment. To address this issue, the monetary-policy strategy is based on two elements: a quantitative definition of price stability and a two-pillar approach for the analysis of the risks to price stability.

Price stability is defined as a year-on-year increase in the Harmonized Index of Consumer Prices (HICP henceforth) of below 2% to be maintained over the medium term (ECB, 1999b). This quantitative

[1] Heteroskedasticity is a standard assumption in the Bayesian literature but the present framework differs from those of Cogley and Sargent (2005) and Primiceri (2005) as they assume an autoregressive structure for the error variance to obtain a stochastic volatility model

value has been chosen to balance the cost of inflation with the necessity for the central bank to maintain an appropriate margin for policy reaction in case of deflationary pressures. On the other hand, the focus on the medium term convey the principle that monetary policy cannot control price developments in the short term with the aim to avoid the introduction of unnecessary volatility into the economy.

The two pillars on which the analysis of price stability is based are the monetary and economic analysis. These approaches are intended to provide two different perspectives on the determination of price developments.

The monetary analysis assigns a prominent role to money growth in the assessment of the outlook for price developments and takes a reference value for the broad monetary aggregate M3 which was derived using the relationship between money, prices, output and the velocity of circulation. As for the target inflation rate, the consideration of a reference value for money growth does not imply a commitment to correct short-term deviations (ECB, 1999b).

On the other hand, the purpose of the economic analysis is to provide a broader outlook for price developments by taking into account the shocks hitting the Euro-area economy and the interplay between supply and demand in the goods and labour markets so that all the risks to price stability can be evaluated. The assessment is made using a wide range of economic indicators that act as leading indicators for prices including wages, the exchange rate, bond prices, the yield curve, measures of real activity, fiscal policy indicators, price and cost indices and business and consumer surveys (ECB, 1999b). Moreover, the economic analysis makes large use of macroeconomic models with the aim of producing projections of the main economic variables as explained by Issing (2004).

This strategy has been reviewed in 2003 (ECB, 2003). The assessment led to a reaffirmation of the main elements of the strategy except for the role of money growth, which has been revised. In particular, the Governing Council decided to no longer consider the reference value of the broad monetary aggregate M3 on an annual basis but to use the monetary analysis as a means of cross-checking the short-term indications coming from the economic analysis from a longer-term point of view.

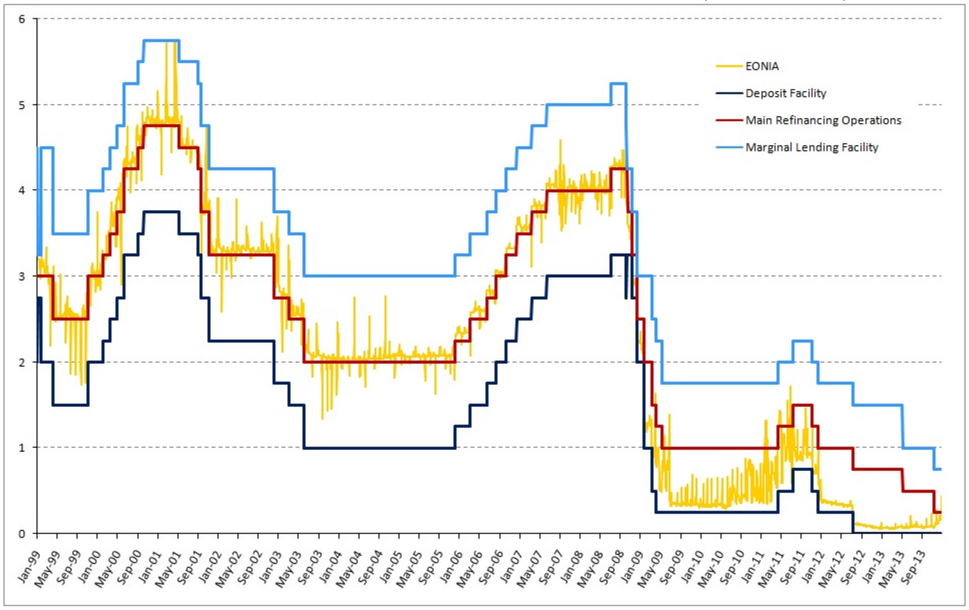
Monetary policy decisions are taken by the Governing Council on the basis of an assessment of the monetary policy stance. The monetary policy stance can be defined as "the contribution made by monetary policy to economic, financial and monetary developments" (ECB, 2010) while the assessment is the procedure that allows to evaluate whether the effects of monetary policy decisions are consistent with the central bank's objectives. More in details, as stated in several different documents issued by the ECB, the assessment involves two elements: the formation of a view on the medium-term inflation outlook and the identification of the contribution that monetary policy makes to the real economy and the maintenance of price stability. The assessment of the monetary policy stance takes into account a broad range of economic, financial and monetary variables.

During official press conferences, the President of the ECB explains the monetary policy decisions taken by the Governing Council in light of the current macroeconomic context focusing on the main elements driving the policy decisions. As regards economic activity, the main macroeconomic variables considered are: GDP and its components (mainly consumption and investments), unemployment and industrial production. As regards prices, the President often mentioned: the HICP, inflation expectations, commodity prices, unit labour costs and industrial output prices. The ECB considers also sentiment indicators like consumer and industrial confidence and investors' sentiment. The most cited financial variables are: the yield curve, market interest rates, nominal and real long-term interest rates, stock market volatility and financial indicators. Of much concern is also the member states' fiscal position and debt ratios while from 2008 the Euro-area credit conditions gained much attention. Then, a final part of the talk is very often devoted to developments in the world economy with a focus on the US economy.

The severe financial crisis that hit the economy in 2008 has complicated the conduct of monetary policy by the ECB. The financial turmoil started in August 2007 and it initially led to an impaired functioning of money markets. Then, in the first half of 2010, the financial crisis evolved into a sovereign debt crisis. From an operative point of view, the ECB admitted that assessing the monetary policy stance became more difficult as the economic situation was rapidly changing and there was a high degree of uncertainty: the structural economic regularities were not reliable anymore and the monetary policy transmission mechanism was disrupted. In this context the ECB intervened by gradually cutting the key interest rates by 400 basis points reaching the level of 0,25% at the end of 2013 and by implementing a wide range of non-standard measures. At the beginning of the crisis, unconventional measures were aimed at ensuring the necessary liquidity provision to banks. For these purposes, the ECB increased the frequency and lengthened the maturity of its refinancing operations and also provided liquidity in foreign currencies. The rationale behind these interventions is that banks are considered a key elements of the monetary policy transmission mechanism as they are the primary source of financing for the real economy. With subsequent unconventional measures the ECB kept on providing liquidity to the banking sector by conducting refinancing operations with fixed rate tender and full allotment procedure and by directly purchasing covered bonds along two covered bonds purchase programs. The effects of these decisions were to change the usual relationship existing between the main refinancing rate and the overnight money market rate as the latter fell significantly below the main refinancing rate towards the deposit facility rate. To deal with the tensions involving sovereign bond markets the ECB implemented the Securities Markets Programme by which it directly purchased Euro-area marketable-debt instruments issued by central governments or public entities. This action was designed not to affect the monetary policy stance as the impact of the interventions has been sterilized through specific operations to re-absorb the injected liquidity. For the same purpose, in August 2012 the ECB announced that it may undertake outright open market operations on European government bonds. Overall the ECB response to the financial crisis is stated to be "geared towards the achievement of the ECB's price stability objective" (ECB, 2010) and all the measures must be considered as temporary.

A broad picture on the conduct of monetary policy in the Euro area is provided by figure 2.1 which shows the evolution of the three key ECB interest rates and the Euro-area overnight index average rate for the period from January 1999 until December 2012. Rates increased until October 2000 and then declined from April 2001 until June 2003. In the period from June 2003 to the end of 2005 rates remained unchanged and then the ECB progressively increased them until June 2007. The unfolding of the financial crisis made necessary a rapid interest rate cut: in April 2009 the MRO rate reached the 1% and in July 2012 it has been further lowered to 0,75 with a deposit facility rate at the zero lower bound. In November 2013 the MRO rate has been set to 0.25% and the marginal lending facility to 0.75%. As regard the EONIA rate, it has always fluctuated around the MRO rate but this regularity broke in October 2008 when it started to progressively decline below the MRO rate.

Figure 2.1: **Euro-area monetary policy rates (daily data)**



Source: Datastream

2.3 Literature Review

This section presents a review of the empirical literature about the estimation of monetary policy rules for the Euro-area. In this field the literature follows three main strands: first, there are papers that compare the conduct of monetary policy in different countries before the EMU, then other works are interested in comparing the Bundesbank with the ECB and finally some authors tried to estimate the reaction function of the ECB.

As regards the first category, Clarida, Galí, and Gertler (1998) estimate monetary policy reaction functions for two sets of countries, Germany, Japan and United States and United Kingdom, France and Italy using monthly data over the sample 1979-1994. The policy function is a forward-looking version of the Taylor rule considering also a set of other variables that can influence the rate setting. Results show that the Bundesbank, the Bank of Japan and the Fed responded both to inflationary pressures and output deviations. On the other hand, the Bank of Italy, the Bank of France and the Bank of England responded less aggressively to inflation and they all followed the Bundesbank closely. Finally, the authors calculate in each point in time a "target" interest rate and compare this with the actual interest rate. The interesting findings are that the gap between the actual and the target rate behaves similarly over time for all countries and the central banks started to track the Bundesbank several years prior to the hard ERM (from 1990 to 1992) while with the onset of the hard ERM the gaps between the actual and the target rates widen. This means that during the hard ERM period the actual policy rate was not appropriate for France, Italy and Spain as the hypothetical interest rate gaps represents a measure of the economic stress connected to the participation to the ERM and that lead to its collapse.

Other papers interested in the conduct of monetary policy in the period before the EMU are those of Ciccarelli and Rebucci (2006) and Trecroci and Vassalli (2010) and they both use time-varying parameters models.

However, the aim of Ciccarelli and Rebucci (2006) is not to compare monetary policy rules but to study the monetary policy transmission mechanism in the Euro area for the period 1981-1998. They apply a two-step methodology as they first estimate the reaction function of four central banks (Germany, France, Italy and Spain), they take the residuals of the German monetary policy rule as to be the monetary policy shock and then they study the monetary policy transmission mechanism by inserting these residual into a VAR model. In both steps they use time-varying heterogeneous coefficient models estimated by means of Bayesian techniques. The final objective is then to evaluate whether the impact of monetary policy has changed and cross-countries differences have decreased over time, as one should expect after the creation of the European Monetary Union.

Time-varying parameters reaction functions are estimated also by Trecroci and Vassalli (2010) for five countries (United States, United Kingdom, Germany, France, Italy) over the sample 1971-1998. They use simple interest rate rules depending on the output gap, inflation expectations and the lagged interest rate. Their findings are that parameters do shift over time in most cases in a smooth and gradual fashion and interest rate policies diverge widely across countries. Most interestingly these differences are evident also across the three Euro-area countries.

Many works focused on the comparison between the conduct of monetary policy in the Euro-area before and after the EMU.

The paper of Hayo and Hofmann (2006) falls in this category. They compare the Bundesbank and the ECB reaction functions specifying a Taylor rule as in Clarida, Galí, and Gertler (1998). For the estimation, monthly data are employed: from 1979 to 1998 for the Bundesbank and from 1999 to 2004 for the ECB. Instruments for the forward-looking and contemporaneous variables are chosen applying an automatic model selection algorithm and estimation is done using GMM. For the Bundesbank results are similar between the pre- and post-unification period and show that the response to inflation is significantly larger than the response to the output gap. The ECB reaction function has an inflation coefficient that is not statistically different neither to one nor to the Bundesbank's coefficient. The big difference between the two central bank is in the output reaction coefficient as the one of the ECB is more than twice as large as the one found for the Bundesbank. By using the monetary model of Svensson (1997), this discrepancy is proved to be due to the relatively higher interest rate elasticity for the German economy, i.e. a weaker transmission of monetary policy for the Euro-area.

Gerlach and Schnabel (2000) compare the interest rate implied by a Taylor rule with the real one for 13 EMU-area countries over the period 1990-1998. The authors create a fictitious central bank by aggregating data of the considered countries so that a unique interest rate for the EMU is calculated. Results show that the actual interest rate does not differ much from the one implied by the Taylor rule and the coefficients are robust to the extensions of the monetary policy rule to other variables. This means that, if the ECB were to conduct monetary policy using the Taylor rule, it would not deviate much from the actual weighted interest-rate setting behaviour in the considered countries. The last econometric exercise is to estimate a forward-looking monetary policy rule where regressors are the inflation rate expected into four periods, the output gap and a constant term. Again this specification captures well the evolution of the EMU interest rate.

Sauer and Sturm (2007) estimates several policy reaction functions for the ECB over the sample

1991:01-2003:04 and compare them with the policy rules followed by the Bundesbank. They consider both contemporaneous and forward-looking policy rules. The contemporaneous rules are estimated using ex-post data and real-time data. The forward-looking rules are estimated using future output growth rates, survey data and a GMM procedure. Their results show that the coefficient on contemporaneous inflation is positive but low for the ECB. However this finding is not anymore valid if a forward-looking rule is considered. In this case the inflation coefficient is positive and almost always greater than one. On the other hand the estimates of the output gap coefficient are more stable through different specifications and they are all positive but lower than one. The degree of partial adjustment in the interest rate is found to be significantly large.

Finally, other authors estimate a monetary policy reaction function for the ECB with the aim of studying the conduct of monetary policy in the Euro area. There is a wide strand of literature dealing with this issue and findings are not always comparable with each other. Table 2.1 summarizes some of the results contained in the papers dealing with this issue.

Table 2.1: **Inflation and output coefficients in estimated reaction functions for the ECB**

Authors	Estimation Period	INFLATION	OUTPUT
Gerdesmeier and Roffia (2004)	1985-2002	>1	<1
Carstensen (2006)	1999-2003	lagged: <1	lagged: <1
Fourçans and Vranceanu (2007)	1999-2006	future: <1	contemp: <1
Blattner and Margaritov (2010)	1999-2007	contemp: <1, future: >1	contemp: <1, future: >1
Gorter, Stolwijk, Jacobs, and de Haan (2010)	1998-2010	>1	'98-'07: >1, '98-'10: <1
Gerlach and Lewis (2010)	1999-2009	<1	<1
Gerlach (2011)	1999-2009	/	<1
Gerlach and Lewis (2014)	1999-2011	<1	<1

Gerdesmeier and Roffia (2004) estimate several reaction functions for the Euro-area over the period 1985:01-2002:02 using GMM. In order to do so, they construct measures of aggregate variables and they derive a fictitious measure of monetary policy for the period before 1999. The theoretical framework is the one of Clarida, Galí, and Gertler (1998) but they also enrich the specification with several other variables and consider different measures of inflation and output. The main results are that both the coefficients of inflation and output are significant and not statistically different from the ones proposed by Taylor (1993) and their magnitude is around 2 and 0.3 respectively. These estimates are not sensitive neither to changes in the measures of inflation and output nor to the inclusion of other explanatory variables. The exchange rate and commodity prices are found to be not significant while the money growth and a stock market index have positive and significant coefficients.

Carstensen (2006) estimates backward-looking monetary policy reaction functions for the ECB over the first four years of the EMU by employing an ordered probit model for the MRO rate. One of the purposes of the paper is to test the significance of monetary variables, and so different measures of money growth, the real money gap and money overhang are included as regressors. The main results are that both the inflation and the output gap coefficients are positive but lower than one. Money growth, money overhang and the real money gap are found to be significant so that it is possible to conclude that the first pillar of the ECB strategy has been important for the policy decisions. Also the significance of the second pillar is tested by considering nominal and real effective exchange rates, an interest rate spread and a real interest rate. Among these variables the only one with a significant and positive coefficient is the interest rate spread. Finally also the presence of asymmetries in the policy reaction function is considered and only a slight asymmetric effect is found.

Fourçans and Vranceanu (2007) analyse the ECB monetary policy over the period 1999-2006 by means of a qualitative and a quantitative analysis. The qualitative analysis is based on the public statements of the ECB while the quantitative analysis employs the estimation of reaction functions to assess whether the policy actions are consistent with the founding principles. The estimated monetary policy rule has the lagged short term rate, inflation and an indicator for real activity as regressors. Both contemporaneous and forward-looking rules are estimated. Results show that the ECB responds significantly to future inflation and to different measures of output gap with coefficients smaller than one while the coefficient on contemporaneous inflation is not significant. Then they estimate a small model of the Euro-area economy made up by the forward-looking monetary policy rule, an IS equation and a Phillips curve. Interest rate rule coefficients are similar to those obtained from the estimation of the single equations.

Blattner and Margaritov (2010) try to find a robust specification of the monetary policy rule of the Euro-area by using a real-time monthly database consisting of 127 series compiled with the data available to each Governing Council meeting over the sample 1999-2007. The first econometric exercise consists of estimating 3300 different specifications of the policy rule and pool the parameter estimates according to some efficiency criteria. The specification of the policy rule is similar to the one in Clarida, Galí, and Gertler (2000). Eventually they find that 291 rules deliver a meaningful description of the ECB interest-rate setting behaviour. Results show that the ECB is neither purely backward nor forward-looking, but it reacts to a synthesis of the available information on the current and future state of the economy. As regards the magnitude of coefficients, those of the contemporaneous inflation and output are positive but lower than one while those of future inflation and output are often greater than one. In the last part of the paper six factor are extracted from the real-time database and they are used to estimate a policy function. Results are consistent with the previous findings.

A last strand of literature faces the issue of characterising the conduct of monetary policy by the ECB during the crisis.

Gorter, Stolwijk, Jacobs, and de Haan (2010) estimate a forward-looking reaction function with both partial adjustment and first-order serially correlated errors over the period 1998-2010 with the aim of analysing the stability of coefficients. They find that the ECB gives priority to price stability and the coefficient of expected inflation is statistically stable over time while the coefficient for expected output gap decreases in the crisis period.

Gerlach and Lewis (2010), Gerlach (2011) and Gerlach and Lewis (2014) analyse the interest rate setting behaviour of the ECB by using a smooth transition model that allows for two regimes in the sample period. Their main finding is that the ECB reaction function is not stable over time. Gerlach (2011) identifies a shift in the reaction function in mid 2008 while Gerlach and Lewis (2014) identify a first switch in autumn 2008 and a second switch in late 2010. As regards the coefficient, the ECB responded more aggressively to expected inflation than to expected output with both coefficients positive and significant in the pre-crisis period and non-significant during the crisis. Moreover the ECB seems to have cut interest rate more rapidly than what the pre-crisis reaction function would have implied. This is compatible with the theoretical literature on optimal monetary policy in the presence of the ZLB which suggests that the central bank should implement an aggressive expansionary monetary policy to maintain long-term interest rate low if it foresees that the ZLB will be binding in the near future[2]

2.4 The ECB Reaction Function

2.4.1 Theoretical Specification

The baseline theoretical framework is similar to those used by Clarida, Galí, and Gertler (1998) except that it is enriched with several other variables to test their explanatory power.

In the baseline specification I assume that the ECB has a target interest rate for the nominal short term interest which depends on the state of the economy:

$$i_t^* = i^* + \beta \left(\mathbb{E}\left[\pi_t | \Omega_t\right] - \pi^* \right) + \gamma \mathbb{E}\left[x_t | \Omega_t\right] \tag{2.1}$$

where: i^* is the long-run equilibrium nominal rate, π_t is the rate of inflation between period t and $t-1$, π^* is the target level of inflation, x_t is the output gap in period t, i.e. the difference between the real output y_t and the natural rate of output y^* and Ω_t is the information set available to the central bank at time t. The current variables π_t and x_t are taken with expectations because their actual value is not known by the central bank at the time in which it takes its policy decisions.

As regards the setting of the actual policy rate, two assumptions are made here. First, the actual policy rate is set before the realization of π_t and x_t and second, the ECB follows a partial adjustment mechanism for the theoretical reasons explained by Woodford (1999)[3], i.e. the central bank has the tendency to smooth the interest rate and to fix it as a weighted average between the past interest rate and the target, plus a random shock:

$$i_t = (1-\rho)\, i_t^* + \rho i_{t-1} + v_t \tag{2.2}$$

Here v_t is an exogenous shock to the interest rate which is assumed to be i.i.d.. There can be several economic interpretations for v_t. Christiano, Eichenbaum, and Evans (1999) report three different interpretations: v_t can reflect exogenous shocks to the preference of the monetary authority, it can be due to some technical factors like measurement errors in the preliminary data available leading to an imperfect response of the central bank to changes in the economy or it can derive from the willingness of the ECB to avoid the social costs of disappointing private agents' expectations so that shocks to their expectations becomes self-fulfilling.

[2]See for example Reifschneider and Williams (2000), Orphanides and Wieland (2000) and Adam and Billi (2006). Indeed Gerlach and Lewis (2014) also produces evidence of the fact that the ZLB has been actually binding from mid 2008 till at least the end of 2009 as the implied target interest rate was negative.

[3]Other reasons that can justify the appearance of the lagged interest rate in the monetary policy reaction function are the fact that the central bank operates in an environment of data uncertainty as its decisions are based on real-time data rather than revised ones (Orphanides, 2001) and the existence of serially correlated shocks which are not captured by the empirical rule (Rudebusch, 2002).

Substituting equation 2.1 in 2.2 I obtain the equation for the actual nominal interest rate:

$$i_t = \alpha + \psi \mathbb{E}\left[\pi_t|\Omega_t\right] + \theta \mathbb{E}\left[x_t|\Omega_t\right] + \rho i_{t-1} + v_t \tag{2.3}$$

where: $\alpha = (1-\rho)\,\delta$, $\psi = (1-\rho)\,\beta$, $\theta = (1-\rho)\,\gamma$ and $\delta = i^* - \beta\pi^*$.

From this equation it is clear that the parameters coming from the empirical estimation of the monetary policy rule are reduced-form parameters, i.e. a convolution of both structural parameters and central bank's preference parameters.

The estimation of equation 2.3 cannot be directly implemented by substituting to $\mathbb{E}\left[\pi_t|\Omega_t\right]$ and $\mathbb{E}\left[x_t|\Omega_t\right]$ their contemporaneous values π_t and x_t as they would be affected by an endogeneity problem. This problem can be overcome by assuming that the ECB has rational expectations and so $\mathbb{E}\left[\pi_t|\Omega_t\right]$ and $\mathbb{E}\left[x_t|\Omega_t\right]$ are instrumented. Here, instruments will be generally indicated as u_t and their importance comes from the fact that they allow to get identifying assumptions. So let u_t be a vector of variables within the central bank's information set at the time it chooses the interest rate (i.e. $u_t \in \Omega_t$) that are orthogonal to v_t. Possible elements of u_t include any lagged variables that help forecast inflation and output, as well as any contemporaneous variables that are uncorrelated with the current interest rate shock v_t. Equation 2.3 and the fact that $\mathbb{E}\left[v_t|u_t\right] = 0$ imply the following set of orthogonality conditions:

$$\mathbb{E}\left[i_t - \alpha - \psi \mathbb{E}\left[\pi_t|\Omega_t\right] - \theta \mathbb{E}\left[x_t|\Omega_t\right] - \rho i_{t-1}|u_t\right] = 0 \tag{2.4}$$

In my specific case u_t are the lagged inflation rate and the lagged output gap. A more extensive specification of the estimation procedure is postponed to the next section.

This baseline "Taylor-type" reaction function is then enriched with several other variables to allow for a clearer identification of the conduct of monetary policy in the Euro-area so that the general specification is the following:

$$i_t^* = i^* + \beta\left(\mathbb{E}\left[\pi_t|\Omega_t\right] - \pi^*\right) + \gamma \mathbb{E}\left[x_t|\Omega_t\right] + \xi \mathbb{E}\left[z_t|\Omega_t\right] \tag{2.5}$$

As regards the variables considered for the estimation, I assume that the monetary policy instrument is the short-term money market rate, i.e. the Euro-area overnight index average. This assumption is standard in the empirical literature on the estimation of monetary policy rules[4]. Even though the EONIA is not under the direct control of the ECB, because it represents the bank funding conditions on the money market, it closely tracks the key policy rates as it fluctuates around the rate on main refinancing operations and between the deposit facility and the marginal lending facility rates as shown by figure 2.1. However this relationships broke during the crisis period as the EONIA fell substantially below the repo rate. This happened because of the unconventional monetary policy measures implemented by the ECB which then makes the low level of the EONIA a direct expression of policy and does not invalidate its use as monetary policy instrument.

The regressors of the policy rule represent the ECB's information set. From this point of view, the necessary assumptions to correctly identify monetary policy shocks are that there are no missing variables as the considered regressors can exhaustively describe the ECB behaviour and that the residuals

[4] See e.g. Bernanke and Blinder (1992), Clarida, Galí, and Gertler (1998), Clarida, Galí, and Gertler (2000) and Judd and Rudebusch (1998).

are orthogonal to the regressors, i.e. the so-called recursiveness assumption. Then regressors' coefficients represent the feedback rule.

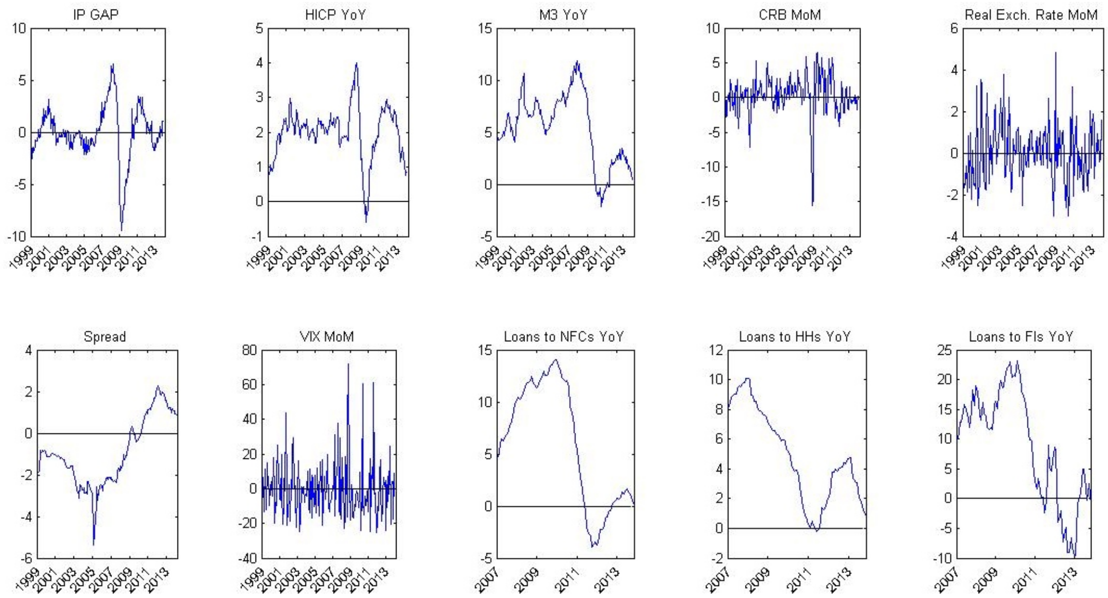
As regressors I use contemporaneous and lagged values of inflation and the output gap. The reference series for inflation is the annual growth of the HICP. It must be noted that the contemporaneous value of the industrial production and of the HICP are not available neither to the monetary authority at the time of policy decision nor to markets in the remaining part of the month. These values are usually published with at least one month lag. For this reason the contemporaneous value of inflation and of the industrial production gap can be considered as a measure of expected inflation and output while its lagged value is what it is actually available at the time of policy decisions. In order to make the equation 2.3 estimable, the ECB is assumed to have rational expectations and so the current inflation rate and output gap are instrumented by taking the fitted values of a time-varying parameters BVAR model with one lag of the endogenous variables and of the policy rate. This approach is consistent with Bernanke and Blinder (1992) and Bernanke and Mihov (1998). The output gap are calculated by applying the Hodrick-Prescott filter to the original series and taking the difference between the actual values and the filtered series that represents the potential output[5].

This basic model is then extended to include other variables that might have been taken into account by the ECB so that both the explanatory power of this additional variables and the robustness of coefficients on inflation and the output gap are tested. The additional variables considered are an index of Euro-area sovereign yield spreads, a stock market volatility index, the real effective exchange rate, an index of commodity prices, the lagged value of a broad monetary aggregate and the annual growth rate of bank loans. The commodity price index is the Thomson Reuters/Jefferies CRB Index and as stock market volatility index I use the VIX index which is a measure of the implied volatility of S&P 500 index options over the next 30 calendar days. The index of sovereign yield spreads is built weighting the bond spreads of 10 Euro-area countries for their relative debt-to-GDP ratio and it has been included in the analysis to capture tensions on sovereign debt markets in the period 2010-2012. Bank loans data come from the statistics on the monetary financial institution (MFI) sector provided by the ECB which summarize the aggregated balance sheet positions of MFIs in the Euro area. Further details over the series used in the estimation can be found in appendix A. This specification is consistent with a closed-economy monetary policy rule as there are no foreign inflation and output among the regressors.

The estimation period goes from January 1999 to December 2013, all the considered variables are in logarithms except for the Eonia and their values are represented in figure 2.2. As regards the output gap, the annual inflation rate, the lagged growth rate of M3, the monthly change of the exchange rate and of the CRB price index, logarithms are applied to the original series and then the necessary transformation are calculated, i.e. the HP filter is run on the logarithm of the industrial production index and annual (or monthly) growth rates are calculated as the difference between the current logarithmic value and its 12-month (or 1-month) lag.

[5]Results are very similar to those obtained by regressing the industrial production on a constant term, a linear trend and a quadratic trend.

Figure 2.2: **Regressors**



2.4.2 Econometric Specification

In order to obtain estimates of the monetary policy reaction function coefficients, it is necessary to estimate two system of equations: the BVAR model and the reaction function.

As I allow coefficients to be time-varying, the ECB reaction function can be re-written in a state-space form. For each time $t = 1, \ldots T$, the model has the following structure:

$$y_t = X_t\beta_t + \varepsilon_t,\ \varepsilon_t \sim N\left(0, \sigma_t\Sigma_\varepsilon\right) \quad (2.6)$$

$$\beta_t = \beta_{t-1} + \eta_t,\ \eta_t \sim N\left(0, \Sigma_\eta\right) \quad (2.7)$$

Here y_t is the short-term interest rate, X_t is the $(1 \times n)$ vector of regressors containing the lagged value of the dependent variable and the $(n-1)$ exogenous regressors, $\beta_t = (\beta_{1t}, \ldots, \beta_{nt})'$ is a $(n \times 1)$ vector of coefficients and ε_t and η_t are the error terms which are normally distributed and orthogonal with each other.

Equation 2.6 is the measurement equation in which parameters are time-varying. The evolution of parameters is random, the βs are treated as latent variables that captures the actual state of the system. In particular they follow a random-walk without drift as described by the state equation 2.7. This assumption is a standard way of modeling permanent structural changes in behaviour due to fundamental changes in policy regime, see for example Cogley and Sargent (2005) and Primiceri (2005).

As regards variances of the error terms, Σ_η is an $(n \times n)$ matrix governing the parameters' evolution, while in the measurement equation errors are heteroskedastic with variance $\sigma_t\Sigma_\varepsilon$, i.e. the parameter σ_t is responsible for time-variation and Σ_ε is a constant scale parameter. Following Ciccarelli and

Rebucci (2006), I assume that σ_t is distributed as a scaled inverse-χ^2 with v degrees of freedom[6] ($\sigma_t \sim Inv - \chi^2(v,1)$). This makes the distribution of ε_t equivalent to a Student-t with v degrees of freedom and scale matrix Σ_ε ($t_v(0,\Sigma_\varepsilon)$)[7] and so large realizations of the monetary policy shocks are possible. As a matter of fact, the purpose of this work is not only to study the monetary policy reaction function, but also to correctly identify monetary policy shocks, i.e. deviations of the short-term rate from the value implied by the policy function. Assuming heteroskedasticity in the residuals is also important to correctly identify time-variation in parameters. A constant variance-covariance matrix could lead to erroneously identify a change in the conduct of monetary policy while it is just a change in the characteristics of the monetary policy shock. However this model does not impose unnecessary heteroskedasticity, i.e. if the heteroskedasticity factor is not significant the coefficients' dynamics and the residuals will be equal to those one would have obtained by estimating an homoskedastic time-varying parameters model. On the other hand, if heteroskedasticity is present, the magnitude of coefficients will be lower that in an homoskedastic framework as some part of the EONIA variations is explained by σ_t.

Priors are set as follow. The prior over the variance-covariance matrix of the parameters is assumed to be Inverse-Wishart with γ degrees of freedom and scale matrix Υ. This scale matrix has a very relevant role in determining parameters' evolution as the greater is the variance, the more time variation will be displayed by parameters. According to what is done in the literature, Υ is considered to be equal to the OLS variance-covariance matrix of the parameters multiplied by the sample size so that a high degree of parameters time-variation is assumed. The parameters are assumed to be normally distributed with mean equal to the OLS estimate and variance-covariance matrix equal to four times the OLS variance-covariance matrix. The OLS estimates are calculated on the 36 observations previous to the estimation sample.

Here it is necessary to more clearly justify the choice of Υ. The literature uses to rescale this matrix by $(0.1)^2$ or $(0.01)^2$ in order to decrease the degree of time variation in coefficients and improve impulse responses and forecasting analysis (Stock and Watson, 1996; Primiceri, 2005). However, the purpose of the current work is to study the evolution of coefficients through time and it appears more appropriate not to decrease the amount of time-variation so that the estimation can reach a better fit of the data.

The output gap and inflation are made exogenous with respect to the short term interest rate by taking the fitted values from the following time-varying parameters VAR system in structural form:

$$A_t(L)\,Z_t = D_t R_{t-1} + V_t \tag{2.8}$$

Here Z_t is a (2×1) vector containing the output gap and inflation at time t in natural logarithms, R_{t-1} is the first lag of the monetary policy instrument, V_t is a (2×1) vector of residuals that have zero

[6] The scaled inverse chi-squared distribution is the distribution for $x = 1/s^2$, where s^2 is a sample mean of the squares of v independent normal random variables that have mean 0 and inverse variance $1/\sigma^2 = \tau^2$. The distribution is therefore parametrised by the two quantities v and τ^2, referred to as the number of chi-squared degrees of freedom and the scaling parameter, respectively. In the case of interest $\tau^2 = 1$ meaning that the v independent normal variables are also standard ($N(0,1)$).

[7] This can be intuitively understood considering that the Student's t distribution (with v degrees of freedom) is the distribution of the ratio of two independent random variables: $Z/\sqrt{W/v}$, where $Z \sim N(0,1)$ and $W \sim \chi^2(v)$. Moreover the Student's t distribution can be interpreted as a mixture of normals with common mean and variances that follows an inverse-Gamma distribution. In the case of interest $\varepsilon_t \sim N(0,\sigma_t\Sigma_\varepsilon)$ with $\sigma_t \sim inv - \chi^2(v,1)$ and the inverse-χ^2 is a special case of the inverse-Gamma distribution. Therefore the vector of errors is a mixture of normals and it is equivalent to a scaled t-distribution with v degrees of freedom $t_v(0,\Sigma_\varepsilon)$.

mean and are serially uncorrelated. Finally, $A_t(L)$ and D_t are the time-varying coefficients matrices with dimension (2×2), and (2×1) respectively and $A_t(L)$ specified in the lag operator L with lag length $p_1 = 1$ [8].

The system defined in equation 2.8 features time-varying coefficients and can be alternatively rewritten as follows:

$$Z_t = X_t \theta_t + w_t, \; w_t \sim N(0, \omega_t \Sigma_w) \tag{2.9}$$

$$\theta_t = \theta_{t-1} + \upsilon_t, \; \upsilon_t \sim N(0, \Sigma_\upsilon) \tag{2.10}$$

Here Z_t is still the (2×1) vector of dependent variables, $X_t = diag\left[X'_{1t}, X'_{2t}\right]$ is a $(2 \times h)$ matrix of regressors where each X_{it} has dimension $(k_i \times 1)$ and $h = k_1 + k_2$ is the total sum of regressors in the model, $\theta_t = [\theta'_{1t}, \theta'_{2t}]'$ is a $(h \times 1)$ vector of coefficients where each θ_{it} has dimension $(1 \times k_i)$ and w_t is the normally distributed error term.

The error terms w_t and υ_t are orthogonal with each other, $\omega_t \Sigma_w$ and Σ_υ are their variance-covariance matrix with dimensions (2×2) and $(h \times h)$ respectively and therefore they govern the parameters' evolution. As before, Σ_w is a constant scale matrix while ω_t is responsible for time-variation and it is assumed to be distributed as a scaled inverse-χ^2 with v degrees of freedom ($\omega_t \sim Inv - \chi^2(v, 1)$) which makes the distribution of w_t equivalent to a Student-t with v degrees of freedom and scale matrix Σ_w ($t_v(0, \Sigma_w)$). The structure of the prior distributions on Σ_υ and on the θs is the same as the one in the model for the monetary policy reaction function.

This two-step estimation procedure is consistent with the VAR models specified by Bernanke and Blinder (1992) and Bernanke and Mihov (1998). The policy rate is assumed not to influence the given macro variables contemporaneously and this allows to correctly identify both the parameters of the reaction function and the monetary policy shocks with the reduced-form coefficient and the residuals of model 2.6 - 2.7. The main advantage of this procedure is therefore to correctly identify parameters without having to identify the entire model structure as the equations for inflation and the output gap have a pure statistical specification.

The Bayesian estimation of the two systems of equations 2.6 - 2.7 and 2.9 - 2.10 is possible through the combination of the Kalman filter and the Gibbs sampler as suggested by Carter and Kohn (1994) and Chib and Greenberg (1995). The procedure is based on the multi-move Gibbs sampler algorithm which iterates the following steps until convergence is achieved:

1. conditional on the model's hyperparameters and the observed data, generate the entire set of state coefficient $\beta_{1:T}$ (or $\theta_{1:T}$ for the VAR model);

2. conditional on $\beta_{1:T}$ (or $\theta_{1:T}$ for the VAR model) and the observed data, generate the model's hyperparameters.

The second step of this procedure is straightforward to implement as, conditional on $\beta_{1:T}$, the measurement and the transition equation are two independent regressions. On the other hand, the first step requires the derivation of the distribution of the generic term β_t conditional on β_{t+1} and the set of observations $y_{1:t}$. Appendix B goes into the details of the estimation algorithm.

[8] The system has been estimated also with $p_1 = 2$ but results do not change. Then for parsimony the lag length has been chosen to be equal to one.

This algorithm generates smoothed estimates, i.e. estimates that are based on the entire set of observations, which are preferable with respect to filtered estimates if, as in this case, the objective is to study the evolution of the latent factors over time.

In order to correct for the generated-regressors bias the two systems are estimated in the same simulation step. For every iteration of the Gibbs sampler, the coefficients of the BVAR system are estimated and used to obtained the fitted variables which are in turns taken as regressors in the second part of the algorithm where the monetary policy reaction function is estimated. By doing so, the generated regressors will change at each iteration depending on the coefficients' draw meaning that their full distribution is considered in the estimation of the monetary policy reaction function. This allows to take into account the uncertainty connected to the generated regressors and then it is not necessary to correct the error terms as done in Kim (2006) and in Kim and Nelson (2006).

The classical estimation of the systems 2.6 - 2.7 and 2.9 - 2.10 would require to obtain the maximum likelihood estimates of the hyperparameters σ_t, Σ_ε, Σ_η and ω_t, Σ_w, Σ_v and then, treating them as true values, to derive the estimates of the state variables $\beta_{1:T}$ (or $\theta_{1:T}$ for the VAR model). This approach has at least two drawbacks. First, even though it is possible to derive the functional form of the likelihood function, its maximization is not a simple task as it is defined on a high-dimensional space. Then, a second possible problem is that a complicated model like this could have a likelihood with multiple peaks and the simple maximization does not ensure to find reasonable values for the parameters. The Bayesian approach can improve on both these issues. As regards the dimensionality of the problem, Bayesian inference is more efficient from a computational point of view than classical inference because it allows to split the estimation problem in smaller and simpler ones. On the other hand, the use of prior distributions can prevent the maximization algorithm to find implausible maxima.

2.5 Estimation Results

In this section I present the results from different specifications of the monetary policy reaction function. The baseline specification is a contemporaneous Taylor rule which is also extended to consider other variables, namely M3 growth, a commodity price index, the real effective exchange rate, a spread index, a stock market index and bank loans. This exercise follows a marginal approach as the variables are added one at a time so to evaluate their marginal significance and whether the coefficients of the baseline specifications are affected. Further details about the series used can be found in appendix A.

For all the following models the algorithm generates 20000 draws from the marginal distributions and the first 5000 draws are used as burn-in and so they are discarded. To eliminate autocorrelation in some parameters and in the heteroskedasticity factor, posterior distributions are built retaining only one draw every three cycles of the Gibbs sampler algorithm, i.e. by using 5000 from the remaining 15000 draws. Convergence is checked for every model by using both graphical analysis and convergence diagnostics.

2.5.1 Contemporaneous Taylor Rule

The first specification is the simplest one as it considers only three regressors: the lagged EONIA rate, the output gap and the inflation gap. Figures 2.3 and 2.4 show the results.

The autoregressive coefficient fluctuates between 0.6 and 1 up to the end of 2008 when it becomes not different from 1. After the peak at the beginning of 2009 the coefficient decreases up to 0.9 and remains constant from 2010 on. This dynamics is consistent with the high volatility of the EONIA during 2007 and with its fall from October 2008. From 2009 the EONIA stabilizes to a level close to the deposit facility rate which justifies the rise in the autoregressive coefficient towards 1.

As regards the output gap, the coefficient is low but positive from 1999 to mid 2001, in 2003 and from 2007 to the beginning of 2009. The mean of the coefficient is always positive but in the remaining periods it is not statistically different from zero. This dynamics shows that the ECB stabilized output mainly during the peak of both the dot-com bubble and the subprime crisis. In particular, during both periods the output gap was positive and the key policy rates have been first increased and then cut. This is due to the fact that probably at the beginning of both periods the ECB tried to contain the fast rise of economic activity which can be interpreted as a predictor of future inflation but then it had to ease monetary policy to fight the recession. This interpretations is confirmed by the coefficient of the annual rate of inflation which is (almost) positive only over the period 1999-2001 and around 2007 while it is either not different from zero or negative over the remaining parts of the sample. This finding can be considered as puzzling at a first sight as the ECB has the clear mandate of reaching the target level inflation of 2%, but from an economic point of view can be justified by the fact that inflation expectations remained almost stable at the inflation target in the first half of the sample while a further investigation is needed in order to understand what happened during the recent crisis.

Moreover this evidence support the idea that the ECB responded more aggressively to economic developments during the crisis started in 2008, in line with the theoretical literature on optimal monetary policy at the ZLB that prescribes a rapid interest rate cut if the ZLB may bind in the near future (Reifschneider and Williams, 2000; Orphanides and Wieland, 2000; Adam and Billi, 2006).

The heteroskedasticity factor and the residuals in figure 2.4 display several peaks around 2001 which tells us that at that time the ECB surprised markets while it did not during the recent crisis. A possible explanation is that from 2008 onwards the ECB aggressively intervened to curb the economic crisis also by using a communicative strategy that helped in making its policy decisions less unexpected by the economic community.

Figure 2.3: **Parameters (mean of posterior distributions with 16th and 84th quantile)**

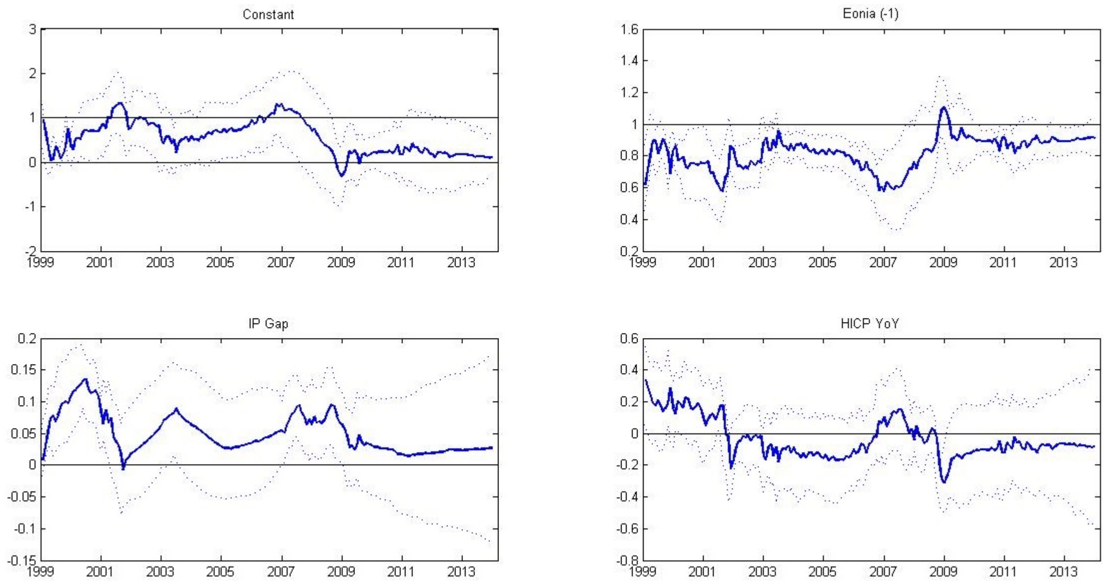
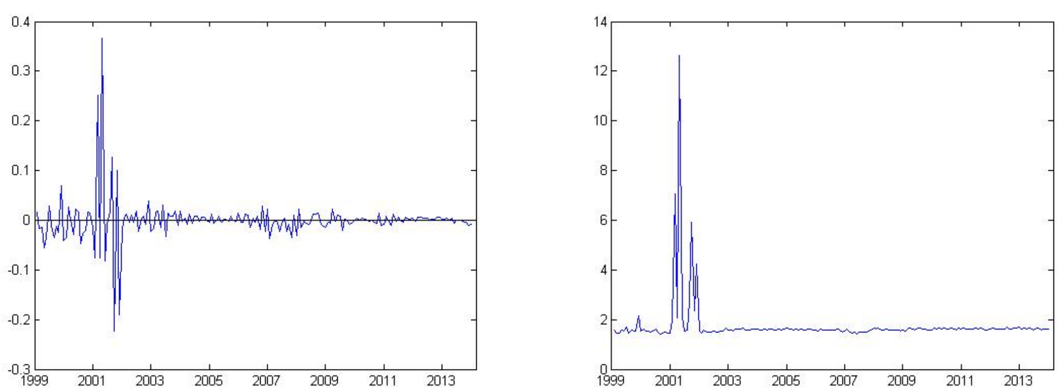


Figure 2.4: **Residuals and heteroskedasticity factor**

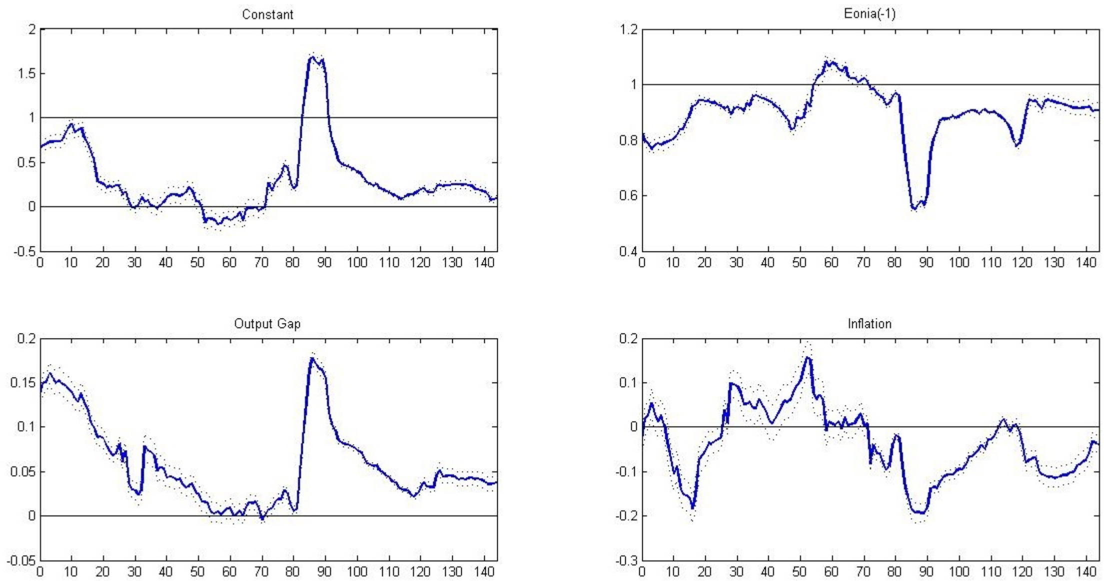


2.5.2 An Assessment

This section compares the previous results with those coming from a simple rolling regression estimation, which are displayed in figure 2.5. Rolling regressions are estimated over 36 observations and then the window is shifted forward of one observation. For sake of comparability, the estimation of the rolling regression is Bayesian[9]. The contemporaneous output gap and inflation come from a constant-coefficients BVAR model.

[9]The regressions have been estimated also with OLS but results are not distinguishable.

Figure 2.5: **Parameters from rolling regressions (3-year sample)**



The results for the constant, the autoregressive coefficient and the output gap are quite in line with those of the time-varying coefficient model, while this is not true for the inflation coefficient.

However it is necessary to notice that the fact that the coefficients coming from the two estimation methodology do not coincides does not invalidate the use of the time-varying coefficient approach. Rather, they are different because the algorithms are substantially different. The time-varying coefficient model produces smoothed estimates, i.e. the full sample of observations is used to estimate parameters. On the other hand, a drawback of the rolling estimation procedure is that results are influenced by the size of the estimation window so that it is a relevant issue. Finally, the time-varying parameter approach is well suited for dealing with monetary policy as it seems appropriate to model policy changes with smooth transitions.

2.5.3 Extensions

In this section the forward-looking Taylor rule is extended for taking into account other variables that might have influenced the ECB in setting the interest rate. A marginal approach is followed here, i.e. the variables are added one by one so that also their effect on the coefficients of output and inflation can be clearly evaluated.

M3

The first variable considered is money growth measured with the annual change in M3. To avoid endogeneity issues the variable is lagged of one period.

As explained in section 2.2, monetary analysis had a preeminent role in evaluating price stability up to 2003, when its role has been revised. The monetary analysis used a reference value for the broad monetary aggregate M3 (ECB, 1999b) which has been abandoned after 2003.

Figures 2.6 and 2.7 show that the inclusion of M3 growth into the monetary policy reaction function leads to some changes in the coefficients of the baseline Taylor rule. The M3 coefficient itself is significant only around 2001 and its mean fluctuates around zero afterwards. Even though the coefficient is almost never significant, this dynamics can be considered as consistent with the revision of the M3 role in defining the monetary policy strategy. The residuals and the heteroskedasticity factor have now only a peak in 2001.

Figure 2.6: **Parameters (mean of posterior distributions with 16th and 84th quantile)**

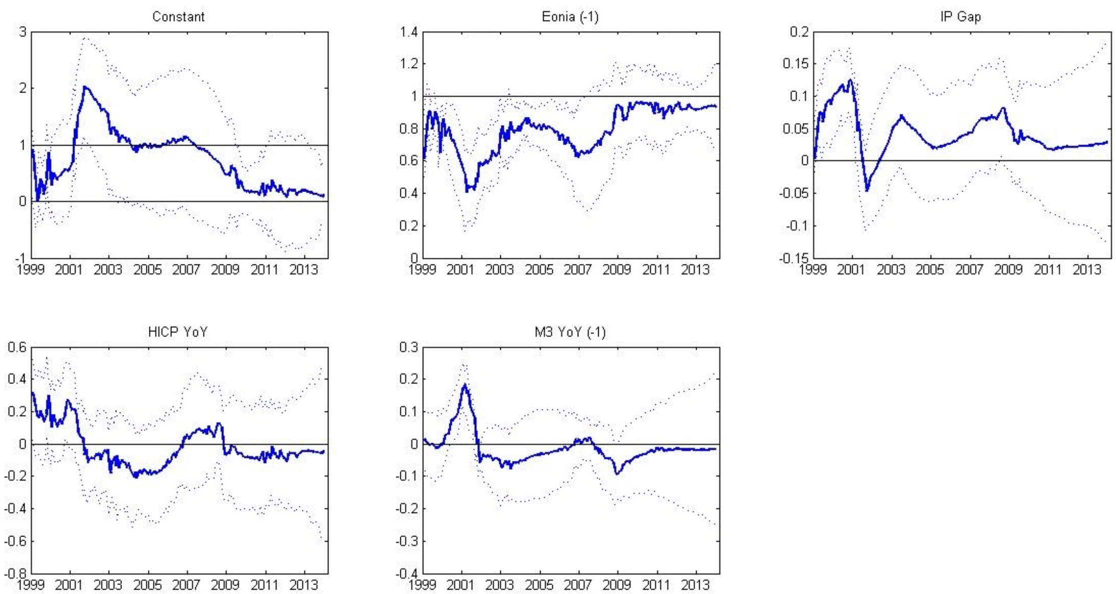
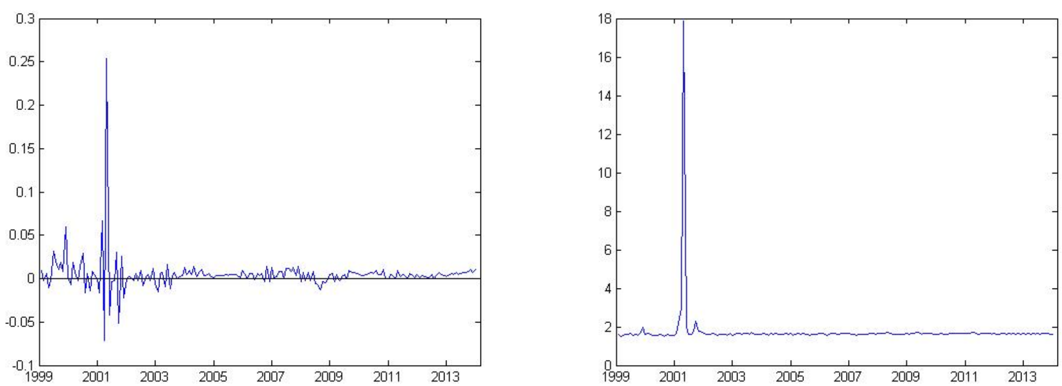


Figure 2.7: **Residuals and heteroskedasticity factor**



Commodity Prices

Commodity prices are added to the monetary policy reaction function to evaluate whether the ECB has a different sensibility with respect to commodity inflation and to final price inflation. The measure considered is the monthly change in the CRB price index.

As shown in figures 2.8 and 2.9, the coefficient of the CRB price index is never significant and does not alter the previous findings.

Figure 2.8: **Parameters (mean of posterior distributions with 16th and 84th quantile)**

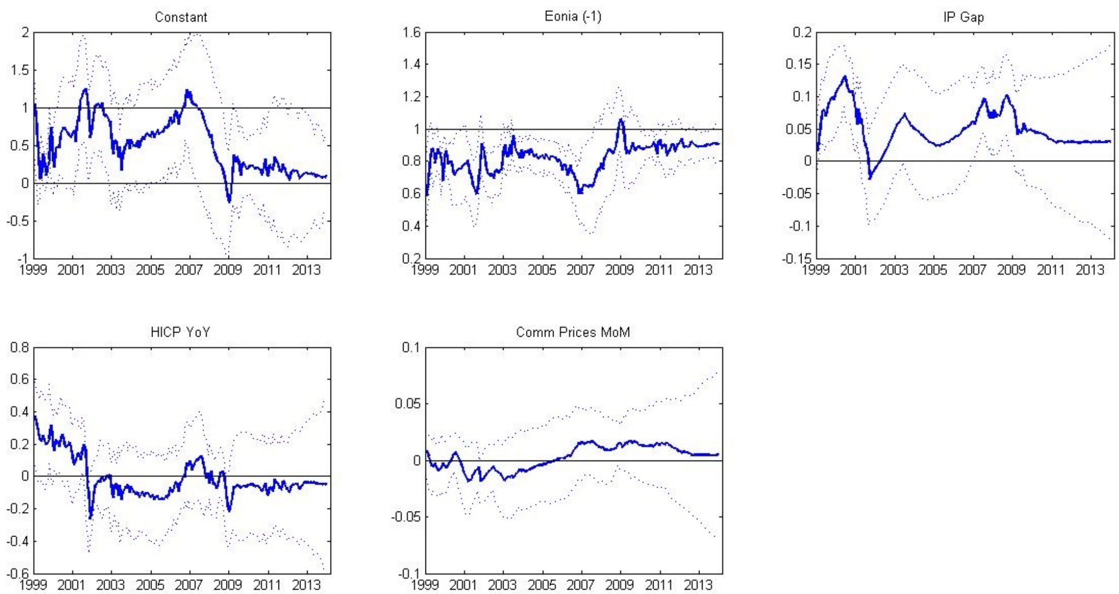
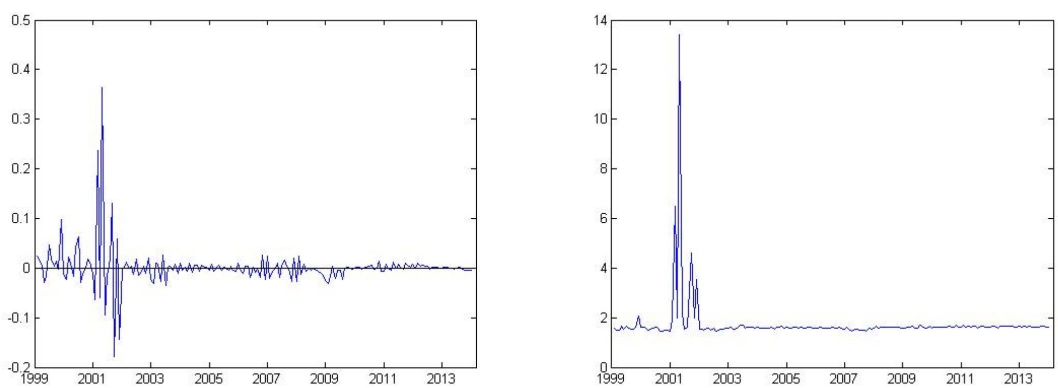


Figure 2.9: **Residuals and heteroskedasticity factor**



Exchange Rate

In this specification the monthly change in the real effective exchange rate[10] is added.

Figures 2.10 and 2.11 display the results. The exchange rate coefficient is rarely significant and the other coefficients are not changed.

Figure 2.10: **Parameters (mean of posterior distributions with 16th and 84th quantile)**

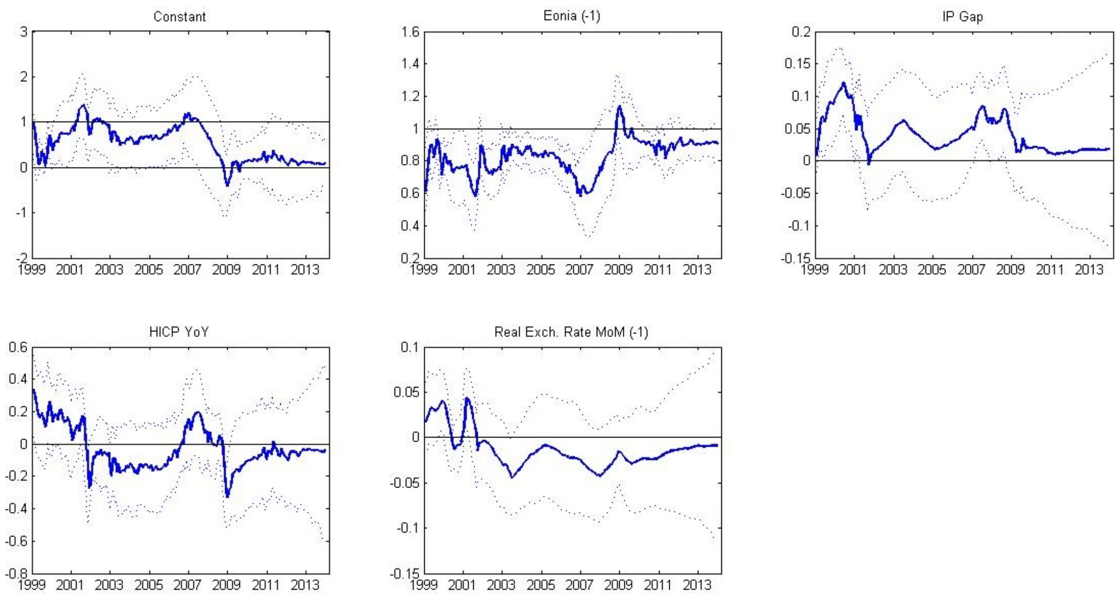
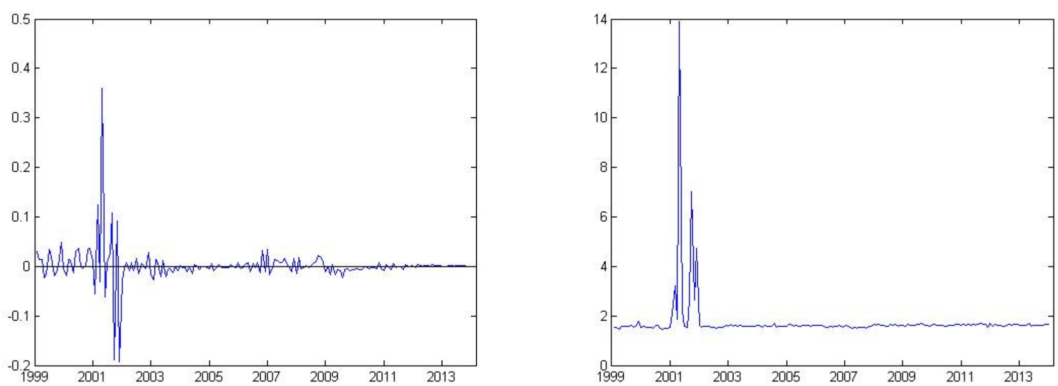


Figure 2.11: **Residuals and heteroskedasticity factor**



[10]The exchange rate is defined such that when it increases the Euro currency appreciates.

Bond Yields Spreads

The recent financial crisis also involved public finances of several European countries leading to tensions in sovereign debt markets. For this reason an index of bond yield spreads is added to the monetary policy reaction function. The index is computed as a weighted sum of government bond yield spreads with respect to Germany of ten Euro-area countries and weights are given by the relative debt-to-GDP ratios. To avoid endogeneity the first lag of the index is considered.

Results are displayed in figures 2.12 and 2.13 and they show that the coefficient of the spread index is negative and significant around 2009 which means that the ECB was trying to curb tensions on sovereign debt markets. In the first part of the sample the coefficient is positive and significant around 2003 but this result does not have any meaningful economic interpretation.

Figure 2.12: **Parameters (mean of posterior distributions with 16th and 84th quantile)**

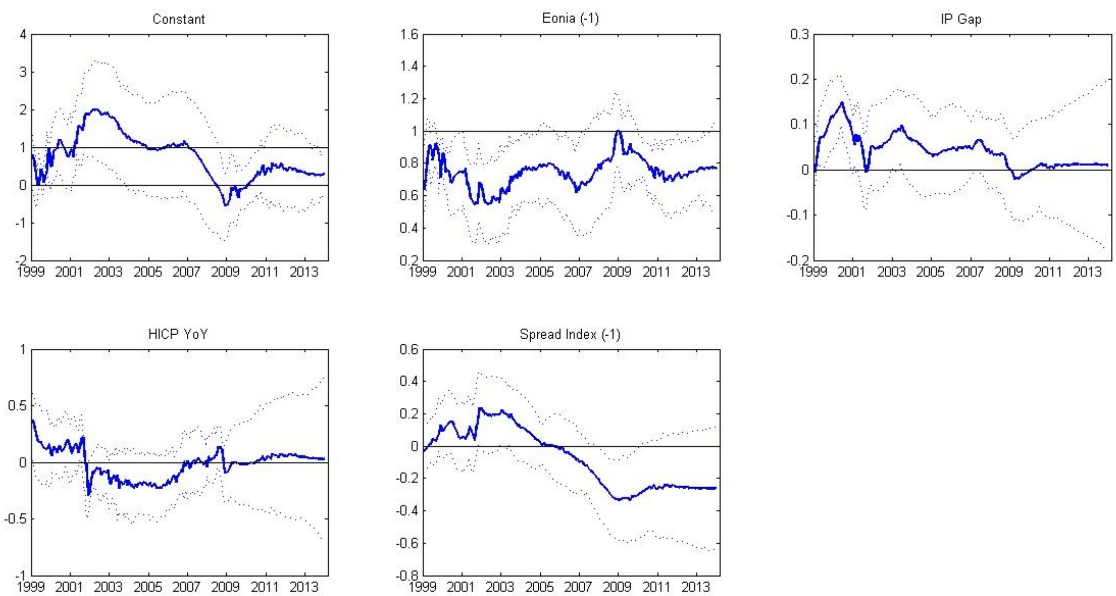
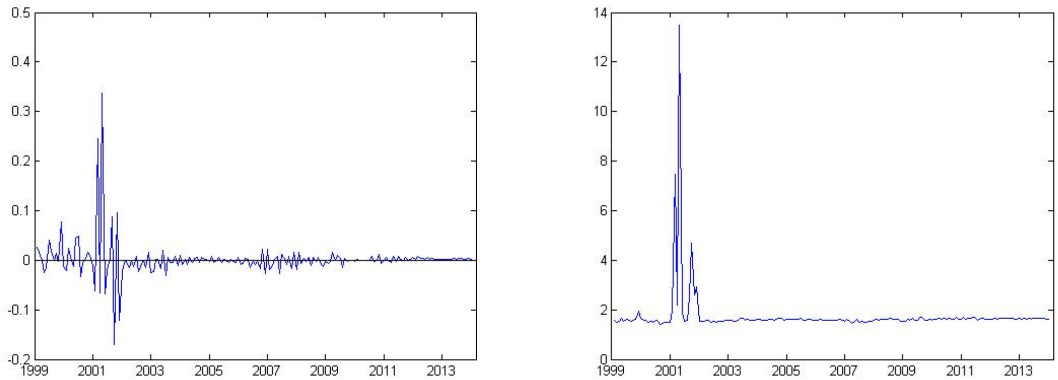


Figure 2.13: **Residuals and heteroskedasticity factor**



Stock Market Volatility

This specification adds a stock market volatility index to the baseline Taylor rule. The index considered is the Chicago Board Options Exchange market volatility index, also known as VIX, which is a measure of the implied volatility of quoted options on S&P 500 index[11]. Its monthly variations are included into the reaction function and, in order to escape any endogeneity issue, the first lag is considered.

As for the previous specifications, the coefficients, the residuals and the heteroskedasticity factor of the baseline Taylor rule are unchanged. The VIX index has a positive coefficient only from 1999 to 2002 and it display a peak in 2001 when the dot-com bubble burst.

[11]The VIX index has been preferred to the volatility index of the European stock market, the VSTOXX, because of data availability. Data for the VSTOXX index are available from 1999 so that it would not be possible to initialize the Kalman filter with its coefficient calculated over the pre-sample. On the other hand data of the VIX index go back to the 1980s. For seek of comparability of the results the VIX has been preferred to the VSTOXX. However the model has also been estimated with the VSTOXX using the period 1999-2001 as a pre-sample but its coefficient turned out to be non-significant.

Figure 2.14: **Parameters (mean of posterior distributions with 16th and 84th quantile)**

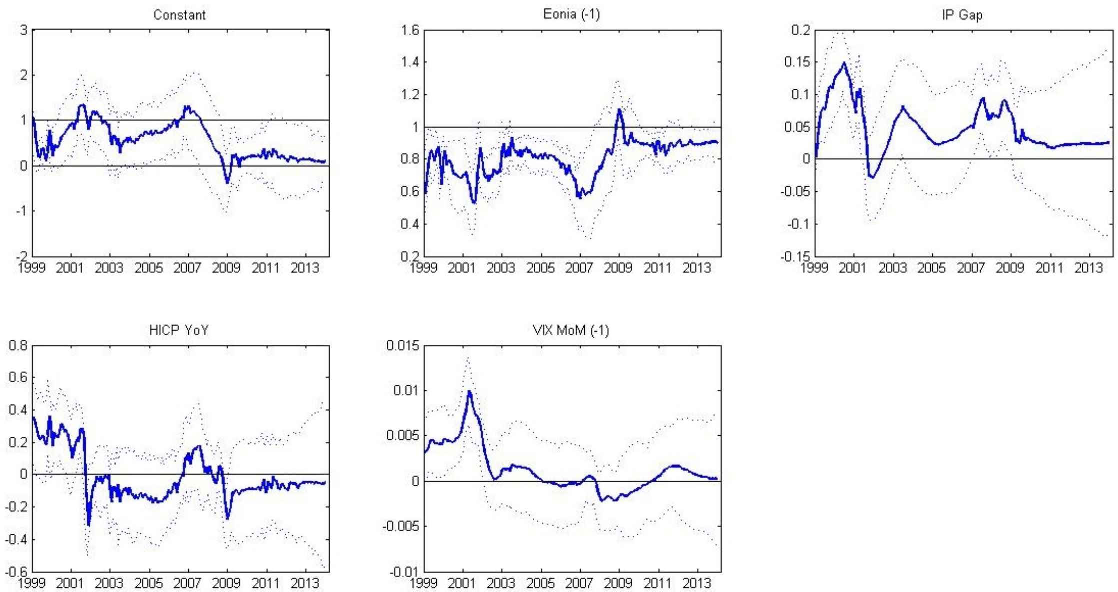
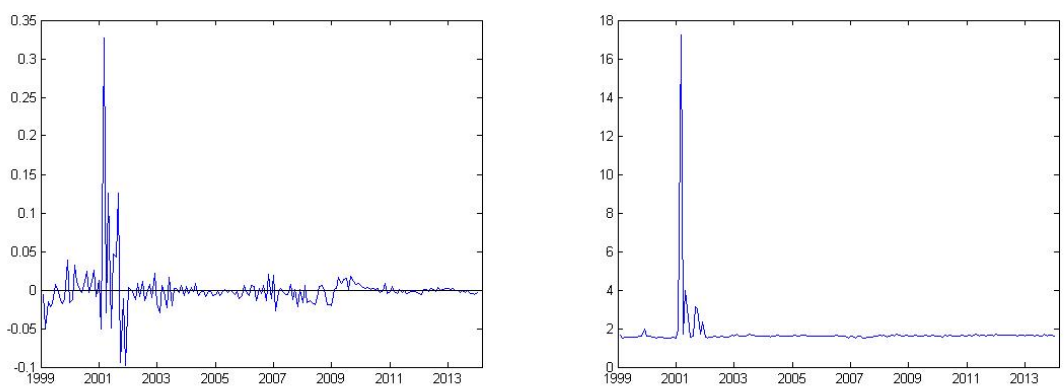


Figure 2.15: **Residuals and heteroskedasticity factor**



Bank Loans

In this specification the monetary policy reaction function is enriched with three bank loans variables, namely the amount of loans to non-financial corporations (NFCs), to households and to other financial institutions coming from the statistics on the monetary financial institution (MFI) sector. These series are available from 2003 and their annual growth rate is considered. Given that a pre-estimation sample is needed to initialize the Kalman filter, the estimation starts in 2007.

Results are displayed in figures 2.16 and 2.17 and they show that the bank loans are significant in explaining the behaviour of the ECB. The first thing to notice is that the inflation and output gap coefficients are comparable to those obtained in the baseline Taylor rule specification signalling they are not affected neither by the new variables considered nor by the shorter sample. The same is true for the residuals and the heteroskedasticity factor. The coefficients of the loans variables are positive and significant for almost the whole sample for loans to non-financial corporations and for loans to households while the coefficient of loans to other financial institutions is not significant. This means that the ECB tried to stabilize the amount of loans to the private sector.

Figure 2.16: **Parameters (mean of posterior distributions with 16th and 84th quantile)**

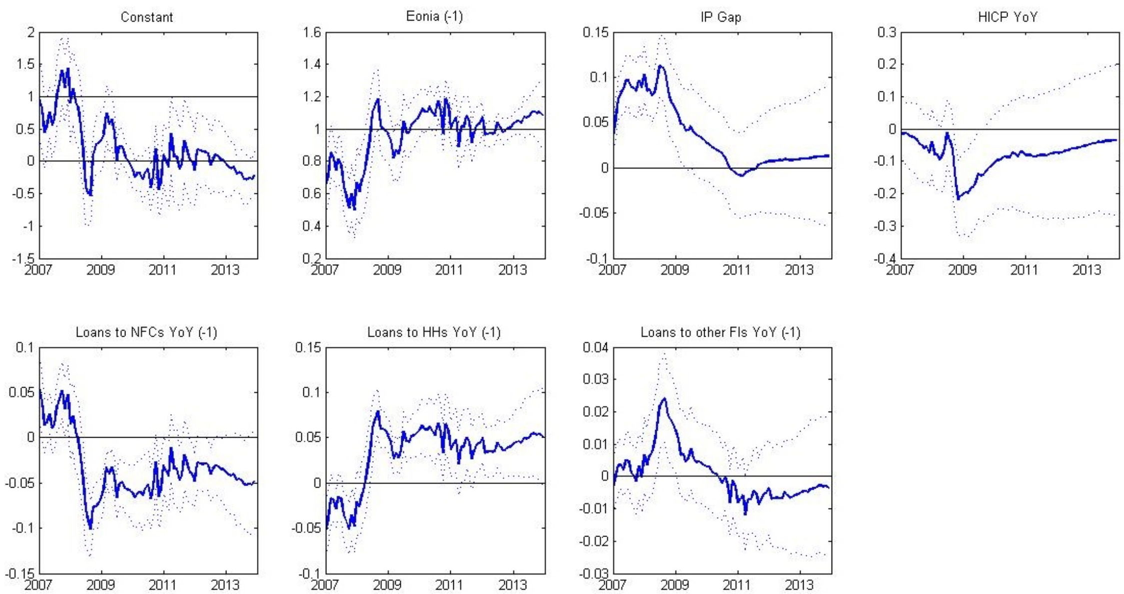
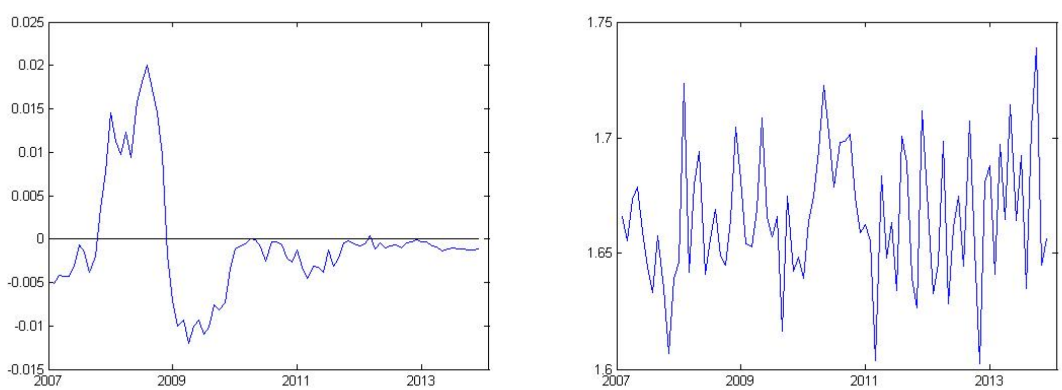


Figure 2.17: **Residuals and heteroskedasticity factor**



2.6 Conclusion

This work produced some evidence on the conduct of monetary policy in the Euro area over the period 1999-2013 by using time-varying coefficient reaction functions with heteroskedastic errors estimated with Bayesian techniques.

Dealing with data of the 2008-2013 period is not an easy task as most of the macroeconomic variables show huge variations which can easily invalidate any econometric analysis. A model with time-varying coefficients combined with heteroskedastic errors offers a very flexible framework that can ideally adapt and capture changes in the macroeconomic environment.

The baseline specification is a Taylor rule with contemporaneous inflation and output gap. Then this specification is extended adding further variables that might have been taken into consideration by the ECB in setting the interest rate, namely M3 growth, a commodity price index, the real exchange rate, a government bond yield spread index, a stock market volatility index and bank loans. The variables are added one at a time so that their marginal influence on the inflation and output coefficients can be evaluated.

In order to avoid endogeneity issues, inflation and output have been instrumented by using a time-varying parameters BVAR model. The BVAR and the monetary policy reaction function are estimated in the same simulation algorithm: at each iteration of the Gibbs sampler the fitted values coming from the BVAR model are used as regressors for the reaction function. This allows to correct for the generated regressors bias that would otherwise affect the coefficients of the monetary policy rule.

The results for the two main variables, i.e. output gap and inflation, are consistent through different specifications and show that the ECB stabilized output mainly during the peak of both the dot-com bubble in 2001 and the crisis in 2009. The coefficient of inflation is significant only over the period 1999-2001 and in 2007 when inflation was increasing. The heteroskedasticity factor and the residuals always display several peaks around 2001 which tells us that at that time the ECB surprised markets while it did not during the recent crisis. A possible explanation is that from 2008 onwards the ECB aggressively intervened to curb the economic crisis also by using a communicative strategy that helped in making its policy decisions less unexpected by the economic community.

Concerning the other variables considered, only some of them are found to be able to significantly explain the conduct of monetary policy, i.e. the government bond yield spread index and the bank loans. In particular, the spread index is not significant in the first subsample but its coefficient becomes negative when the financial crisis evolved into tensions on sovereign debt markets. In the period 2007-2013 the ECB reacted also to bank loans and in particular the loans to the private sector have a positive coefficient. Overall it is possible to conclude that the second pillar of the analysis of price stability has gained importance during the crisis.

As regards the related literature, the results of this work are at odds with all the literature finding significant coefficients on both future and current inflation like Gerdesmeier and Roffia (2004) and Sauer and Sturm (2007) as over the same period I found that inflation is rarely significant. On the other hand, the results regarding the output gap show that its coefficient is almost always significant and greater than the one of inflation and its magnitude is often consistent with much of the literature which identifies it to be lower than 1. Finally, as in much of the literature I also presented evidence of a high degree of partial adjustment.

Overall it is possible to conclude that over the period 1999-2006 the ECB seems to pursue a stabilizing policy mainly towards output. Consistently with Gerlach and Lewis (2010), Gerlach (2011) and Gerlach and Lewis (2014) I found evidence of a shift in the conduct of monetary policy during the crisis as from 2008 on the ECB increased again its sensitivity towards output but it also started to track new variables like sovereign bond yield spreads and bank loans.

Appendix A. Data Description

The overall data sample goes from January 1996 to December 2013. The monetary policy reaction functions are estimated over the period January 1999 - December 2013 and the 36 observations from January 1996 to December 1998 are used to calculate the OLS values necessary to initialize the Kalman filter. Two of the regressors comes from the estimation of a VAR model starting in January 1996 and, for lack of data, the OLS values to initialize the Kalman filter are calculated in-sample.

Variables are monthly and the logarithmic transformation is applied, except for the Eonia which is taken in level. When not specified, data comes form Datastream and they are constructed in order to take into account the evolving membership of the Euro area. The dependent variable is the Euro area overnight index average (EONIA). The series is constructed by the ECB as the average of the daily EONIA rate calculated by the European Banking Federation.

Variables used as regressors are:

- the industrial output gap: it is calculated as the difference between the logarithm industrial production series (calculated by the Eurostat) and its HP filtered output trend;
- the annual growth rate of inflation: it is calculated as the 12-month logarithmic difference of the HICP series coming from the ECB;
- the annual growth rate of M3: it is calculated as the 12-month logarithmic difference of the seasonally adjusted M3 series coming from the ECB;
- the Thomson Reuters/Jefferies CRB Index: it is a commodity futures price index and it is comprised of 19 commodities sorted into 4 groups with different weightings (petroleum based products, liquid assets, highly liquid assets, diverse commodities)[12];
- the monthly changes of the real effective exchange rate: it considers 20 trade partners, it is adjusted using the CPI and it is defined such an increase indicates an appreciation of the Euro currency;
- the VIX index: it is a measure of the implied volatility of S&P 500 index options over the next 30 calendar days on the Chicago Board Options Exchange Market and it represents market's expectation of stock market volatility;
- a sovereign bond yield spread index: it is calculated as a weighted sum of government bond yields' spreads with respect to Germany of ten Euro-area countries (Austria, Belgium, Finland, France, Greece, Ireland, Italy, Netherlands, Portugal and Spain) and weights are given by the relative debt-to-GDP ratios calculated by the Eurostat;
- the annual growth rate of bank loans in the Euro area to non-financial corporations, to households and to other financial institutions: these data come from the statistics on the monetary financial institution (MFI) sector provided by the ECB[13] and the annual growth rate is calculated as the 12-month logarithmic difference.

[12] For further details see:
http://thomsonreuters.com/products_services/financial/thomson_reuters_indices/indices/commodity_indices/

[13] Further information can be found in the Manual of MFI Balance Sheet Statistics available at: http://www.ecb.europa.eu/pub/pdf/other/manualmfibalancesheetstatistics201204en.pdf

Appendix B. Estimation Procedure

Priors and Posteriors[14]

Monetary Policy Reaction Function

The complete-data likelihood of the model is:

$$L\left(y|X_t,\beta,\Sigma_\varepsilon,\sigma,\Sigma_\eta\right) = \left[\prod_{t=1}^{T}\left(2\pi\sigma_t^2\right)^{-\frac{1}{2}}\right]|\Sigma_\varepsilon|^{-\frac{T}{2}}\exp\left\{-\frac{1}{2}\sum_{t=1}^{T}\left(y_t-X_t\beta_t\right)'\left(\sigma_t\Sigma_\varepsilon\right)^{-1}\left(y_t-X_t\beta_t\right)\right\}\cdot$$
$$(2\pi)^{-\frac{T}{2}}|\Sigma_\eta|^{-\frac{T}{2}}\exp\left\{-\frac{1}{2}\sum_{t=1}^{T}\left(\beta_t-\beta_{t-1}\right)'\Sigma_\eta^{-1}\left(\beta_t-\beta_{t-1}\right)\right\} \quad (2.11)$$

where $\beta = (\beta_0, \beta_1, \ldots, \beta_T)$ and $\sigma = (\sigma_1, \ldots, \sigma_T)$.

To implement the Gibbs sampler it is necessary to derive the conditional posterior distributions from the product of the likelihood and the priors.

The parameters' priors are assumed to be independent with each other so that the joint prior is:

$$p\left(\beta,\Sigma_\varepsilon,\sigma,\Sigma_\eta\right) = p\left(\beta\right)p\left(\Sigma_\varepsilon\right)p\left(\sigma\right)p\left(\Sigma_\eta\right)$$

For the slope coefficients β_t a time-varying Minnesota prior is assumed, i.e. the coefficients follow a random walk (see Litterman (1986) for details), where errors are assumed to be normally distributed with zero mean and variance-covariance matrix Σ_η.

Furthermore, for the constant scale parameter of the error term Σ_ε a diffuse prior is assumed:

$$p\left(\Sigma_\varepsilon\right) \propto |\Sigma_\varepsilon|^{-1} \quad (2.12)$$

This corresponds to the Jeffreys prior density $|\Sigma_\varepsilon|^{-\frac{(k+1)}{2}}$ with $k = 1$ (see Jeffreys (1961) for details). The Jeffreys prior density is the limit of an inverse-Wishart distribution[15], which is a conjugate prior distribution for the covariance matrix of the multivariate normal distribution, with 1 degree of freedom and scale matrix that tends to zero.

The time-varying component of the of the variance of the error term is assumed to be distributed as

[14] Definitions and derivations in this section follow Gelman, Carlin, Stern, and Rubin (2003).

[15] The Wishart distribution is a generalization to multiple dimensions of the chi-squared distribution, or, in the case of non-integer degrees of freedom, of the gamma distribution. The relationship between the Wishart and the inverse-Wishart is that if $X \sim W(v, S)$ then $X^{-1} \sim IW\left(v, S^{-1}\right)$ where S is a symmetric and positive-definite $k \times k$ scale matrix and v are the degrees of freedom.

The probability density function of a Wishart distribution is:

$$p\left(X;v,S\right) = \left(2^{\frac{vk}{2}}\cdot\Gamma_p\left(\frac{v}{2}\right)\right)^{-1}|S|^{-\frac{v}{2}}|X|^{\frac{v-k-1}{2}}\exp\left\{-\frac{1}{2}\text{tr}\left(S^{-1}X\right)\right\},$$

where $\Gamma_p\left(\frac{v}{2}\right) = \pi^{\frac{k(k-1)}{4}}\prod_{i=1}^{k}\Gamma\left(\frac{v+1-i}{2}\right)$ is the multivariate gamma function.

a scaled inverse-χ^2 distribution with v degrees of freedom and scale parameter 1 [16]:

$$\sigma_t \sim Inv - \chi^2(v, 1) \tag{2.13}$$

The degrees of freedom are set as $v = 5$ as it is the value that ensures the maximum depart from normality for ε_t. In fact, $\varepsilon_t|\sigma_t \sim t_v(0, \Sigma_\varepsilon)$ converges in distribution to $N(0, \Sigma_\varepsilon)$ as v approaches infinity because the mean of σ_t tends to one and its variance tends to zero in the limit. Moreover for $v \leq 4$ the variance of the distribution is infinite and so $v = 5$ is the value that maximizes the prior variance but restricting it to be finite.

The variance-covariance matrix of the parameters is assumed to be distributed as an inverse-Wishart with γ degrees of freedom and scale parameter Υ:

$$\Sigma_\eta \sim IW(\gamma, \Upsilon) \tag{2.14}$$

The degrees of freedom are imposed to be equal to the sample size. The scale matrix is assumed to be equal to the OLS variance-covariance matrix of the parameters estimated on the pre-sample and it is multiplied by the sample size. This set-up allows for a greater variance in the parameters which translates into a high degree of time-variation and a better fit of the data.

Posteriors distributions for the parameters are derived from the product between the likelihood and the relative prior as they are assumed to be independent.

In particular, the full conditional posterior distribution of the constant part of the residuals' variance Σ_ε is an inverse-Wishart distribution with T degrees of freedom and scale matrix S^{-1}:

$$p(\Sigma_\varepsilon|y, X_t, \beta, \sigma, \Sigma_\eta) \quad \propto \quad |\Sigma_\varepsilon|^{-\frac{(T+1+1)}{2}} \exp\left\{-\frac{1}{2}\mathrm{tr}\left(S\Sigma_\varepsilon^{-1}\right)\right\} = IW\left(T, S^{-1}\right) \tag{2.15}$$

where: $S = \left[\sum_t (y_t - X_t\beta_t)\sigma_t^{-1}(y_t - X_t\beta_t)'\right]$.

As we are in the univariate case (Σ_ε is a scalar), the inverse-Wishart distribution degenerates into an inverse-gamma distribution with shape parameter $\alpha = \frac{T}{2}$ and scale parameter $\beta = \frac{S}{2}$.

The full conditional posterior distribution of σ_t is a scaled inverse-χ^2 distribution with $v+1$ degrees of freedom and scale matrix s_t^2:

$$p(\sigma_t|y, X_t, \beta, \Sigma_\varepsilon, \Sigma_\eta) \quad \propto \quad \sigma_t^{-\left(\frac{v+1}{2}+1\right)} \exp\left\{-\frac{(v+1)s_t^2}{2\sigma_t}\right\} = Inv - \chi^2\left(v+1, s_t^2\right) \tag{2.16}$$

where: $s_t^2 = \left[\frac{v}{v+1} + \frac{(y_t - X_t\beta_t)'\Sigma_\varepsilon^{-1}(y_t - X_t\beta_t)}{v+1}\right]$.

In general, to obtain a draw θ from an $Inv - \chi^2\left(v, s_t^2\right)$ distribution it is necessary to draw x from a χ^2distribution with v degrees of freedom and then let $\theta = \frac{vs_t^2}{x}$.

The full conditional posterior distribution of Σ_η is an an inverse-Wishart distribution with $\bar{\gamma}$ degrees

[16] The probability density function of a scaled inverse-χ^2 distribution with v degrees of freedom and scale parameter τ^2 is:

$$p\left(x; v, \tau^2\right) = \frac{\left(\frac{v}{2}\right)^{\frac{v}{2}}}{\Gamma\left(\frac{v}{2}\right)}\tau^2 x^{-\left(\frac{v}{2}+1\right)} \exp\left\{-\frac{v\tau^2}{2x}\right\},$$

which is equivalent to an inverse-gamma distribution with shape parameter $\frac{v}{2}$ and scale parameter $\frac{v\tau^2}{2}$.

of freedom and scale matrix $\bar{\Upsilon}$:

$$p\left(\Sigma_\eta|y,X_t,\beta,\Sigma_\varepsilon,\sigma\right) \propto \left|\Sigma_\eta\right|^{-\frac{(\bar{\gamma}+n+1)}{2}}\cdot\exp\left\{-\frac{1}{2}\mathrm{tr}\left(\bar{\Upsilon}\Sigma_\eta^{-1}\right)\right\}=IW\left(\bar{\gamma},\bar{\Upsilon}^{-1}\right) \tag{2.17}$$

where: $\bar{\gamma}=\gamma+T$ and $\bar{\Upsilon}=\left[\Upsilon+\sum_t\left(\beta_t-\beta_{t-1}\right)\left(\beta_t-\beta_{t-1}\right)'\right]$.

The derivation of the joint conditional posterior distribution of the state variables deserves a more extensive comment and the procedure is analysed in the next section.

VAR Model

The complete-data likelihood of the model is:

$$\begin{aligned} L\left(Z|X_t,\theta,\Sigma_w,\omega,\Sigma_v\right) &= \left[\prod_{t=1}^{T}\left(2\pi\omega_t^2\right)^{-\frac{1}{2}}\right]\left|\Sigma_w\right|^{-\frac{T}{2}}\exp\left\{-\frac{1}{2}\sum_{t=1}^{T}\left(Z_t-X_t\theta_t\right)'\left(\omega_t\Sigma_w\right)^{-1}\left(Z_t-X_t\theta_t\right)\right\}\cdot \\ &\quad \left(2\pi\right)^{-\frac{T}{2}}\left|\Sigma_v\right|^{-\frac{T}{2}}\exp\left\{-\frac{1}{2}\sum_{t=1}^{T}\left(\theta_t-\theta_{t-1}\right)'\Sigma_\eta^{-1}\left(\theta_t-\theta_{t-1}\right)\right\} \end{aligned} \tag{2.18}$$

where $\theta=\left(\theta_0,\theta_1,\ldots,\theta_T\right)$.

As before the parameters' priors are assumed to be independent with each other so that the joint prior is:

$$p\left(\theta,\Sigma_w,\omega,\Sigma_v\right)=p\left(\theta\right)p\left(\Sigma_w\right)p\left(\omega\right)p\left(\Sigma_v\right)$$

For the slope coefficients θ_t a time-varying Minnesota prior is assumed. Errors are assumed to be normally distributed with zero mean and variance-covariance matrix Σ_v.

For the variance-covariance matrix of the error term in the measurement equation a diffuse prior is assumed:

$$p\left(\Sigma_w\right)\propto\left|\Sigma_w\right|^{-\frac{2+1}{2}} \tag{2.19}$$

The time-varying component of the variance of the error term is assumed to be distributed as a scaled inverse-χ^2 distribution with v degrees of freedom and scale parameter 1:

$$\omega_t\sim Inv-\chi^2\left(v,1\right) \tag{2.20}$$

As before, to ensure the maximum degree of departure from normality, v is set equal to 5.

The variance-covariance matrix of the parameters is assumed to be distributed as an inverse-Wishart with ψ degrees of freedom and scale parameter Ψ:

$$\Sigma_v\sim IW\left(\psi,\Psi\right) \tag{2.21}$$

As before the degrees of freedom are imposed to be equal to the sample size and the scale matrix is assumed to be equal to the OLS variance-covariance matrix of the parameters estimated on the pre-sample multiplied by the sample size.

Posteriors distributions for the parameters are derived from the product between the likelihood and the relative priors as they are assumed to be independent.

In particular, the full conditional posterior distribution of the residuals' variance Σ_w is an inverse-Wishart distribution with T degrees of freedom and scale matrix $\bar{\Phi}^{-1}$:

$$p\left(\Sigma_v|Z,X_t,\theta,\omega,\Sigma_v\right) \quad \propto \quad |\Sigma_w|^{-\frac{(T+2+1)}{2}} \exp\left\{-\frac{1}{2}\operatorname{tr}\left(S\Sigma_w^{-1}\right)\right\} = IW\left(T,S^{-1}\right) \tag{2.22}$$

where: $S = \left[\sum_t \left(Z_t - X_t\theta_t\right)\omega_t^{-1}\left(Z_t - X_t\theta_t\right)'\right]$.

The full conditional posterior distribution of ω_t is an inverse-χ^2 distribution with $v+n$ degrees of freedom and scale matrix s_t^2:

$$p\left(\omega_t|Z,X_t,\theta,\Sigma_w,\Sigma_v\right) \quad \propto \quad \omega_t^{-\left(\frac{v+n}{2}+1\right)} \exp\left\{-\frac{(v+n)\,s_t^2}{2\omega_t}\right\} = Inv-\chi^2\left(v+2,s_t^2\right) \tag{2.23}$$

where n is the number of dependent variables in the VAR and $s_t^2 = \left[\frac{v}{v+2} + \frac{(Z_t-X_t\theta_t)'\Sigma_w^{-1}(Z_t-X_t\theta_t)}{v+2}\right]$.

The full conditional posterior distribution of Σ_v is an inverse-Wishart distribution with $\bar{\psi}$ degrees of freedom and scale matrix $\bar{\Psi}^{-1}$:

$$p\left(\Sigma_v|Z,X_t,\theta,\Sigma_\epsilon\right) \quad \propto \quad |\Sigma_v|^{-\frac{(\bar{\psi}+n+1)}{2}} \cdot \exp\left\{-\frac{1}{2}\operatorname{tr}\left(\bar{\Psi}\Sigma_v^{-1}\right)\right\} = IW\left(\bar{\psi},\bar{\Psi}^{-1}\right) \tag{2.24}$$

where: $\bar{\psi} = \psi + T$ and $\bar{\Psi} = \left[\Psi + \sum_t \left(\theta_t - \theta_{t-1}\right)\left(\theta_t - \theta_{t-1}\right)'\right]$.

The following section derives the procedure to estimate the state variables.

Procedure to estimate the state variables

The procedure to estimate the systems of equations 2.6 - 2.7 and 2.9 - 2.10 is based on Carter and Kohn (1994) and Chib and Greenberg (1995).

Here β indicates a general vector of latent factors and this procedure is valid for any system written in state-space form.

A state-space model has the following structure:

$$\begin{aligned}
(y_t|\beta_t) &\sim p\left(y_t|\beta_t, y_{1:t-1},\varphi\right)\\
(\beta_t|\beta_{t-1}) &\sim p\left(\beta_t|\beta_{t-1}, y_{1:t-1},\varphi\right)\\
\beta_0 &\sim p\left(\beta_0|\varphi\right)\\
\psi &\sim p\left(\varphi\right)
\end{aligned}$$

Here φ is the vector of hyperparameters, $p\left(y_t|\beta_t, y_{1:t-1},\varphi\right)$ is the measurement density, $p\left(\beta_t|\beta_{t-1}, y_{1:t-1},\varphi\right)$ is the transition density, $p\left(\beta_0|\varphi\right)$ is the initial distribution, i.e. the prior distribution on the initial state of the system, and $p\left(\varphi\right)$ is the prior distribution of the hyperparameters.

In a Bayesian setting, estimates for the states and the parameters are obtained as the mean of the joint posterior density of the state and parameters vectors $p\left(\beta_{0:T},\varphi|y_{1:T}\right)$. This can be done by applying MCMC methods when it is not possible to analytically evaluate the posterior mean.

The easiest solution to simulate the posterior distribution is to implement a single-move Gibbs sampler. This algorithm generates the states one at a time conditioned on the neighbouring states, i.e.

sampling β_t from its conditional distribution which does not contain β_t, $p\left(\beta_t|\beta_{1:t-1}, \beta_{t+1:T}, y_{1:T}\right)$. The drawback of this algorithm is that the outputs of the Gibbs sampler are highly correlated. As a matter of fact the states of Markov chain are highly correlated to the neighbouring ones and the algorithm slowly explore the state-space and will slowly converge to the posterior distribution.

To solve the autocorrelation problem, when the model is linear and gaussian, it is possible to apply the multi-move Gibbs sampler which generates simultaneously all the state vectors from the joint distribution $p\left(\beta_{0:T}|y_{1:T}, \varphi\right)$ using analytical filtering and smoothing relations, as proposed by Carter and Kohn (1994). For this purpose the Kalman filter and smoother can be applied.

Therefore the objective is to simulate the sequence of parameters vectors $\{\beta_t\}$ given the whole set of observations of the dependent variable $y_{1:T}$ and the remaining parameters φ .

The first step is to write the joint smoothing density of β in reverse-time order as in Chib and Greenberg (1995) and in Carter and Kohn (1994):

$$\begin{aligned}
p\left(\beta|y_{1:T}, \varphi\right) &= p\left(\beta_T|y_{1:T}, \varphi\right) \cdot p\left(\beta_{T-1}|\beta_T, y_{1:T}, \varphi\right) \cdot \ldots \cdot p\left(\beta_1|\beta_{2:T}, y_{1:T}, \varphi\right) \\
&= p\left(\beta_T|y_{1:T}, \varphi\right) \cdot p\left(\beta_{T-1}|\beta_T, y_{1:T}, \varphi\right) \cdot \ldots \cdot p\left(\beta_1|\beta_2, y_{1:T}, \varphi\right) \\
&= p\left(\beta_T|y_{1:T}, \varphi\right) \cdot \prod_{t=1}^{T-1} p\left(\beta_t|\beta_{t+1}, y_{1:T}, \varphi\right) \\
&= p\left(\beta_T|y_{1:T}, \varphi\right) \cdot \prod_{t=1}^{T-1} p\left(\beta_t|\beta_{t+1}, y_{1:t}, \varphi\right)
\end{aligned} \tag{2.25}$$

Following Carter and Kohn (1994), the second equality comes from the Markov property of the process $\{\beta_t\}$, i.e. $\beta_{t+i}|\beta_t$ is independent of any previous realization β_{t-j}, while the last equality comes from the Markov structure of the problem, i.e. conditional on β_t and $y_{1:t-1}$, β_{t+1} and $y_{t:T}$ carries no information about β_{t-1} beyond that contained in β_t and $y_{1:t-1}$.

This last observation can be proved by applying the Bayes theorem for the three-variable case[17] to the generic distribution $p\left(\beta_t|\beta_{t+1}, y_{1:T}, \varphi\right)$:

$$\begin{aligned}
p\left(\beta_t|\beta_{t+1}, y_{1:T}, \varphi\right) &= p\left(\beta_t|\beta_{t+1}, y_{1:t}, y_{t+1:T}, \varphi\right) \\
&= \frac{p\left(y_{t+1:T}|\beta_t, \beta_{t+1}, y_{1:t}, \varphi\right) \cdot p\left(\beta_t|\beta_{t+1}, y_{1:t}, \varphi\right)}{p\left(y_{t+1:T}|\beta_{t+1}, y_{1:t}, \varphi\right)} \\
&= \frac{p\left(y_{t+1:T}|\beta_{t+1}, y_{1:t}, \varphi\right) \cdot p\left(\beta_t|\beta_{t+1}, y_{1:t}, \psi\right)}{p\left(y_{t+1:T}|\beta_{t+1}, y_{1:t}, \varphi\right)} \\
&= p\left(\beta_t|\beta_{t+1}, y_{1:t}, \varphi\right)
\end{aligned} \tag{2.26}$$

So, to obtain a draw from the joint distribution, first draw $\tilde{\beta}_T$ from $p\left(\beta_T|y_{1:T}, \varphi\right)$, then draw $\tilde{\beta}_{T-1}$ from $p\left(\beta_{T-1}|\beta_T, y_{1:T-1}, \varphi\right)$ and so on until $\tilde{\beta}_1$ is drawn from $p\left(\beta_1|\beta_2, y_1, \varphi\right)$. So, practically, the only thing needed for this algorithm is the distribution of the generic term $p\left(\beta_t|\beta_{t+1}, y_{1:t}, \varphi\right)$.

[17] The Bayes theorem for three variables states that:

$$P\left(A|B,C\right) = \frac{P\left(B|A,C\right) \cdot P\left(A|C\right)}{P\left(B|C\right)}$$

This can be easily derived by using the law of conditional expectations. As a matter of fact one can combine $P\left(A|B,C\right) = \frac{P(A,B,C)}{P(B,C)}$ and $P\left(B|A,C\right) = \frac{P(A,B,C)}{P(A,C)}$ to obtain: $P\left(A|B,C\right) = \frac{P(B|A,C) \cdot P(A,C)}{P(B,C)}$. Then the last step is to substitute $P\left(A,C\right) = P\left(A|C\right)P\left(C\right)$ and $P\left(B,C\right) = P\left(B|C\right)P\left(C\right)$.

This distribution can be found by applying the Bayes theorem so that:

$$\begin{aligned} p\left(\beta_t|\beta_{t+1}, y_{1:t}, \varphi\right) &= \frac{p\left(\beta_{t+1}|\beta_t, y_{1:t}, \varphi\right) \cdot p\left(\beta_t|y_{1:t}, \varphi\right)}{p\left(\beta_{t+1}|y_{1:t}, \psi\right)} \\ &\propto p\left(\beta_{t+1}|\beta_t, y_{1:t}, \varphi\right) \cdot p\left(\beta_t|y_{1:t}, \varphi\right) \end{aligned} \tag{2.27}$$

This is true as the denominator is a normalizing constant, i.e. it does not contains β_t.

These two results can be obtained from the Kalman filter as $\beta_t|y_{1:t}, \varphi \sim N\left(\hat{\beta}_{t|t}, P_{t|t}\right)$.

Here $\hat{\beta}_{t|s} \equiv \hat{\mathbb{E}}\left[\beta_t|y_{1:s}, \varphi\right]$ and $P_{t|s} = \operatorname{cov}\left(\beta_t|y_{1:s}, \varphi\right)$ for $s \leq t \leq T$ and from the Kalman filter recursion:

$$\hat{\beta}_{t|t} = \hat{\beta}_{t|t-1} + K_t\left(y_t - X\hat{\beta}_{t|t-1}\right) \tag{2.28}$$

$$P_{t|t} = \left(I - K_t X\right) P_{t|t-1} \tag{2.29}$$

where $\hat{\beta}_{t|t-1} = \hat{\beta}_{t-1|t-1}$, $P_{t|t-1} = P_{t-1|t-1} + \Sigma_\eta$, $K_t = \frac{P_{t|t-1}X'}{Z_{t|t-1}}$ and $Z_{t|t-1} = XP_{t|t-1}X' + \sigma_t\Sigma_\varepsilon$.

These results must be substituted in equation 2.27 to find that $\beta_t|\beta_{t+1}, y_{1:t}, \varphi \sim N\left(\hat{\beta}_{t|t+1}, P_{t|t+1}\right)$.

In particular, the algorithm uses the last elements of the recursion, $\hat{\beta}_{T|T}$ and $P_{T|T}$, to make a draw for β_T as $\beta_T \sim N\left(\hat{\beta}_{T|T}, P_{T|T}\right)$, i.e. they are the mean and the variance of the normal distribution from which β_T is drawn. The draw of β_T and the output of the filter are then used for the first step of the backward recursion to obtain $\hat{\beta}_{T-1|T}$ and $P_{T-1|T}$. As before these two elements are necessary to make a draw for β_{T-1} because $\beta_{T-1} \sim N\left(\hat{\beta}_{T-1|T}, P_{T-1|T}\right)$. The backward recursion continues until time zero. For a generic time t, the updating formulas of the backward recursion are:

$$\hat{\beta}_{t|t+1} = \hat{\beta}_{t|t} + M_t\left(\beta_{t+1} - \hat{\beta}_{t+1|t}\right) \tag{2.30}$$

$$P_{t|t+1} = P_{t|t} - M_t P_{t+1|t} M_t' \tag{2.31}$$

where $M_t = P_{t|t}P_{t+1|t}^{-1}$.

The procedure to estimate the state vector is summarized in algorithm 2.1.

Algorithm 2.1 Gibbs sampler for the state vector

Simulate the state vectors by sampling from $p\left(\beta|y_{1:T}, \psi\right)$ in reverse time order by means of the recursive factorization of the smoothing density:

- $\beta_T \sim p\left(\beta_T|y_{1:T}, \psi\right) = N\left(\hat{\beta}_{T|T}, P_{T|T}\right)$
- $\beta_{T-1} \sim p\left(\beta_{T-1}|\beta_T, y_{1:T-1}, \psi\right) = N\left(\hat{\beta}_{T-1|T}, P_{T-1|T}\right)$
- ...
- $\beta_t \sim p\left(\beta_t|\beta_{t+1}, y_{1:t}, \psi\right) = N\left(\hat{\beta}_{t|t+1}, P_{t|t+1}\right)$
- ...
- $\beta_1 \sim p\left(\beta_1|\beta_2, y_1, \psi\right) = N\left(\hat{\beta}_{1|2}, P_{1|2}\right)$

Kalman Filter

The Kalman filter is a tool to deal with discrete linear and gaussian dynamical systems by state-space modelling. When a system is modelled in a state-space form, the assumption is that its development over time is determined by an unobserved series of vectors to whom are associated a series of observations. The objective of the Kalman filter is to update the knowledge of the system each time a new observation y_t is brought in. So it consists in an iterative procedure in two steps, forecast and update, that allows to calculate linear least squares forecasts of the state vector on the basis of data observed through date t. Since all distributions are normal, joint conditional distributions of one set of observations given another set are also normal.

The Kalman filter is applied to the the model described in equations 2.6 - 2.7 to obtain the elements necessary to run the Gibbs sampler.

Forecast The forecast step allows to obtain the distribution of β_t given the measurement up to $t-1$: $\beta_t|y_{1:t-1} \sim N\left(\hat{\beta}_{t|t-1}, P_{t|t-1}\right)$.

The forecast of the state vector coincides with the expected value of the distribution and it is: $\hat{\beta}_{t|t-1} \equiv \mathbb{E}\left[\beta_t|y_{1:t-1}\right] = \mathbb{E}\left[\beta_{t-1}+\eta_t|y_{1:t-1}\right] = \hat{\beta}_{t-1|t-1}$.

The variance of the distribution is: $P_{t|t-1} = \text{Var}\left(\beta_t|y_{1:t-1}\right) = \text{Var}\left(\beta_{t-1}+\eta_t|y_{1:t-1}\right) = P_{t-1|t-1}+\Sigma_\eta$. It is also possible to prove that this quantity coincides with the mean squared error of the forecast.

Given the forecast of the coefficients' vector it is possible to obtain the distribution of the data given the state: $y_t|\beta_t, y_{1:t-1} \sim N\left(\hat{y}_{t|t-1}, V_{t|t-1}\right)$.

The expected value of this distribution, which is also the forecast of the measurement equation, is: $\hat{y}_{t|t-1} = X\hat{\mathbb{E}}\left[\beta_t|y_{1:t-1}\right] = X\hat{\beta}_{t|t-1}$.

The variance of the distribution is: $V_{t|t-1} = \text{Var}\left(X\hat{\beta}_{t|t-1}+\varepsilon_t\right) = XP_{t|t-1}X' + \sigma_t\Sigma_\varepsilon$.

The forecast error is: $y_t - \hat{y}_{t|t-1} = X\left(\beta_t - \hat{\beta}_{t|t-1}\right) + \varepsilon_t$.

The mean squared error of this forecast is: $Z_{t|t-1} = XP_{t|t-1}X' + \sigma_t\Sigma_\varepsilon$.

Update From the update step I obtain the elements to use in the Gibbs sampler, i.e. the parameters of the distribution $\beta_t|y_{1:t} \sim N\left(\hat{\beta}_{t|t}, P_{t|t}\right)$:

$$\begin{aligned}\hat{\beta}_{t|t} &= \hat{\beta}_{t|t-1} + \frac{P_{t|t-1}X'}{Z_{t|t-1}}\left(y_t - \hat{y}_{t|t-1}\right)\\ &= \hat{\beta}_{t|t-1} + K_t\left(y_t - X\hat{\beta}_{t|t-1}\right)\end{aligned} \tag{2.32}$$

$$P_{t|t} = \left(I - K_tX\right)P_{t|t-1} \tag{2.33}$$

Then the procedure continues with the next iteration that allows to obtain the distribution of β_{t+1} given the measurement up to t: $\beta_{t+1}|y_{1:t} \sim N\left(\hat{\beta}_{t+1|t}, P_{t+1|t}\right)$.

The forecast of the state vector is:

$$\hat{\beta}_{t+1|t} = \hat{\beta}_{t|t-1} + K_t\left(y_t - X\hat{\beta}_{t|t-1}\right) \tag{2.34}$$

The mean squared error of this forecast is: $P_{t+1|t} = P_{t|t} + \Sigma_\eta$.

Kalman Smoother

The Kalman smoother is a procedure to estimate the latent variable of a linear dynamical system using the measurements from a fixed interval. Usually the estimation considers all the information contained in data, i.e. the full set of observations $y_{1:T}$. Therefore this is a post-processing procedure, i.e. it can be run once after the regular Kalman filter algorithm, and it is based on a backward recursion.

The main equations of this procedure are the smoothed states of t-th time step and the corresponding state error covariance matrix:

$$\hat{\beta}_{t|t+1} = \hat{\beta}_{t|t} + M_t \left(\beta_{t+1} - \hat{\beta}_{t+1|t}\right) \tag{2.35}$$

$$P_{t|t+1} = P_{t|t} - M_t P_{t+1|t} M_t' \tag{2.36}$$

where $M_t = P_{t|t} P_{t+1|t}^{-1}$.

So, in other words, the objective of the Kalman smoother is to compute the distribution of $\beta_t|y_{1:T}$ given the distribution of $\beta_{t+1}|y_{1:T} \sim N\left(\hat{\beta}_{t+1|T}, P_{t+1|T}\right)$.

This distribution can be derived according to the following steps.

1. Computation of the joint distribution $p\left(\beta_t|y_{1:t}, \beta_{t+1}|\beta_t\right)$ (which is the distribution in equation 2.27) where, for seek of simplicity, I denote the distribution of $\beta_t|y_{1:t}$ as $\beta_{t|t} = N\left(\hat{\beta}_{t|t}, P_{t|t}\right)$ and the distribution of $\beta_{t+1}|\beta_t$ as $\beta_{t+1|t} = N\left(\hat{\beta}_{t+1|t}, P_{t+1|t}\right)$, :

$$\begin{aligned} \begin{pmatrix} \beta_t|y_{1:t} \\ \beta_{t+1}|\beta_t \end{pmatrix} &\sim N\left(\begin{bmatrix} \mathbb{E}\left(\beta_{t|t}\right) \\ \mathbb{E}\left(\beta_{t+1|t}\right) \end{bmatrix} \begin{bmatrix} Var\left(\beta_{t|t}\right) & Cov\left(\beta_{t|t}; \beta_{t+1|t}\right) \\ Cov\left(\beta_{t+1|t}; \beta_{t|t}\right) & Var\left(\beta_{t+1|t}\right) \end{bmatrix}\right) \\ &= N\left(\begin{bmatrix} \hat{\beta}_{t|t} \\ \hat{\beta}_{t+1|t} \end{bmatrix} \begin{bmatrix} P_{t|t} & P_{t|t} \\ P_{t|t} & P_{t+1|t} \end{bmatrix}\right) = p\left(\beta_{t|t}, \beta_{t+1|t}\right) \end{aligned} \tag{2.37}$$

where:

$$\begin{aligned} Cov\left(\beta_{t|t}, \beta_{t+1|t}\right) &= Cov\left(\beta_{t|t}, \beta_{t|t} + \eta_{t+1}\right) \\ &= Cov\left(\beta_{t|t}, \beta_{t|t}\right) + Cov\left(\beta_{t|t}, \eta_{t+1}\right) \\ &= Var\left(\beta_{t|t}\right) = P_{t|t} \end{aligned} \tag{2.38}$$

2. Computation of the conditional distribution $p\left(\beta_{t|t}|\beta_{t+1|t}\right)$ given a specific value of β_{t+1}, i.e. the

distribution of $p(\beta_t|\beta_{t+1}, y_{1:t})$[18]:

$$\begin{aligned} p(\beta_t|\beta_{t+1}, y_{1:t}) &\sim N\left(\mathbb{E}(\beta_t|\beta_{t+1}, y_{1:t}), Var(\beta_t|\beta_{t+1}, y_{1:t})\right) & (2.39)\\ \mathbb{E}(\beta_t|\beta_{t+1}, y_{1:t}) &= \hat{\beta}_{t|t} + M_t\left(\beta_{t+1} - \hat{\beta}_{t+1|t}\right) & (2.40)\\ Var(\beta_t|\beta_{t+1}, y_{1:t}) &= P_{t|t} - M_t P_{t+1|t} M_t' & (2.41)\end{aligned}$$

where $M_t = P_{t|t} P_{t+1|t}^{-1}$.

However the value β_{t+1} is unknown and we only have its distribution $\beta_{t+1}|y_{1:T} \sim \beta_{t+1|T} = N\left(\hat{\beta}_{t+1|T}, P_{t+1|T}\right)$.

3. Computation of the distribution of $\beta_t|y_{1:T}$ which is $\beta_{t|T} = N\left(\mathbb{E}\left(\beta_{t|T}\right) = \hat{\beta}_{t|T}, Var\left(\beta_{t|T}\right) = P_{t|T}\right)$.

   This distribution can be derived from $p\left(\beta_{t|t}|\beta_{t+1|t}\right)$ by unconditioning on $\beta_{t+1} \sim \beta_{t+1|T} = N\left(\hat{\beta}_{t+1|T}, P_{t+1|T}\right)$ so that $\beta_{t+1|t} = \beta_{t+1|T}$, and using the law of total expectation and of total variance[19].

   From step 2 we have that:

$$\begin{aligned} \mathbb{E}\left(\beta_{t|t}|\beta_{t+1|t} = \beta_{t+1|T}\right) &= \hat{\beta}_{t|t} + M_t\left(\beta_{t+1|T} - \hat{\beta}_{t+1|t}\right) & (2.42)\\ Var\left(\beta_{t|t}|\beta_{t+1|t} = \beta_{t+1|T}\right) &= P_{t|t} - M_t P_{t+1|t} M_t' & (2.43)\end{aligned}$$

   So that:

$$\begin{aligned} \mathbb{E}\left(\beta_{t|T}\right) &= \mathbb{E}\left(\mathbb{E}\left(\beta_{t|t}|\beta_{t+1|T}\right)\right)\\ &= \mathbb{E}\left(\hat{\beta}_{t|t} + M_t\left(\beta_{t+1|T} - \hat{\beta}_{t+1|t}\right)\right)\\ &= \hat{\beta}_{t|t} + M_t\left(\hat{\beta}_{t+1|T} - \hat{\beta}_{t+1|t}\right) = \hat{\beta}_{t|T} & (2.44)\end{aligned}$$

$$\begin{aligned} Var\left(\beta_{t|T}\right) &= \mathbb{E}\left(Var\left(\beta_{t|t}|\beta_{t+1|T}\right)\right) + Var\left(\mathbb{E}\left(\beta_{t|t}|\beta_{t+1|T}\right)\right)\\ &= \mathbb{E}\left(P_{t|t} - M_t P_{t+1|t} M_t'\right) + Var\left(\hat{\beta}_{t|t} + M_t\left(\beta_{t+1|T} - \hat{\beta}_{t+1|t}\right)\right)\\ &= P_{t|t} - M_t P_{t+1|t} M_t' + M_t P_{t+1|T} M_t'\\ &= P_{t|t} + M_t\left(P_{t+1|T} - P_{t+1|t}\right) M_t' = P_{t|T} & (2.45)\end{aligned}$$

[18] This result comes from standard multivariate normal regression theory. As a matter of fact, given a bivariate normal distribution $\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \sim N\left(\begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}\begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix}\right)$, the conditional distribution of X_1 given X_2 is also normally distributed as: $p(X_1|X_2 = x_2) = N\left(\mu_1 + \Sigma_{12}\Sigma_{22}^{-1}(X_2 - \mu_2), \Sigma_{11} - \Sigma_{12}\Sigma_{22}^{-1}\Sigma_{21}\right)$. These formulas are applied to the joint distribution defined in equation 2.37.

[19] The law of total expectation (or law of iterated expectation) states that if X is an integrable random variable (i.e., a random variable satisfying $\mathbb{E}(|X|) < \infty$) and Y is any random variable, not necessarily integrable, on the same probability space, then: $\mathbb{E}(X) = \mathbb{E}(\mathbb{E}(X|Y))$. The law of total variance (or variance decomposition formula) states that, if X and Y are random variables on the same probability space and the variance of X is finite: $Var(X) = \mathbb{E}(Var(X|Y)) + Var(\mathbb{E}(X|Y))$.

Gibbs Sampler

Here the Gibbs sampler to obtain the marginal posterior distributions of the parameters runs iteratively through the conditional distributions 2.15, 2.16, 2.17 and algorithm 2.1 for 20000 times and the first 5000 iterations are discarded. Then, to correct for autocorrelation in draws, only one draw each three is retained so that posterior distributions are made up of 5000 draws. The only thing needed to initialize the procedure are the initial states of the variables which are taken from the OLS estimation of the monetary policy reaction function over the period from January 1997 - December 1998.

Convergence is checked by using the Matlab code for CODA[20] containing convergence diagnostics modelled after S-Plus CODA. The function computes diagnostics based on Raftery and Lewis (1992) and Geweke (1992).

[20]This code has been written by J.P. LeSage and can be freely downloaded from the website www.spatial-econometrics.com.

Appendix C. Simulation Exercise

Simulation Exercise

It is necessary that the Matlab code can capture the real value of parameters. To check if this property is met I constructed an artificial dataset by generating six variables to use as regressors, six time-varying coefficients and the dependent variable.

The size of my artificial sample is 180 observations. Regressors are generated from normal distributions with different means and unit variance. Coefficients are assumed to be constant along the first 100 observations and then to switch of 0.5 from observation 101 on. The dependent variable is then constructed as the product between regressors and coefficients. Details about the artificial dataset are summarized in table 2.2.

Table 2.2: **Artificial dataset**

Regressors	
$X_1 \sim N(1,1)$	$X_4 \sim N(0.3,1)$
$X_2 \sim N(-2,1)$	$X_5 \sim N(0.2,1)$
$X_3 \sim N(0.5,1)$	$X_6 \sim N(1.3,1)$
Coefficients	
From observation 1 to 100:	From observation 101 to 168:
$\beta_1 = 1$	$\beta_1 = 1.5$
$\beta_2 = -0.5$	$\beta_2 = 0$
$\beta_3 = 3$	$\beta_3 = 3.5$
$\beta_4 = -1.5$	$\beta_4 = -1$
$\beta_5 = 0.4$	$\beta_5 = 0.9$
$\beta_6 = -0.2$	$\beta_6 = 0.3$

The dependent variables and the set of regressors are put in the Gibbs sampler to verify whether the algorithm is able to capture the true values of parameters. The state variables are initialized at zero and the number of simulation is 20000. Only the last 15000 draws are used for posterior inference.

The results of the simulation exercise are displayed in figure 2.18 which shows the posterior means of parameters through time. The first thing to notice is that the Gibbs sampler is able to retrieve the true parameters' value for most of the times. Deviations from the true value happen at the beginning of the time period and around the switch date. These results due to the fact that the Kalman filter and smoother are recursive algorithms that cannot immediately capture jumps but adjust only gradually.

Convergence is checked by both graphical analysis and convergence diagnostics. Figure 2.19 displays the cumulative average of the time-varying parameters at selected times. The choice of the times is arbitrary and aims at showing that parameters seem to converge all along the time window and, in particular, that the empirical cumulative average of the simulations seems to stabilize after a limited number of draws. The analysis of these figures and further graphical inspections justifies a burn-in size of 5000 draws as from then on cumulative average fluctuates around the fourth decimal. Moreover the sample autocorrelation shows that draws are not correlated and so no thinning is needed.

The convergence diagnostics considered are those of Raftery and Lewis (1992) and Geweke (1992). Table 2.3 shows a summary of the Raftery and Lewis (1992) statistics for the estimated parameters on the entire set of draws. As a matter of fact, the inputs to calculate these statistics are all the simulated values for all the parameters which are 180 for each β. As the statistics are the same through times for each parameter, I only reported them once. I perform the diagnostics for three quantiles of the posterior distributions: 0.16, 0.5 and 0.84. The imposed level of accuracy is 0.01 and the related probability is 0.95 which are standard values for these parameters.

Results show that convergence is achieved, no thinning is needed as draws are not autocorrelated and that the size of my burn-in and of the posterior sample are sufficient to estimate the posterior quantiles with the desired level of accuracy.

As regards Geweke diagnostics, the relative numerical efficiency (RNE) is constructed as the ratio between the variance of iid draws from the posterior distribution and the empirical spectral density and it therefore represents the number of draws that would be required to produce the same numerical accuracy if the draws had been made from an iid sample drawn directly from the posterior distribution: a value lower than one indicates that it is necessary to increase the number of draws while a value bigger than one indicates that the same numerical accuracy could be reached with less draws. The RNE statistics should ideally be close to one while the NSE should be as close as possible to zero. Table 2.4 shows that these requirements are met as it reports values of these statistics for the time-varying parameters considering the entire set of draws. The RNE is equal to one for each parameter in each time while for NSE the lowest and the highest value are reported and both are close to zero. Figure 2.20 displays the p-value of the test for the equality of the means of the first 20% of the draws and the last 50% of the entire set of draws. The test is performed under the assumption that draws are iid and also considering draws as autocorrelated and uses 15% autocovariance tapered estimates. The null hypothesis of the test is that the two means are not statistically different that would signal that the algorithm has reached convergence. The null hypothesis is rejected for p-values lower than 0.05. This is the case only for very few parameters which indicates that some initial draws should be discarded.

Figure 2.18: **Posterior means of the coefficient states**

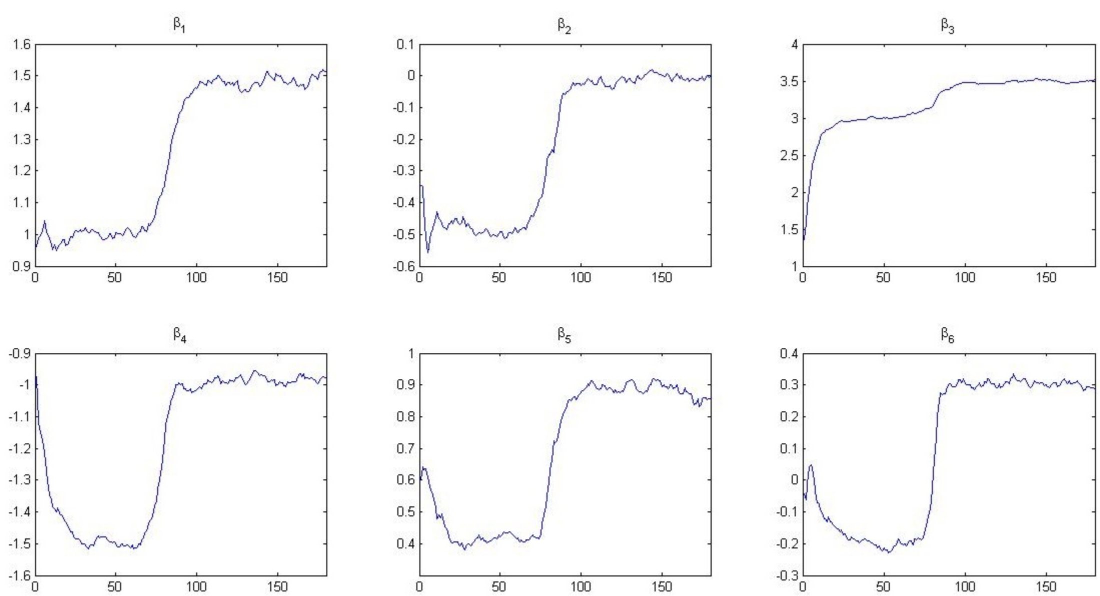


Figure 2.19: **Cumulative average of time-varying parameters for selected times**

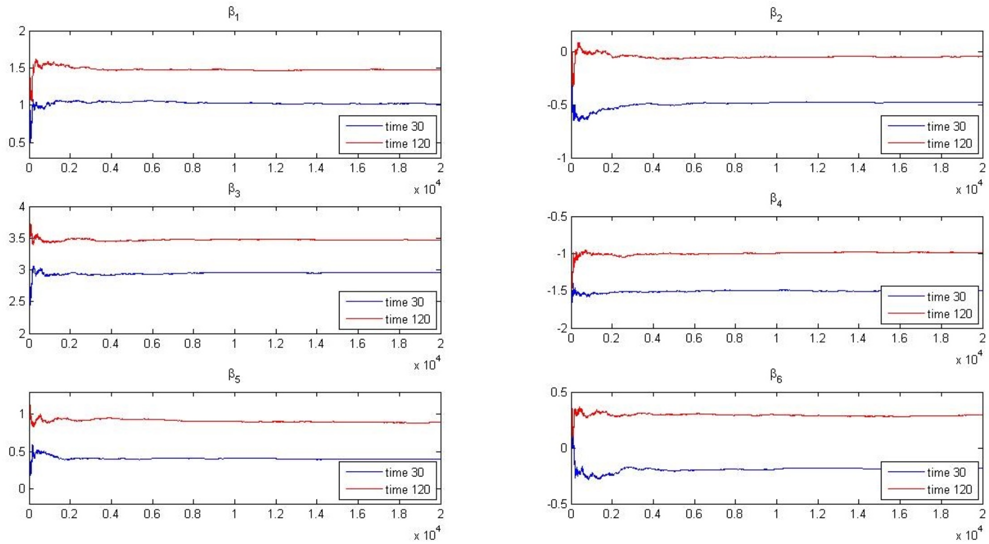


Table 2.3: **Raftery and Lewis (1992) convergence diagnostics for the coefficients**

Parameter	β_1			β_2		
Quantile	0.16	0.5	0.84	0.16	0.5	0.84
Thin	1	1	1	1	1	1
Burn-in	2	2	2	2	2	1
Total	5294	9760	5341	5266	9387	5151
Nmin	5163	9604	5163	5163	9604	5163
I-stat	1.025	1.016	1.034	1.020	0.977	0.998

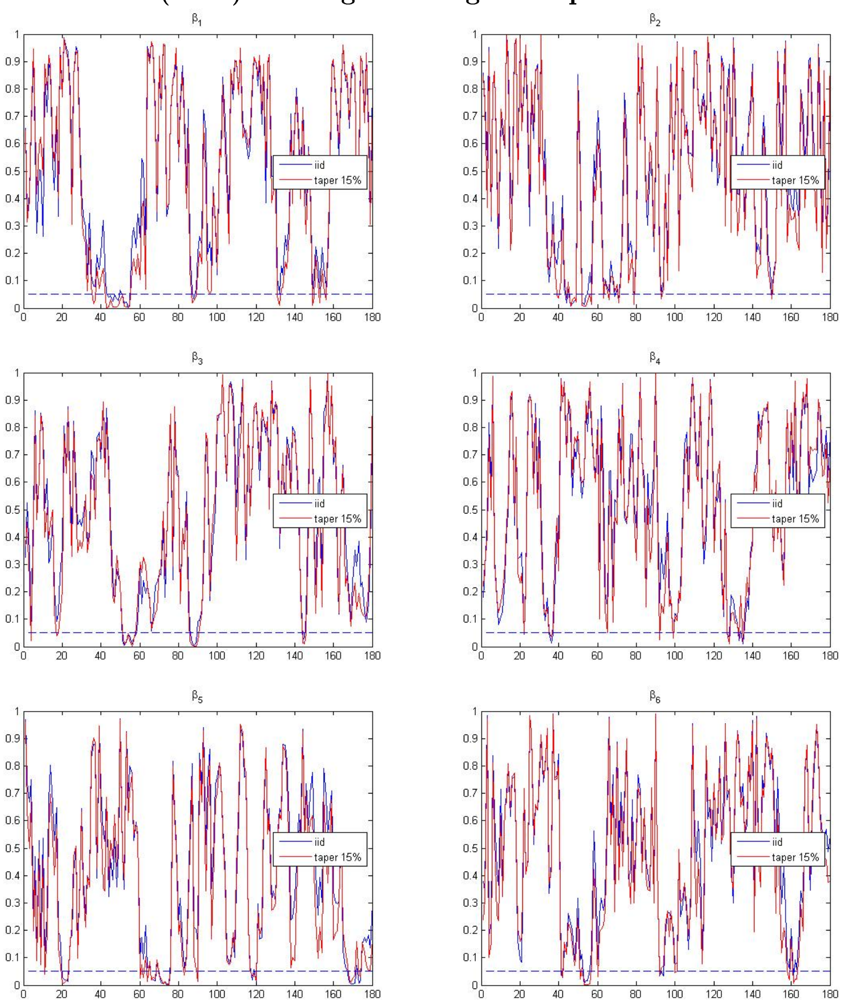
Parameter	β_3			β_4		
Quantile	0.16	0.5	0.84	0.16	0.5	0.84
Thin	1	1	1	1	1	1
Burn-in	2	2	2	2	2	2
Total	5044	9253	5146	5267	9601	5143
Nmin	5163	9604	5163	5163	9604	5163
I-stat	0.977	0.963	0.997	1.02	1.001	0.996

Parameter	β_5			β_6		
Quantile	0.16	0.5	0.84	0.16	0.5	0.84
Thin	1	1	1	1	1	1
Burn-in	2	2	2	2	1	2
Total	5203	9498	5135	5306	9434	5104
Nmin	5163	9604	5163	5163	9604	5163
I-stat	1.008	0.989	0.995	1.028	0.982	0.989

Table 2.4: **Geweke (1992) convergence diagnostics for the coefficients**

Parameter	RNE (iid)	NSE (iid)
β_1	1	0.0097 - 0.0206
β_2	1	0.0078 - 0.0137
β_3	1	0.0108 - 0.0202
β_4	1	0.010 - 0.0193
β_5	1	0.0104 - 0.0195
β_6	1	0.009 - 0.0179

Figure 2.20: **Geweke (1992) convergence diagnostic p-values for the coefficients**



Chapter 3

Heterogeneity in the Euro Area and the Crisis

3.1 Introduction

The recent economic crisis led to a strong recession in both United States and the Euro area. The crisis started with the burst of an housing market bubble in the US which rapidly involved the credit and the financial sector of both sides of the Atlantic. The 2008-2009 recession was followed by a mild recovery. Then, in 2010 the Euro area has been hit by a sovereign debt crisis following concerns about public finances of the most indebted member countries which caused a second round of recession.

The crisis has been extensively studied both theoretically and empirically in order to understand its causes and consequences and to study the best policy measures to overcome it.

This chapter will analyse the effects of the recent economic crisis on the macroeconomic developments in the Euro area but it will do so from a different point of view with respect to the rest of the literature. As a matter of fact, the objective of the chapter is not to study the crisis mechanism but rather to evaluate the developments in the Euro area in light of historical macroeconomic relationships. So, a first issue this work will try to address is whether structural relationships remained stable from 2008 on.

Another peculiarity of this work is that it will not only take into account structural economic relationships inside the Euro area, but also their interplay with the US economy.

More explicitly, the empirical model is a large Bayesian VAR with US and Euro area variables estimated over the period 1995-2007 with quarterly data. The effects of the crisis on the Euro-area are evaluated through a conditional forecast exercise in which some country-specific macroeconomic variables are forecasted conditioning their path on the realization of some exogenous variables. The exogenous variables used in the conditional forecast exercise are US GDP growth and inflation, the Fed funds rate and an index of oil prices so that the actual size of the US crisis is taken into account. The estimation of the pre-crisis VAR is necessary to obtain the structural parameters used to produce the conditional forecast. By comparing the actual path of European variables with their forecasts it is possible to evaluate whether macroeconomic relationships have changed significantly, given the US crisis.

The exercise is useful to provide a better understanding of the developments in the Euro area during the crisis from which some policy implications could be drawn. When actual values are in line with their conditional forecast it means that actual developments reflect deep structural relationships so that policy reforms would be necessary to influence them. On the contrary, the change in the relationships across countries can have a structural nature or reflects some Euro-area specific shocks but the conditional forecast exercise is not able to distinguish between the two. The main difference between this two explanations is that a break in the structural macroeconomic relationships would be a permanent feature looking forward, while an idiosyncratic shock would be temporary.

The Euro area will be studied both as a whole as well as considering single countries, namely the four biggest European economies: France, Germany, Italy and Spain which also well represent the different macroeconomic developments occurred during the crisis. The reason for considering also single countries is to study heterogeneity. Therefore two different models are going to be estimates, one with US variables and Euro-area aggregates and the other with US and single-country variables. For both the Euro area and the single-countries the variable considered are GDP growth, inflation and 2- and 10 years government bond yields. The first two aspects are the main dimensions in which heterogeneity has been studied in the context of the EMU. The latter have been added to the analysis because they gained importance in the light of the 2010-2012 sovereign debt crisis.

The reason for considering also single countries is to study heterogeneity. Heterogeneity is a bread concept and many different definitions can be taken into account. The issue of heterogeneity, i.e. asymmetries in macroeconomic fundamentals, in the Euro area has become popular in macroeconomic literature since the establishment of the European Monetary Union (EMU henceforth). The literature of the 1990s was mainly focused on evaluating whether countries' economic fundamentals were actually converging. After 1999 another issue became relevant: whether asymmetries were still present and which are their sources. A big strand of economic literature focused on the interplay between monetary policy and countries' heterogeneity while other authors focused on the degree and the sources of real, nominal and financial heterogeneity. The kind of heterogeneity this work refers to is in the response to the crisis shock, i.e. the asymmetries in the level of economic activity, inflation and sovereign borrowing conditions recorded after 2008. However here heterogeneity is not quantitatively measured but simply the actual developments in single-countries macroeconomic variables are taken into account.

The recent economic crisis led to very different developments in Euro-area countries and a wide strand of literature dealt with the possible explanations of this kind of heterogeneity. Taken this into account, this work will try to answer to the following question: is the heterogeneity brought about by the recent economic crisis in line with pre-crisis structural macroeconomic relationships? Therefore, the objective of this work is not to evaluate the degree of heterogeneity across Euro-area countries by itself as many authors already presented evidence about the fact that heterogeneity increased during the recent crisis. Instead, this work tries to relate the developments in Euro-area countries with structural international macroeconomic relationships.

The present work is similar to Giannone, Lenza, and Reichlin (2010) as they study business cycles in the Euro area from 1980 to 2006 and use conditional forecast exercises to evaluate the joint output dynamics of European countries and to investigate the relationship between the Euro-area and the US cycles. Their objective was to see whether heterogeneity across European countries and aggregate GDP growth since the beginning of the EMU were in line with historical regularities. Recently, conditional forecast exercise have been used to evaluate monetary policy in the Euro area by Lenza, Pill, and Reichlin (2010), Giannone, Lenza, Pill, and Reichlin (2011), Giannone, Lenza, Pill, and Reichlin (2012) and Altavilla, Giannone, and Lenza (2014). From this point of view my work integrate the paper of Giannone, Lenza, and Reichlin (2010) as the same type of analysis is applied to the period 2007-2013.

The outline of the chapter is as follows. Section 3.2 presents some stylized facts regarding cross-country heterogeneity and the relationship between the Euro-area and the US economy. Section 3.3 reviews the literature. Section 3.4 explains the large Bayesian VAR and the conditional forecast methodologies. Section 3.5 presents the results and Section 3.6 concludes.

3.2 Stylized Facts

This work is not concerned with a formal evaluation of heterogeneity across Euro-area countries but the existence of asymmetries in economic cycles is taken as given. Rather, the chapter compares the evolution of single macroeconomic variables across countries in light of structural relationships. In order to better understand the issue of heterogeneity since the beginning of the EMU, this section presents some stylized facts about the evolution of GDP, inflation and government bond yields in the Euro area and about the correlation between Euro-area and US cycles.

3.2.1 Heterogeneity in the Euro area

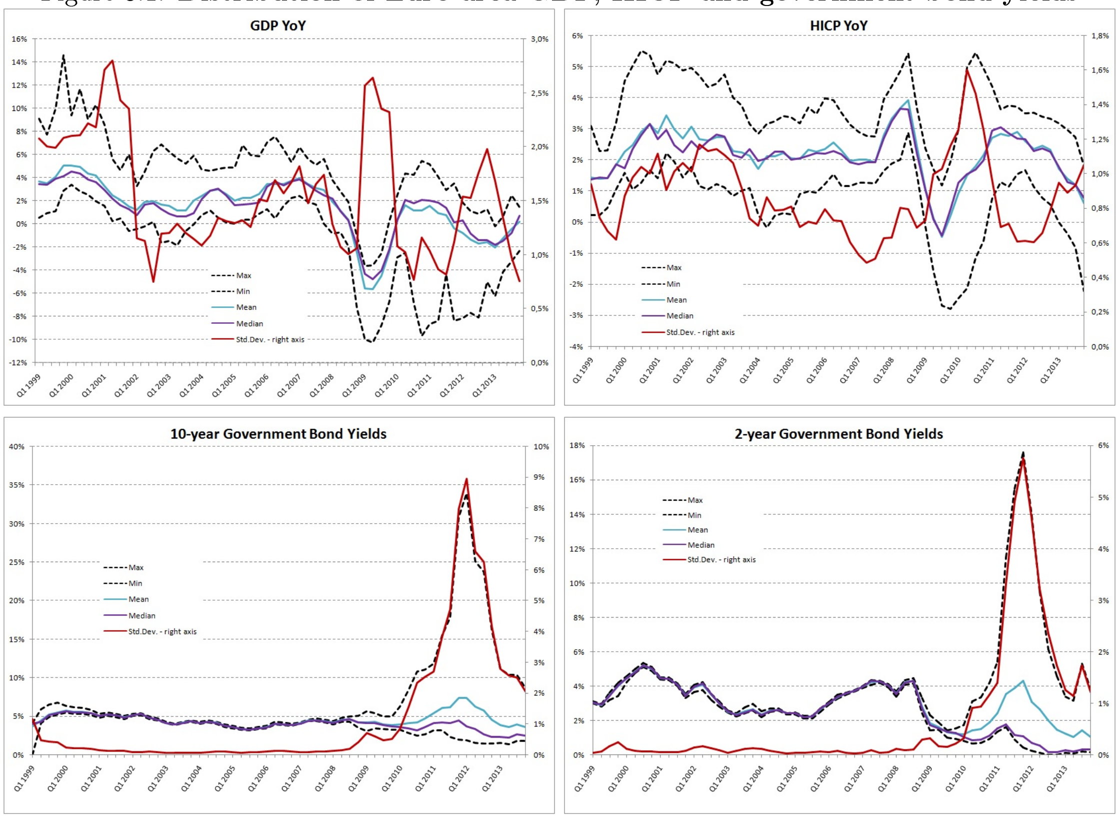
Figures 3.1 and 3.2 display the distribution of the GDP annual growth rate, annual inflation and 2- and 10-year government bond yields in the Euro area.

Figure 3.1 considers 11 countries for GDP, HICP and 10-year government bond yields and 7 countries for 2-year government bond yields[1]. Two main patterns are identifiable in all charts. The first is the fact that over the first part of the sample (before 2008) the standard deviation of all variables was quite stable and low. The only exception is GDP growth in 2001 whose standard deviation reached almost the 3% level, even higher than the level reached in 2009. This was due to the strong rise in Irish GDP.

The second relevant pattern is that the heterogeneity across Euro-area countries increased during the recent crisis. The standard deviation of GDP growth started to increase in the third quarter of 2008 and reached it maximum in Q2 2009 when annual GDP growth was at its lower level. The sovereign debt crisis led to again to an increase in the spread of the GDP growth distribution mainly for the fall in Greek GDP. The standard deviation of inflation started to increase at the beginning of 2009 and reached its peak in Q2 2010 when annual inflation was again rising after the drop in 2009. During the sovereign debt crisis inflation dispersion decreased and went back rising from the start of 2013. Government bond yields display a peak in Q4 2011 in periphery countries and their standard deviation at that time was more than six time those of the previous year. This was due not only to the rise in yields of Greece,

[1] The distributions of GDP, HICP and 10-year government bond yields consider data of 11 Euro-area countries: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal and Spain. Due to data availability issues, the chart of 2-year government bond yields has been constructed considering data of just 7 Euro-area countries: Finland, France, Germany, Italy, Netherlands, Portugal and Spain.

Figure 3.1: **Distribution of Euro-area GDP, HICP and government bond yields**



Ireland, Italy, Portugal and Spain, but also to the decrease of French, German, Finnish and Dutch yields as a consequence of a flight to quality.

Figure 3.2 considers only France, Germany, Italy and Spain. In this case the standard deviation of GDP growth still increases in 2009 and 2011 but only up to 6%. On the other hand, inflation dispersion shows a negative trend from 2007 on. The standard deviation of government bond yield still display a peak in 2012.

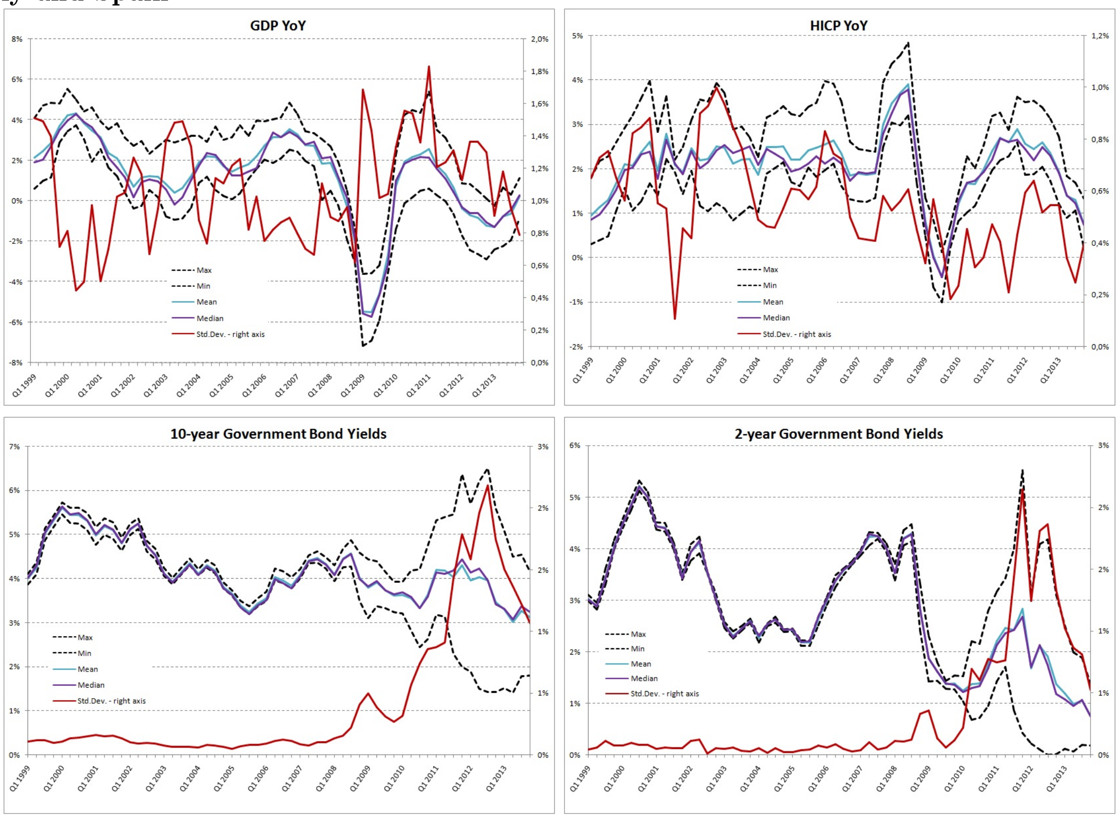
As regards Euro-area structural macroeconomic relationships, figure 3.3 present some evidence about the relationship between GDP growth and inflation. In the period between 1999 and 2007 this relationship was positive with a correlation coefficient of 0.6. Instead, over the crisis period the correlation coefficient is slightly negative and equal to -0,03. Therefore after 2008 no significant relationship is identifiable between GDP growth and inflation.

3.2.2 Euro area - US correlations

As the purpose of this work is to analyse structural macroeconomic relationships, the following figure presents some evidence regarding the relationship between GDP growth, inflation and government bond yields in the Euro-area and the correlation between Euro-area and US variables.

Figure 3.4 displays charts in which US and Euro-area variables are plotted together. In particular, they show the evolution of annual GDP growth, inflation, 10-year and 2 year government bond yields.

Figure 3.2: **Distribution of GDP, HICP and government bond yields of France, Germany, Italy and Spain**



The considered Euro-area countries are France, Germany, Italy and Spain which are also the countries considered in the VAR. The Euro-area aggregates are added for a more complete comparison.

As for GDP growth, Euro-area and US appear to have quite correlated business cycles. The drop started in 2008 has been contemporaneous in both areas. Most interestingly, starting from the end of 2011 the US and Euro-area GDPs started to diverge as US economy expanded while Euro-area contracted. Inflation rates appear to be less correlated in the first part of the sample but more during the crisis period. As regards heterogeneity across Euro-area countries, Italy and Spain display a higher volatility all along the sample. Finally, Euro-area government bond yields follow US yields up to 2010 when they start to increase, mainly in periphery countries, due to the sovereign debt crisis.

Overall these charts show that the dynamics of the considered variables at the beginning of the crisis was very similar, much more than in previous periods, while from 2010 macroeconomic relationships became less stable and heterogeneity increased. What is this decoupling due to? Can structural macroeconomic relationships in place before 2008 explain the evolution of Euro-area variables in more recent years? The conditional forecast exercise in this chapter will try to shed some light on these issues.

Figure 3.3: **Relationship between annual GDP growth and inflation**

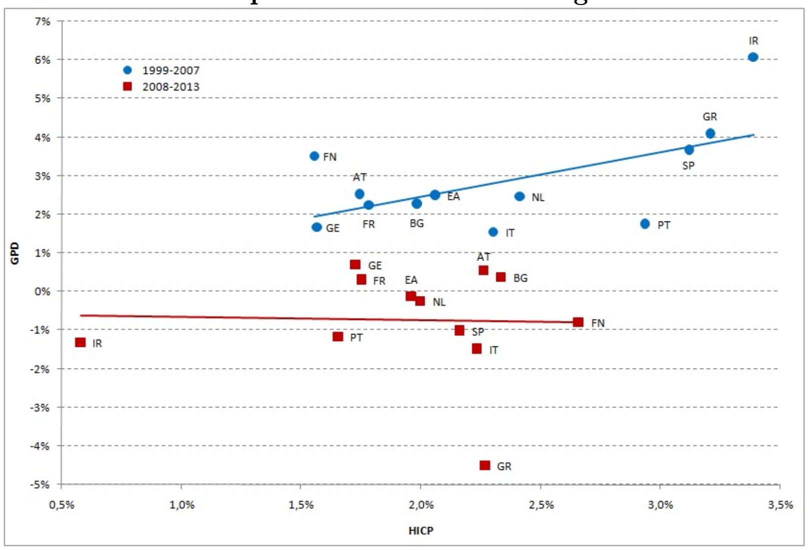
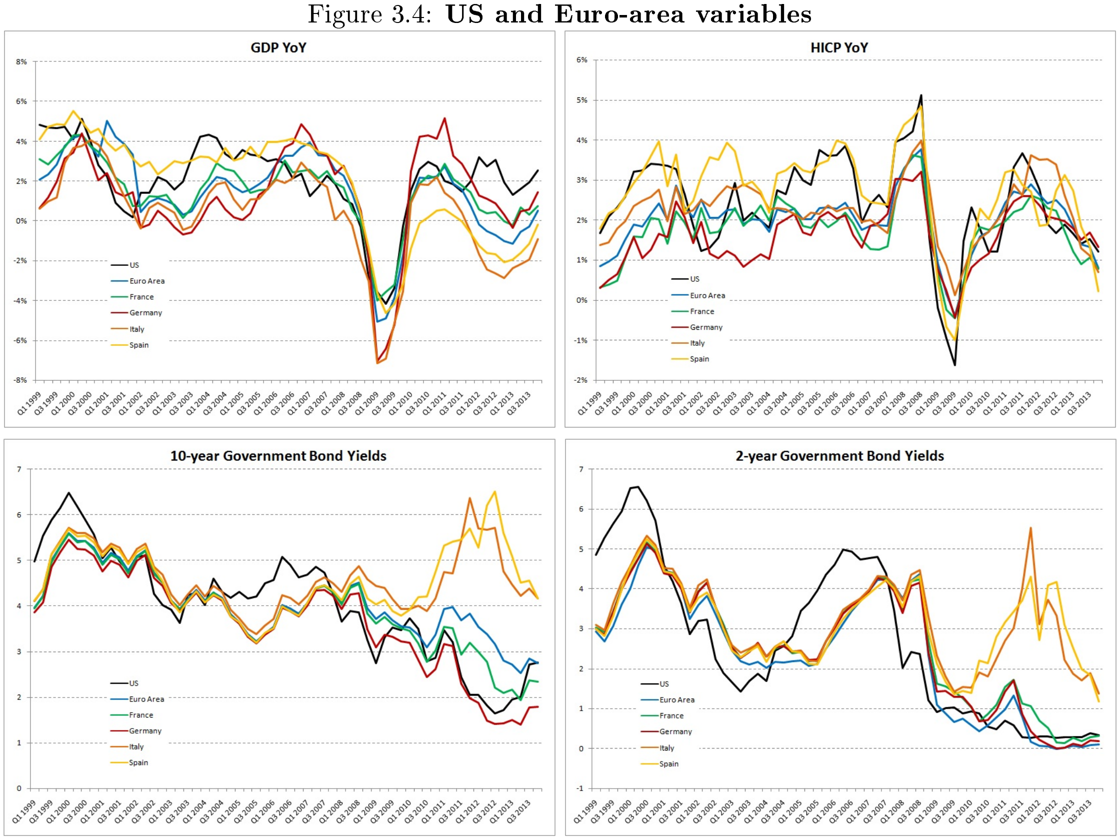


Figure 3.4: **US and Euro-area variables**



3.3 Literature Review

This work is connected with several different issues. One of them is the relationship between US and the Euro area. The literature dealing with it is reviewed in section 3.4.3 as further evidence is also produced. Another connected strand of literature is the one represented by papers using the conditional forecast tool, which have been briefly mentioned in the introduction as they are concerned about monetary policy issues.

However, the main goal of the chapter is to understand whether the increase in Euro area cross-country heterogeneity, i.e. the very different economic developments due to the crisis, is in line with structural relationships, given the crisis shock. The related literature is the one dealing with economic asymmetries across Euro-area countries. In this field, the literature either studied nominal or real heterogeneity, i.e. inflation differentials or business cycle heterogeneity. During the last years also financial conditions have caught the attention of researchers. This section will review some papers dealing with these issues.

3.3.1 Inflation Differentials

The economic literature has put lots of effort in understanding the sources of prolonged inflation differentials. Temporary price misalignments should not be a source of concern by itself as they can be the consequence of adjustment processes. As a matter of fact, in the presence of regional economic imbalances or asymmetric shocks, price and wage flexibility and factor mobility are important elements of the convergence process. On the other hand, persistent inflation differentials are a cause of concern because they can reflect structural differences in the adjustment process to economic shocks or inappropriate domestic policies and, in absence of a national monetary policy, other national policies should be implemented in response of persistent deviation from price stability (ECB, 1999a).

From a political point of view, inflation differentials are particularly relevant for the unpopularity of inflation in EMU countries, especially if it cannot be mitigated by a weaker exchange rate or by targeted monetary policy actions. As a consequence, the public opinion could blame the currency area to be the source of high inflation in some countries, as stressed by Honohan and Lane (2003).

The main sources of inflation differentials and the related literature are reviewed by De Haan (2010). The author classifies the factors influencing inflation differentials into five categories: (i) convergence, (ii) business cycles, (iii) asymmetric shocks and different adjustment mechanism to common shocks, (iv) characteristics of the national goods, labour and factor markets, (v) price/wage rigidities.

These factors can also be distinguished according to the time horizon over which they influence inflation as in ECB (2012b). Structural factors like inflation persistence, labour productivity and price/wage rigidities are likely to influence prices for a long period of time. On the other hand business cycles and other pro-cyclical factors and import price shocks affect inflation in the short-medium term.

The first set of factors refers to the fact that inflation differentials can be due to the price level convergence process to a homogeneous inflation rate if initially prices were different across countries. This process operates through the higher level of market integration, which leads to homogeneous prices of traded goods, and the Balassa-Samuelson effect generating higher inflation in the countries experiencing a more rapid productivity growth. Beck and Weber (2005) find that the convergence occurs only at a modest pace and it is a nonlinear process as its speed seems to decrease the further it proceeds.

As also the business cycle can influence inflation differentials through its effects on prices, business cycle heterogeneity is a matter of concern. Business cycles and inflation are endogenous to each other and one of the main connections between the two is the real rate: an ease in monetary policy leads to lower real rates in countries with higher inflation which in turns put a stronger upward pressure on prices. The opposite is true for a monetary policy tightening and overall the real rate channel can exacerbate inflation differentials.

The effects of the real rate can be offset by the decline in competitiveness in high-inflation countries due to the real appreciation leading to lower exports, weaker demand and lower prices. As regards international trade, also exchange rate shocks and import prices are relevant in shaping inflation differentials. Trade openness and trade patterns are different across countries so that the impact on domestic inflation of movements in the euro currency, i.e. the so-called pass-through, is not homogeneous. From this point of view, inflation differentials can be considered as necessary to converge to the purchasing power parity when import prices differ. The nominal effective exchange rate has been found to be relevant for the determination of inflation differentials in the period 1999-2001 by Honohan and Lane (2003).

The last two elements affecting inflation differentials, i.e. characteristics of the national goods, labour and factor markets and price/wage rigidities, are structural factors that can lead to higher inflation by itself or by influencing the propagation of shocks. With this respect, Beck, Hubrich, and Marcellino (2009) find that structural factors are the main determinants of inflation differentials in the Euro area.

A further source of heterogeneous inflation rates is found to be inflation persistence. Angeloni and Ehrmann (2004) estimate an aggregate demand equation and a Phillips curve for a panel of 12 countries and finds that the main driver of inflation differentials over the period 1998-2003 was inflation persistence, even if equal across countries. Therefore the prescription for monetary policy is to minimize deviations of Euro-area prices from their long-run values in order to lower cross-country inflation differentials.

The 2008 crisis is taken into account by very few authors. Lopez and Papell (2012) find that the 2008 crisis led to an initial weakening of the convergence process with an increase in the inflation persistence followed by a period of faster convergence. Pirovano and Van Poeck (2011) tests the stability of inflation differentials over the period 1999-2011 which are found to be stable during the pre-crisis period, in line with Lopez (2009), while the null hypothesis of stability is rejected when the full sample is considered. When coming to the analysis of the determinants of inflation differentials, they find that they are originated by persistent structural and country-specific factors.

The existence of a rebalancing effect after 2008 is documented also by ECB (2012b) that presents evidence of the fact that inflation persistence has been higher over the period 2002-2008 than after 2008. This outcome is due to the implementation of fiscal consolidation measures and of structural measures aimed at increasing the flexibility in the product and labour market, the decrease of unit labour costs, the rise in real interest rates and the negative output gaps. Most of these factors were already influencing inflation in the pre-crisis period but after the crisis they started to operate in the opposite direction.

3.3.2 Real Heterogeneity

Many authors studied business cycle heterogeneity across Euro area economies. Starting from the adoption of the Exchange Rate Mechanism (ERM) in 1992 and further with the introduction of the unique currency in 1999, the literature discussed three related issues. First, whether business cycles in the Eurozone have become more similar, second, which are the factors that drive business cycle synchronization, and third, whether the transmission of monetary policy shocks is homogeneous across countries. In general, business cycle divergence can be caused by asymmetric shocks or differences in national policies but also by an heterogeneous transmission mechanism of common shocks due to differences in structural characteristics.

Haan, Inklaar, and Jong-A-Pin (2008) review the empirical literature concerned with business cycles synchronization in the Euro area. Evidence shows that periods of of greater and lesser synchronization tend to alternate but in general business cycle heterogeneity decreased during the 1990s. The main factors driving business cycle synchronization are trade intensity, monetary integration, financial integration and fiscal policies. Trade openness and financial integration can increase synchronization as they increase the sensitivity of domestic demand to foreign demand but they also lead to a higher degree of production specialization, i.e. different economic structures, which, in case of sectoral shocks, decreases business cycle correlations. Finally, monetary integration can foster synchronization through the unique monetary policy and the exchange rate stability. However, in a monetary union, the exchange rates cannot anymore absorb shocks which in turns causes more divergences in business cycles.

Camacho, Perez-Quiros, and Saiz (2008) evaluate business cycles of European countries considering both synchronization and the form of the cycles, i.e. length, depth and shape. The study uses monthly data of the industrial production from 1962 to 2004 finding that European business cycles can be classified into different clusters featuring different cycle characteristics. When two subsamples are considered, the results show that the exchange rate mechanism implemented in early 1990s did not lead to convergence in business cycle characteristics.

Giannone, Lenza, and Reichlin (2010) study the evolution of heterogeneity in the Euro-area through a conditional forecast exercise where single-country GDP growth rates are conditioned on the realised path of aggregate GDP growth. Euro-area countries can be divided into two groups and for both the business cycle characteristics did not change with the introduction of the Euro. The first group consists of countries with similar business cycles over the sample 1970 to 2006, i.e. Austria, Belgium, France, Germany, Italy and Netherlands, while the second group is composed by countries where economic activity was more heterogeneous and volatile, i.e. Finland, Greece, Ireland, Luxembourg, Portugal and Spain.

As regards the crisis period, Ciccarelli, Ortega, and Valderrama (2012) analyse heterogeneity and spillovers in macro-financial linkages across 10 developed economies (5 of them are part of the EMU) over the period 1980-2011 by using a time-varying parameter panel-VAR model and show that the developments in Euro-area variables were mainly driven by a common component and, to a lesser extent, by country-specific factors. The opposite is true for the pre-crisis period. Then the two factors lost their significance in 2010 and 2011.

These results are in line with Giannone and Reichlin (2006) that analyses output dynamics in 12 EMU countries from 1970 on finding that output differentials have remained stable over time while business cycles have become more synchronized. Cross-country heterogeneity turns out to be due to small and persistent idiosyncratic shocks while output fluctuations are caused by area-wide shocks with a similar transmission mechanism. Euro-area and US business cycles are found to be highly correlated. US shocks are the main drivers of output fluctuations, their effects on the Euro-area are lagged but more persistent and less volatile than in the US meaning that the two economies have different structural characteristics shaping the transmission mechanism.

Overall, the results of the latter two papers are interesting because they shed some light on the sources of heterogeneity across different countries pointing towards the relevance of idiosyncratic factors in explaining divergent macroeconomic developments.

Heterogeneity regards also the monetary policy transmission mechanism. As of the effects of the crisis on the transmission mechanism of monetary policy shocks, Ciccarelli, Maddaloni, and Peydró (2013) find that in distressed countries the credit channel played a strong amplification effect. They obtain this result through the estimation of a panel VAR model with 15 macro, financial and credit variables for 12 Euro-area countries over the period 2002Q4 - 2011Q3 with an expanding rolling window. The monetary policy transmission process turns out to be time-varying with shocks having the strongest impact on GDP at the height of the crisis. Also the cross-country dimension is important because the effects of monetary policy have changed in an heterogeneous way across countries and across the different credit channels.

The effects of credit dynamics in Euro area countries are studied also by Bijsterbosch and Falagiarda (2014) which find that credit supply shocks have played an important role in business cycle fluctuations in most Euro-area countries and that their effect increased after the recent crisis. In particular, credit supply shocks had a positive effect on GDP growth in the pre-crisis period and a negative effect afterward with a positive correlation is the size of the two opposite contributions. Credit supply shocks are also found to contribute to an increase in cross-country heterogeneity and in the variability of real GDP, inflation, short term interest rate and lending in the post-crisis period.

Bagliano and Morana (2010) investigate whether the spillovers of macroeconomic and financial shocks from the US have affected the convergence process in the Euro area. The empirical model consists of a FAVAR considering 50 countries and the sample goes from 1980 to 2009. Their results point towards a likely contribution of US real and financial factors to real and financial divergence in the Euro area while the opposite is true for inflation.

3.3.3 Financial Heterogeneity

Heterogeneity in financial conditions, i.e. credit and government bond markets, has been documented by ECB (2012a). The financial and sovereign debt crisis has increased the degree of heterogeneity in financial conditions across Euro area countries by affecting those countries that benefited the most from the access to the EMU. As a matter of fact, the EMU brought about a process of financial integration which led to a decrease in nominal interest rate and financing costs in all countries. This provided incentives for households, corporations and government to increase spending and the incentive was higher for the countries that experienced higher interest rates before joining the EMU. The lack of structural reforms in these countries led to an accumulation of macroeconomic, fiscal and financial imbalances which created the basis for the increase in the heterogeneity after 2008.

During the crisis, financial heterogeneity appeared with impaired money market functioning, a decrease in credit supply and eventually tensions on sovereign debt markets. Financial heterogeneity is a source of concern because it can by itself foster heterogeneity in macroeconomic fundamentals as it prevents the most affected countries from accessing the funds needed to stimulate growth.

The ECB intervened by cutting interest rates and implementing unconventional monetary policy measures aimed at restoring homogenous financing conditions as the high degree of heterogeneity poses challenges in the conduct of monetary policy impairing the transmission mechanism. ECB (2014) retraces the developments in sovereign bond yields, analyses the effects of unconventional monetary policy measures and reviews some of the related literature.

As regards the dynamics of government bond yields during the crisis, the literature has found that spreads have been driven by both common international factors, as risk aversion, and country-specific factors, as default and liquidity risk.

Afonso, Arghyrou, Bagdatoglou, and Kontonikas (2013) study the determinants of sovereign bond yield spreads over the period 1999-2011 and identify country-specific time variation in the relationship between spreads and fundamentals. In particular they find that the set of financial and macroeconomic variables influencing spreads became richer during the crisis mainly for periphery countries pointing towards an increase in heterogeneity. The new determinants of sovereign spreads were fiscal fundamentals and international financial risk while liquidity risk increased its significance.

Similar results are found by Bernoth and Erdogan (2012) that apply time-varying coefficients to a non-parametric fixed-effects panel model for the sovereign bond yields of 10 Euro-area countries for the period 1999-2011. The main finding is that the increase in yield spreads during the financial crisis can be explained by an increase in investors' risk aversion, a deterioration of governments' fiscal position and by an increase in the price of risk, i.e. financial markets reacted more strongly to risk variables.

Credit and liquidity risk as well as higher international risk aversion are found to be the determinant of sovereign bond yields over the period 2007-2009 by Attinasi, Checherita-Westphal, and Nickel (2009).

Arghyrou and Kontonikas (2012) confirm that after 2007 sovereign bond yields have been driven mainly by macro fundamentals and international risk while in the pre-crisis pricing can be explained by a "convergence-trade" pricing model, i.e. investors bought the bonds of periphery countries leading to a convergence of their yields with those of Germany. Furthermore, the crisis period can be divided into two subperiods. During the first one, up to the beginning of 2010, yields were mainly driven by the Greek debt crisis which has been caused by an unfavourable shift in country-specific market expectations. The second period, from March 2010, is instead characterized by an increase in the sensitivity of bond yields to fundamentals and several contagion sources were active.

Contagion is found to significantly affect bond yields also by Favero and Missale (2012). Fiscal fundamentals are the key variable driving it as they influence the sensitivity of domestic yields to other countries' spreads.

More recently, Costantini, Fragetta, and Melina (2014) found that also inflation differentials affect sovereign bond yield spreads of Euro-area periphery countries. Here cumulated inflation differentials are used to capture asymmetric shocks leading to a divergence in competitiveness and the fact that they are statistically significant is an indication that those countries do not belong to an optimal currency area. Moreover, the sensitivity of spreads to expected debt-to-GDP ratios turns out to be 20 times higher in periphery countries than in core countries. Therefore financial markets punished the deterioration of public finances of those countries that are not perceived as members of the optimal currency area.

3.4 The Methodology

The econometric methodology is based on the estimation of a large Bayesian VAR and the calculation of a conditional forecast. This section briefly discuss both approaches and the assumption of US exogeneity.

3.4.1 Large Bayesian VARs

Large Bayesian VARs have been introduced by Banbura, Giannone, and Reichlin (2010) as a tool to handle systems of many variables so to avoid the curse of dimensionality. The overfitting problem is avoided through the application of Bayesian shrinkage which amounts at increasing the tightness of the priors as more variables are added. The rationale behind this approach is that by using informative priors it is possible to shrink the highly parametrised VAR model towards a more parsimonious benchmark representation captured by the prior distributions.

The choice of the informativeness of the prior distribution is a crucial issue because it influences the fit of the model and its forecasting performance. The tightness of the prior can be chosen so as to maximize the out-of sample forecasting performance of the model as in Litterman (1980) and in Doan, Litterman, and Sims (1984) or by targeting a desired in-sample fit as in Banbura, Giannone, and Reichlin (2010).

Here the appropriate degree of shrinkage is chosen as in Giannone, Lenza, and Primiceri (2012), i.e. it is automatically selected by maximizing the posterior distribution of the hyperparameters. This is possible by exploiting the hierarchical structure of the model as hyperparameters are treated as any other unknown parameter so that the Bayes theorem can be applied to produce inference on them. In particular, maximizing their posterior distribution amounts at maximizing the marginal likelihood with respect to them. The MCMC algorithm used to estimate the parameters of the model is based on a Metropolis step to draw the vector of hyperparameters which is then used to draw the vector of parameters from a Normal - Inverse-Wishart distribution. As regards priors, a combination of the Minnesota, sum-of-coefficients and initial-dummy-observation priors is considered. As a result, priors will be tighter when the model is overparametrised and they will be looser in the opposite case. Appendix B reviews this approach in some more details.

Two different BVARs are estimated in this work. The first one considers US variables, the oil price index and Euro-area aggregate variables. The second VAR considers 16 Euro-area country-specific variables instead of the aggregate ones so that it has 21 variables overall. The US variables are GDP growth, inflation, the Fed funds rate and 10-year government bond yields. The Euro area aggregate and country-specific variables are GDP growth, inflation and 2- and 10-years government bond yields. The countries considered are France, Germany, Italy and Spain because they are the four biggest European economies but also well represents heterogeneity. Finally, the index of oil prices is included with the aim of capturing exogenous determinants of inflation. Collecting all the variables in the vector Y_t, both

VARs can be written in the following reduced-form:

$$Y_t = C + A_1 Y_{t-1} + \ldots + A_p Y_{t-p} + \varepsilon_t, \tag{3.1}$$

where C is a vector of constants and A_l with $l = 1 \ldots p$ are the matrices capturing the relationship between Y_t and its p lags.

The model is estimated over the period from Q1 1995 to Q2 2007 with quarterly data and five lags ($p = 5$). The estimation sample has been chosen in order to capture only pre-crisis structural macroeconomic relationships. Variables enter in log-levels, except from interest rates. Appendix A describes the sources and the exact transformation applied to each variable.

3.4.2 Conditional Forecast

The estimation of the BVAR model is necessary to obtain the structural parameters which will be used to produce the conditional forecast. The conditional forecast amounts at the following exercise: from a period t_0 on, where $t = 1 \ldots t_0 \ldots T$, we want to produce the conditional forecast of Euro-area variables given the US developments during the crisis period.

Therefore, the variables of the VAR can be divided into two subset, the variable of which we want to derive the conditional expectations (Z) for the period $t \geq t_0$, and the variables in the conditioning set (X) so that, for every Euro-area variable z of the VAR model, the algorithm computes the forecast based on the parameters coming from the VAR, the past value of the Euro-area variables and the past and future observations of US variables, i.e

$$\mathbb{E}_{A(L)} \left[z_t | Z_t, t = 1 \ldots t_0 - 1, \wedge X_t, t = 1 \ldots T \right] \tag{3.2}$$

More precisely, in the forecasting period the VAR system has the following state-space representation:

$$X_t = BZ_t + \varepsilon_t \tag{3.3}$$

$$Z_t = DZ_{t-1} + \eta_t \tag{3.4}$$

Here X_t is a $(k \times 1)$ vector of observables, Z_t is a $(m \times 1)$ vector of latent state variables and B and D are two, respectively, $(k \times m)$ and $(m \times m)$ matrices of coefficients. Observables are the conditioning variables, i.e. US variables and the oil price index in this case, unobservables are the variables to forecast, i.e Euro-area variables, and coefficient matrices come from the estimation of the large BVAR model on the pre-crisis period.

The conditional expectations of Euro-area variables are computed using the Kalman-filter based algorithm discussed in Banbura, Giannone, and Lenza (2014) which in turn is based on the simulation smoother developed by Carter and Kohn (1994). This smoothing algorithm allows to estimate a value for Z_t taking into account the full sample of observations with their variance-covariance matrix, meaning that also the size of the shocks occurred to the conditioning variables is taken into account.

In conclusion, the conditional forecast gives a probability distribution to evaluate how likely are actual values, given pre-crisis structural macroeconomic relationships and the US crisis. The comparison of actual values of Euro-area variables with their conditional forecasts will allow to evaluate whether the correlations between the variables in the VAR model have changed after Q3 2007.

3.4.3 US exogeneity

One issue when dealing with conditional forecasts is the endogeneity of the conditioning set with respect to the forecasted variables. As a matter of fact, the conditional forecast exercise tries to evaluate whether, given the structural macroeconomic relationships, the variables in the conditioning set are able to correctly reproduce the path of the forecasted variables. Endogeneity means that the conditioning set is itself influenced by the realised path of the forecasted variables so that it already contains information about it. Therefore, if endogeneity is present the results will be difficult to interpret as the direction of causality between the two sets of variables is not clear.

In this work the conditioning set contains four US macroeconomic variables and an oil price index and therefore the conditional forecast exercise lies on the assumption that the US economy is exogenous to the Euro-area economy. This section will try to justify this assumption briefly reviewing some literature dealing with this issue and running an out-of-sample forecasting exercise to prove that the Euro area does not Granger-cause US.

Giannone and Reichlin (2005) model the interactions between the US and the Euro area cycle over the period 1970-2003. Stylized facts show that cycles are longer in US than in the Euro area while recessions are shorter and the Euro-area cycle is smoother than the US one. The analysis of growth rates show that US have higher output volatility while persistence is larger in the Euro area and lags the US analog. Then there are two interesting findings regarding US exogeneity. The first is that that Euro-area growth does not Granger-cause US growth, i.e. world growth is led by the US and the Euro area follows with a lag. The second one is that cointegration analysis shows that the two economies are driven by only one shock in the long run and model simulation demonstrate that this shock can be interpreted either as a world shock or as a shock originating in the US as the outcomes of the two are not statistically distinguishable. Finally, the model also proves that US output can be fully explained by a technology shock while for Euro-area output a further idiosyncratic shock is necessary. The same authors, in a later paper (Giannone and Reichlin, 2006) analyse output dynamics in 12 EMU countries from 1970 on and they again find that US shocks are the main drivers of output fluctuations.

Giannone, Lenza, and Reichlin (2010) produced evidence about the exogeneity of US GDP growth by evaluating the forecasting performance of a bivariate VAR with Euro-area and US GDP growth over the sample 1980-2006 by comparing it with a random-walk model. Results show that US GDP helps to predict Euro-area GDP but the opposite is not true. This finding allows them to use US GDP as conditioning variable to study the evolution of Euro-area GDP.

Further evidence on the effects of US shocks in the Euro area is produced by Favero and Giavazzi (2008) and Bagliano and Morana (2010). Favero and Giavazzi (2008) study Euro-area yields on long-term bonds and find that their level is almost entirely explained by US shocks and by the systematic response of US and Euro-area variables to these shocks. Bagliano and Morana (2010) find that US real and financial factors contributed to real divergence in the Euro area as a contraction in US economic activity leads both to a decrease in the average Euro-area GDP growth and to an increase of the standard deviation and skewness of its cross-sectional distribution. Also financial convergence is influenced by US developments while the opposite is true for the Euro-area inflation.

Table 3.1: **RMSFE of US and Euro-area GDP from different models**

US GDP			
	Model with US only	**Extended Model**	**Percentage difference**
$t+1$	2,77	2,8158	1,7%
$t+2$	2,3612	2,4850	5,2%
$t+3$	2,1665	2,3399	8,0%
$t+4$	2,0592	2,2188	7,7%
Euro-Area GDP			
	Model with EA only	**Extended Model**	**Percentage difference**
$t+1$	3,0295	2,5596	-15,5%
$t+2$	2,9354	2,4977	-14,9%
$t+3$	2,8142	2,3680	-15,9%
$t+4$	2,7257	2,2604	-17,1%

The weakness of the previous studies is that they do not consider the crisis period. Billio, Casarin, Ravazzolo, and Van Dijk (2013) in turns, studied the interactions between US and Euro-area cycles over the sample 1991-2013. The empirical model is a Bayesian panel Markov-switching VAR with three regimes, recession, recovery and expansion, for seven countries, six Euro-area economies plus the US. Their main findings are in line with the above literature as US cycle turns out to lead the Eurozone one and reinforcement effects in the recession probabilities are present.

In order to reproduce these results in the current framework, an out-of-sample forecasting exercise is run. The forecasting exercise allows to evaluate whether European variables Granger-cause US ones. The exercise is structured as follows. The forecasts coming from two country-specific BVAR models for US and Euro-area aggregate variables are compared with the one from an extended model considering both set of variables. The direction of causality, i.e. if US Granger-cause Euro area or viceversa, is assessed comparing the effect of US variables on the Euro-area forecast with the effect of Euro-area variables on the US forecast.

Overall three BVAR models[2] are estimated recursively, using the Giannone, Lenza, and Primiceri (2012) framework, on an expanding window with the first estimation sample going from 1995 to the end of 2006. At each iteration the sample is increased with one observation and for all the estimated models the four-period-ahead forecast is produced[3]. Eventually, the last estimation sample ends in Q4 2012 and the forecast for the conditioning variables is produced up to Q4 2013. The forecast is evaluated in terms of growth rates with respect to the last observation in the estimation sample and then it is rescaled to obtain annual growth rates, as in Stock and Watson (2004). Finally, the forecast accuracy is evaluated through the calculation of the root mean square forecast error (RMSFE henceforth) with respect to the realised path of the variables[4].

Table 3.1 reports the average RMSFE of the variables for the four forecast periods.

[2]The US model considers the variables in the conditioning set, i.e. US GDP, US HICP, the Fed funds rate, the US 10-year government bond yields and the oil price index. The Euro-area model considers Euro-area GDP, HICP and 2- and 10-years government bond yields. The extended model combines the variables of the two previous models.

[3]The forecast is produced using the entire posterior distribution of the BVAR parameters so that a density forecast is obtained. The forecast has been calculated also considering the mode of the parameters' posterior distributions but results are not qualitatively different.

[4]The RMSFE is calculated using the median of the forecast distribution.

Results show that the extended model worsen the forecast of US GDP of around 5.5% on average while it improves the forecast of Euro-area GDP of around 15.5% on average meaning that US variables are useful to forecast Euro-area GDP but the converse is not true. Therefore it is possible to conclude that it is the US business cycle to Granger-cause the Euro-area one.

3.5 Results

This section reports and comments the results of the conditional forecast produced for GDP growth, inflation and 2- and 10-year government bond yields of the Euro area, Germany, France, Italy and Spain. The exogenous variables used to produce the conditional forecast are US GDP growth and inflation, the Fed funds rate, the 10-year government bond yield and an index of oil prices. Further details about the dataset can be found in appendix A.

3.5.1 Conditional Forecast of Euro-Area Aggregates

Figure 3.5 reports the results of the conditional forecast exercise starting in Q3 2007 for aggregated Euro-area variables.

The black solid lines refer to the actual values, the red lines display the 5th, 16th, 50th, 84th and 95th percentiles and the mean of the conditional forecast distribution. Finally, the blue line is the median of the unconditional forecast and is included to better understand the effect of conditioning on the forecast. All variables are in percentage annual growth rates.

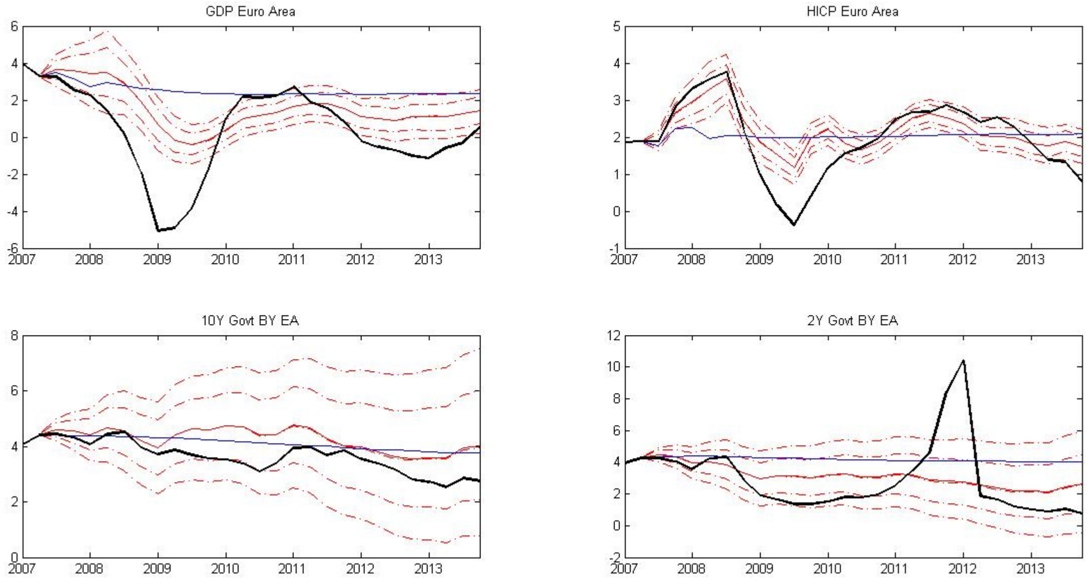
As the blue line highlights, the unconditional forecasts perform worse than the conditional forecast as they only take into account pre-crisis structural macroeconomic relationships but not the information regarding the crisis brought by the US variables and the oil price index.

Coming to the conditional forecast, Euro-area GDP is predicted to slow down in 2008 but the actual values are well below the conditional forecast distribution meaning that in that period either a structural break or an idiosyncratic shock occurred. The subsequent rebound is on the 95th quantile and others very unlikely values of the annual GDP growth rate are recorded in the second half of 2012 after the sovereign debt crisis.

Inflation is almost always in line with its conditional expectation even though the actual value often lies in the tails of the distribution. The values in the period from 2009 to mid 2010 are far below the conditional forecast distribution. Inflation lies again below the forecasted distribution in the last two quarters of 2013 justifying the concerns about deflation as these values cannot be explained neither by structural relationships nor by the US crisis evolution.

On the other hand, 10-year government bond yields closely track the mean and the median of the conditional forecast meaning that for this variable no structural break or idiosyncratic shock can be detected. The conclusions are different for 2-year government bond yields as in 2009 yields lie in the lower part of the conditional forecast distribution, probably driven by the liquidity injections of the ECB to curb the financial crisis, and the peak at the beginning of 2012 is outside the distribution meaning that the developments of the sovereign debt crisis cannot be explained by pre-crisis macroeconomic relationships, even when the US crisis is taken into account.

Figure 3.5: **Actual values, conditional and unconditional forecast of Euro-area variables**



3.5.2 Conditional Forecast of Euro-Area Countries

Euro-area aggregate variables showed that the financial crisis and the sovereign debt crisis caused a decline in GDP growth rate, inflation and 2-year government bond prices that cannot be explained by pre-crisis structural relationships and the US crisis shock.

The purpose of this section is to compare country-specific developments with the results for the Euro-area aggregate variables and to evaluate whether the increase in cross-country heterogeneity from 2008 on is somehow predictable.

Figures 3.6 and 3.7 display the results of the conditional forecast exercise for single Euro-area countries which starts in Q3 2007. As before, the black solid lines refer to the actual values, the red lines are the percentiles and the mean of the conditional forecast distribution and the blue line is the median of the unconditional forecast. All variables are in percentage annual growth rates.

As before, the conditional forecast improves a lot with respect to the unconditional one. The unconditional forecast can somehow capture the evolution of the variables at the beginning of the sample but from then on it predicts that they should remain almost unchanged. Therefore the difference from the conditional and the unconditional forecast is due to the conditioning, i.e. it comes from the relationship between US and Euro area and the size of US shocks.

The four conditional forecasts of GDP growth have similar patterns as they all decrease around 2009 and then go up again. The levels are however different, heterogeneity is definitely present all along the crisis period and it is often not in line with the conditional forecast. The starting point is around 4% for Germany and Spain and around 2% for France and Italy. The actual values of GDP growth are often outside the distribution of the conditional forecast. For the first four periods, up to around Q3 2008, the actual GDP is in line with the conditional forecast meaning that the structural

Figure 3.6: **Actual values, conditional and unconditional forecast of GDP and HICP YoY**

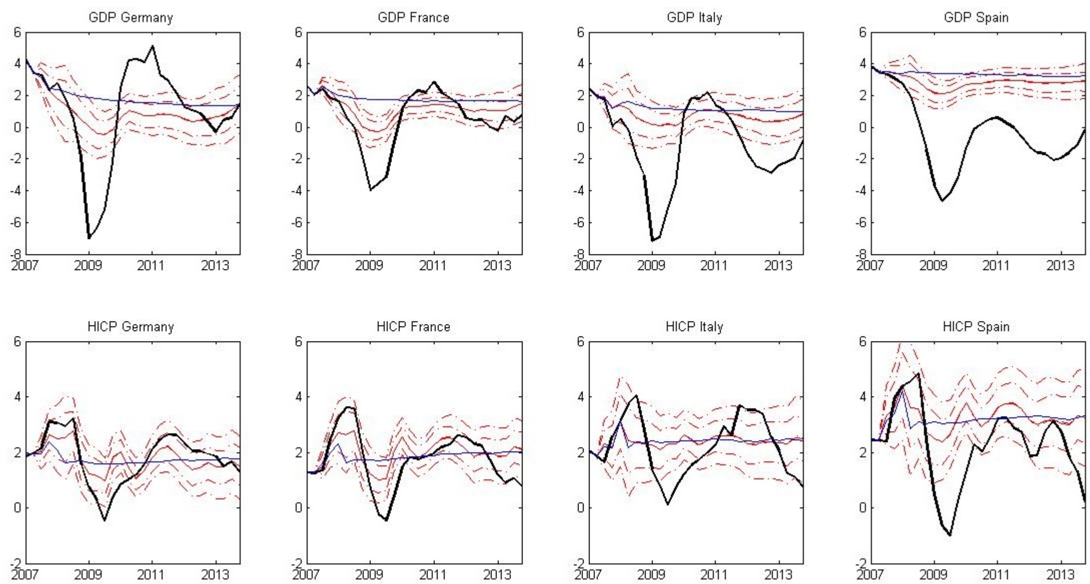
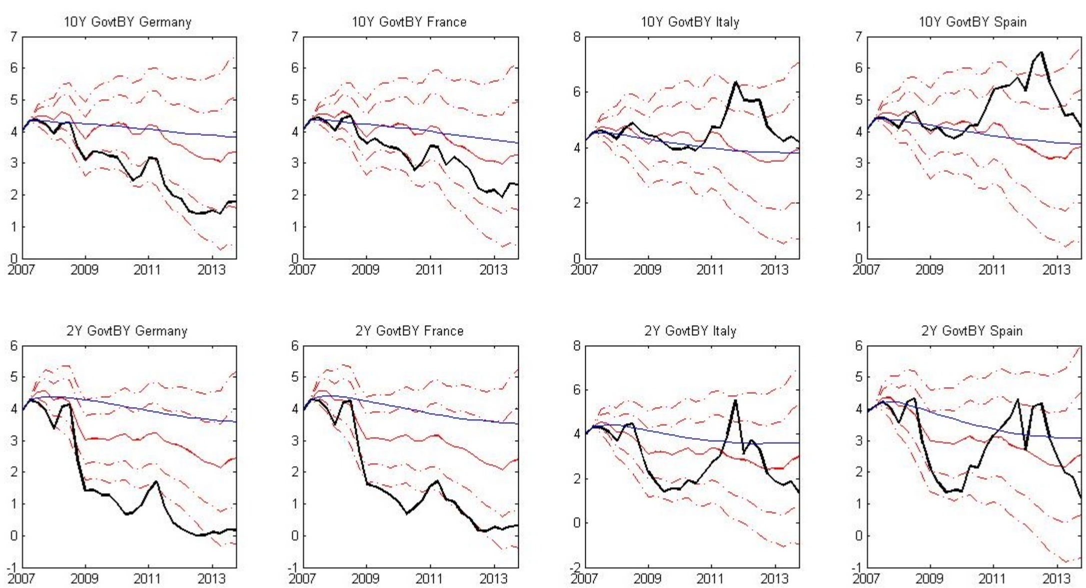


Figure 3.7: **Actual values, conditional and unconditional forecast of 10-year and 2-year government bond yields**



macroeconomic relationships remained stable. In the second half of 2008 all the GDPs fall abruptly and reach a negative peak in the second quarter of 2009. Also the conditional forecasts display a slowdown in that period but the actual values are well below it. This evolution can be easily connected to the Lehman Brothers bankruptcy. More in details, the recession has been stronger for Germany and Italy as GDP contracted of more than 7%. Unexpectedly, the conditional forecast predicts a stronger recession in Germany reaching the level of -2% while for France and Italy it does not even cross the -1%. The conditional expectation of Spain is even more surprising as it always fluctuates between 1% and 4%. The first conclusion stemming from the comparison of actual and forecasted values at the beginning of the crisis is that the European recession has been far too strong with respect to what the pre-crisis macroeconomic relationships would have implied and given the path of US variables.

Afterwards the recession mitigates in all countries and differences appear markedly. GDP growth rates slowly go back to positive values from mid 2010. France and Italy GDP growth remains in line with the conditional forecast up to 2011 and then display a positive peak above it. For France and Italy the peak is just above the 5th percentile of the distribution while for Germany the peak is much higher and GDP growth reaches a value which is more than double the one implied by the conditional forecast, i.e. the effects of the recovery have been much stronger in Germany. After the peak of 2011 the German GDP growth slows down and goes back in line with the conditional forecast up to the end of the sample. A second negative peak is recorded at the beginning of 2013. This slowdown of economic activity is in line with the conditional forecast for Germany and outside for France and Italy. French and German GDP remained stable in Q1 2013 while Italian GDP declined at a 2% rate as in Spain.

Spain deserves a special comment as the results have some peculiarities. Even though the fluctuations of its GDP growth are similar to the other ones, its level never goes back to the 4% of the beginning of 2007 and its always far below the conditional forecast. The positive peak in 2011 is just below 1% and, as for Italy, output was still contracting at a 2% rate at the beginning of 2013. The crisis had strong negative consequences in Spain and it seems that the austerity measures and reforms implemented did not succeed in reestablishing the potential pre-crisis level of growth. These particularly negative results for Spain are consistent with Ciccarelli, Ortega, and Valderrama (2012) as they find that Spain was the only country among the four considered here to be significantly influenced by a negative country-specific factor from 2008 on.

Single-country GDP evolution is very different from Euro-area aggregate and it is much less in line with the conditional forecast.

The divergence between Euro-area GDPs and their conditional forecasts is relevant in light of the fact that Giannone, Lenza, and Reichlin (2010) found that Euro-area GDP growth remained in line with historical regularities up to 2006. The results for the crisis period could be due to a break in the structural macroeconomic relationships or to some idiosyncratic shocks generated in the Euro area. Answering to this question would mean to condition the forecast on all the possible sources of idiosyncratic shock for all the countries considered. However, the use of endogenous variables in the conditioning set would impair the interpretation of the causal relationships. So, as for the current results, the only possible conclusion is that the underlying structural relationships are not able to explain the evolution of GDP in the four Euro-area countries considered and so either a break or an idiosyncratic shock must be occurred.

Results are different for inflation, measured as the annual growth rate of the HICP for each country, as the actual values are more often in line with the conditional expectation and are less heterogeneous than GDP growth rates. This finding points towards a more structural-based explanation of inflation developments, in line with most of the literature analysing inflation differentials, e.g. Beck, Hubrich, and Marcellino (2009) and Pirovano and Van Poeck (2011). More in details, the dynamics of the forecast is very similar for Germany and France, as it fluctuates around a mean value lower than 2%, while it has a wider distribution for Italy and Spain. Italian and Spanish predicted inflation fluctuate around 2% and 3% respectively. Again, given the pre-crisis structural relationship and the US economic crisis, the Spanish level is above the remaining three countries' forecasts. As regards actual inflation, all countries display an acceleration up to mid 2008 and then a slowdown with a negative peak in mid 2009 which is outside the conditional forecast distribution meaning that the effects of the financial crisis were not in line with previous structural macroeconomic relationships. Spain distinguishes because of the greater difference between the lower bound of the forecast distribution and the realised value which is close to -1%. Such a deflation in Spain implied higher real rates with respect to the other three countries, partially compensating for the cut in Euro-area interest rates by the ECB and justifying the slower recovery in GDP. Afterward inflation increases again and goes back in line with the predictions for all countries. Only in the last part of the sample it crosses again the lower bound of the distribution for France, Italy and Spain and this justifies the deflation concerns in this countries. Germany HICP is instead in line with its conditional expectation. This heterogeneity is particularly relevant from the point of view of policy makers as some measures to fight deflation are needed in France, Italy and Spain but not in Germany.

As regards government bond yields, the conditional forecasts are similar to each other: they have wide distributions whose means are predicted to remain almost stable around 3-4%. The relationship between the conditional forecast and the actual bond yields is similar across countries up to 2011. From 2009 on the 2-year yields fall in the lower part of the distribution probably as a consequence of the unconventional monetary policy measures implemented by the ECB. After 2011 the countries can be divided into two groups, Germany and France, whose actual yields are always in the lower part of the conditional forecast distribution, and Italy and Spain as they display a peak at the end of 2011 which is located in the upper part of the distribution. The pattern of German and French yields reflects a flight to quality effect which is particularly strong in 2-year government bond yields in 2010 and 2012 while 10-year government bond yields are more in line with pre-crisis structural macroeconomic relationships as they always lie inside the 5th and 95th quantiles of the conditional forecast distribution. As a consequence of the sovereign debt crisis, Italian and Spanish bond yields display a peak around 2012 which lies in the upper part of the forecast distribution signalling that the probability of those values to realize is low given the structural macroeconomic relationships. Therefore, what can be considered as abnormal, given the developments in US variables, is more the increase in short-term German and French bond prices rather than the rise in the Italian and Spanish yields. Overall, the 2008 brought about an increase in the heterogeneity between Euro-area government bond yields which is partly too strong with respect to what implied by the pre-crisis macroeconomic relationships.

In conclusion, the conditional forecast of single-countries variables shows that their evolution is much more less predictable than the one of Euro-area aggregate variables meaning that either a structural break or an idiosyncratic shock occurred.

3.5.3 Conditional Forecast with Euro-area Government Bond Yields in the Conditioning Set

The reason for the poor performance of the conditional forecast in predicting the actual path of Euro area variables is that either a structural break or an Euro-area specific shock occurred. A candidate explanation of this evidence is the Euro-area sovereign debt crisis which is an example of an idiosyncratic shock.

In order to test this conjecture, 2- and 10-year government bond yields have been used as conditioning variables in addition to US variables and the oil price index. However it is necessary to point out that this exercise suffers from an endogeneity problem due to the fact that the Euro-area bond yields are endogenous to the business cycle so that they might also reflect shocks originated in other sectors of the economy. Therefore a shortcoming of this exercise is that it cannot give a precise account of economic causality and results should be taken with caution.

Results for the Euro area aggregate and the single countries are displayed in figures 3.8 and 3.9.

Figure 3.8: **Actual values and conditional forecast of Euro-area GDP and HICP YoY**

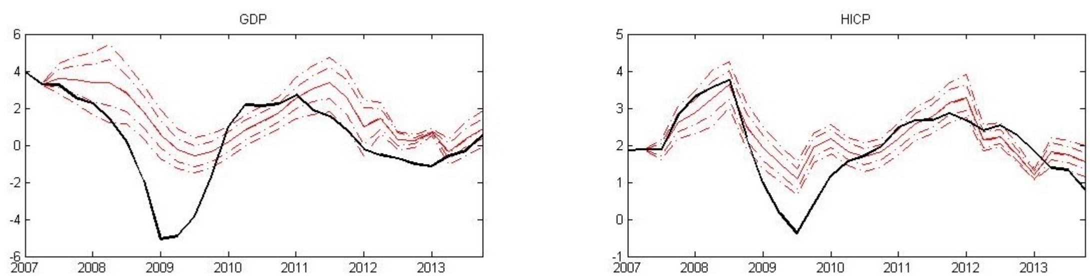
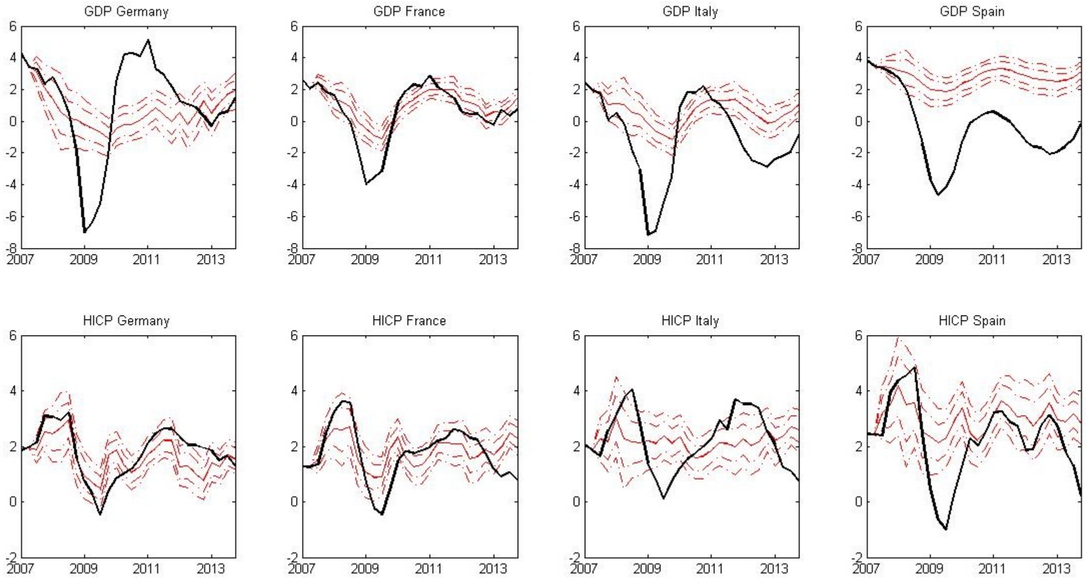


Figure 3.8 reports the results of the model with Euro-area aggregate variables. The comparison with figure 3.5 reveals that the conditional forecast distributions are tighter when the 2- and 10-year government bond yields are included into the conditioning set. However the forecast is not improved as it predicts a higher recovery in 2011, in the middle of the sovereign debt crisis. Finally, no information seem to be added to the period before 2011.

The results for the single Euro-area countries are displayed in figure 3.9. The inclusion of 2- and 10-year government bond yields makes the conditional forecast distributions a bit tighter mainly for Italy and Spain. The conditional expectations better approximate the 2009 and 2012 recessions. However the general results do not change, GDP growth and inflation are often not in line with its conditional forecast. One interesting finding is that the prediction ability of the conditional forecast for inflation worsen significantly at the end of the sample so that the current low levels of inflation in France, Italy and Spain seem to be even more worrisome.

Overall, taking into account the developments in sovereign debt markets does not help predicting real variables of the Euro area suggesting that the recent recession and economic slack cannot be attributed to financial market tensions and other reasons, either structural or idiosyncratic, should be investigated.

Figure 3.9: **Actual values and conditional forecast of GDP and HICP YoY**



3.6 Conclusion

This chapter has dealt with the analysis of the effects of the recent economic crisis in the Euro area in light of historical macroeconomic relationships. The aim is to provide the reader with a broad understanding of macroeconomic developments in the Euro area. This objective has been achieved through a conditional forecast exercise which allowed to predict the path of some European macroeconomic variables taking into account the developments in the US variables to capture the crisis shock. A large Bayesian VAR has been estimated up to mid 2007 and the parameters have been used to compute the conditional forecast up to the end of 2013. The comparison of the actual path of Euro area variables with their conditional forecast has allowed to evaluate whether the developments of the crisis period can be considered unusual given the structural macroeconomic relationships and the crisis shock.

The main focus of the analysis is on cross-country heterogeneity. Indeed, the macroeconomic variables of four Euro-area countries have been considered and two different VAR models, a first one with Euro-area aggregate variables and a second one with country-specific variables, have been estimated. In both models the conditioning set contains four US variables (GDP, CPI, the Fed funds rate and the 10-year government bond yield) and an oil price index.

The conditional forecast of Euro-area aggregate variables shows that the recessions caused by the financial and sovereign debt crisis are not in line with pre-crisis structural macroeconomic relationship. More interestingly, actual inflation was outside the conditional forecast distribution in 2009 and again in the last part of 2013 justifying the concerns about the current low level of inflation. The 10-year government bond yields lie instead always in the high-density region of the conditional forecast distribution. The effects of the sovereign debt crisis are visible in the peak of 2-year government bond yields at the beginning of 2012. The conclusion of this first analysis is that something like a structural break or an idiosyncratic shock occurred in the Euro-area in the first and second phase of the crisis.

The second VAR model considers country-specific variables in order to study the pattern of heterogeneity across the main 4 European economies, namely France, Germany, Italy and Spain. Results show that heterogeneity is present as country-specific variables are much less in line with their conditional forecast. Again the stronger effects of the financial and sovereign debt crisis cannot be explained neither by structural macroeconomic relationships nor by the crisis shock. The most interesting findings regard GDP and HICP. GDP is the variable which shows the higher degree of heterogeneity and it is less in line with its expectations, mainly for Spain. On the other hand, inflation shows less heterogeneity up to 2013 confirming the previous findings but the last values are outside the conditional forecast for France, Italy and Spain. This means that some measures to foster inflation are needed in these countries but not in Germany and this can be an issue for monetary policy. Results are less clear-cut for government bond yields. The developments outside the forecast distributions are due to the sovereign debt crisis and are the flight to quality in German and French yields and the rise in Italian and Spanish yields.

Overall, the effects of the crisis have been much more heterogeneous than what implied by structural relationships and the crisis shock. Moreover, the conditional forecast of single-countries variables shows that their evolution is much more less predictable than the one of Euro-area aggregate variables confirming that either a structural break or a strong idiosyncratic shock affected the Euro area after 2008. Finally, the sovereign debt crisis by itself seems not to be able to explain neither business-cycle and inflation heterogeneity, nor the recent recession and economic slack.

Appendix A. Data Description

The BVAR models consider US and Euro-area variables. The models are estimated over the sample 1995-2013 with quarterly data and five lags as variables are in levels.

US variables comes from Datastream and are:

- GDP growth: the log of real GDP multiplied by 4;
- Inflation: the log of CPI multiplied by 4;
- the Fed funds rate.

The oil price index is calculated by the IMF.

Euro-area aggregate variables are:

- GDP growth: the log of real GDP multiplied by 4, real GDP data come from the ECB;
- Inflation: the log of HICP multiplied by 4, HICP data come from Datastream;
- 2-year and 10-year government bond yields: data come from Datastream.

Euro-area country-specific variables are the same for Germany, France, Italy and Spain:

- GDP growth: the log of real GDP multiplied by 4, real GDP data come from the ECB;
- Inflation: the log of HICP multiplied by 4, HICP data come from the ECB;
- 2-year and 10-year government bond yields: data come from Datastream.

Appendix B. Estimation Procedure

This work is based on the estimation of a large Bayesian vector-autoregressive model.

The estimation is possible through the application of Bayesian shrinkage which amounts at increasing the tightness of the priors as more variables are added, i.e. by using informative priors it is possible to shrink the highly parametrised VAR model towards a more parsimonious benchmark representation as explained in Banbura, Giannone, and Reichlin (2010).

The priors are set as in Giannone, Lenza, and Primiceri (2012), i.e. the appropriate amount of shrinkage is automatically selected by maximizing the posterior distribution of the hyperparameters.

Giannone, Lenza, and Primiceri (2012) apply a Bayesian approach to the choice of the tightness of priors as they treat hyperparameters as any other unknown parameter and produce inference on them. In details, the VAR model is conceived as a hierarchical model described by a likelihood function $p(y|\theta)$ and a prior distribution $p(\theta|\gamma)$, where θ is the vector of the model's parameters and γ collects the hyperparameters. In this setting the hyperparameters can be assigned a hyperprior $p(\gamma)$ so that their posterior can be evaluated as follows:

$$p(\gamma|y) = p(y|\gamma) \cdot p(\gamma) \tag{3.5}$$

Here $p(y|\gamma)$ is the marginal likelihood, i.e. the density of the data as a function of the hyperparameters obtained after integrating out the uncertainty about the model's parameters θ, which can be decomposed into two terms, one capturing the in-sample fit and the other one penalizing for the model complexity. As the hyperprior is assumed to be flat, maximizing the posterior simply amounts at maximizing the marginal likelihood.

Another interesting feature of this approach is that the unconditional prior of the parameters $p(\theta)$ has fatter tails than its component distributions $p(\theta|\gamma)$, i.e. the conditional prior distributions, so that the posterior is less sensitive to discrepancies between the prior and the likelihood and inference is more robust.

As regards priors, Giannone, Lenza, and Primiceri (2012) consider a Normal - Inverse-Wishart distributions and a combination of the Minnesota, sum-of-coefficients and dummy-initial-observation priors for the VAR coefficients. The characteristics of these priors are briefly described in the following subsection. The use of this prior distributions on the VAR coefficients allows to take into account cointegration and unit roots, leading to more robust inference.

In general, this approach allows to obtain very accurate out-of-sample forecasts and impulse-response functions.

The posterior distributions of the model's parameters θ is derived by applying the MCMC algorithm 3.1 which features a Metropolis step to draw the vector of hyperparameters and a Gibbs sampler step to draw the parameters.

Algorithm 3.1 MCMC algorithm for the posterior of θ from Giannone, Lenza, and Primiceri (2012)

1. The hyperparameters γ are initialized at their posterior mode by maximizing the marginal likelihood.
2. Draw a candidate value of the hyperparameters γ^* from a Normal distribution with mean $\gamma^{(j-1)}$ and variance $c \cdot W$ where $\gamma^{(j-1)}$ is the previous draw of γ, W is the inverse Hessian of the negative of the log-posterior of the hyperparameters at the peak, and c is a scaling constant calibrated to obtain an acceptance rate of approximately 20%.
3. Set
$$\gamma^{(j)} = \begin{cases} \gamma^* & \text{with probability } \alpha \\ \gamma^{(j-1)} & \text{with probability } (1-\alpha) \end{cases}$$
where the acceptance probability is the ratio between the value posterior distribution in the candidate point and the value of the posterior in the previous step of the chain:
$$\alpha^{(j)} = \min\left\{1, \frac{p(\gamma^*|y)}{p\left(\gamma^{(j-1)}|y\right)}\right\}$$
4. Draw the parameters of the model $\theta^{(j)} = \left[\beta^{(j)}, \Sigma^{(j)}\right]$ from their conditional posterior distribution $p\left(\beta, \Sigma|y, \gamma^{(j)}\right)$ which is Normal - Inverse-Wishart.
5. Increment j to $j+1$ and go to 2.

Priors

One of the main issues in dealing with VAR models is the overfitting problem, i.e. the fact that the number of parameters to be estimated is much higher than the number of data in the sample. In a model with n endogenous variables, p lags and d exogenous variables, the number of parameters to estimate is $n(np+d)$ and this quantity grows geometrically with the number of variables n and proportionally with the number of lags p. Actually, in macroeconomics, the available time series include not many data, and then the estimation process will yield distorted estimates. In practice, this turns into estimates that are not significant but with a high value of the R^2.

Various solutions to the overfitting problem have been proposed and they all amount at putting prior constraints on the value of the model's parameters. Prior restrictions can be exact, i.e. some coefficients are pre-set to zero, or inexact, i.e. the uncertainty on the real value of the parameter is described by a prior distribution. This last case falls into the Bayesian approach to estimate VARs and the resulting issue is how to determine the parameters of the prior distributions.

Giannone, Lenza, and Primiceri (2012) use the following Normal - Inverse-Wishart priors for the model's parameters:

$$\Sigma \sim IW(\Psi, d) \tag{3.6}$$
$$\beta|\Sigma \sim N(b, \Sigma \otimes \Omega) \tag{3.7}$$

Here Σ is the variance-covariance matrix of the residuals and β is the coefficients vector and the hyperparameters Ψ, d, b, and Ω are functions of the lower-dimensional vector of hyperparameters γ.

As for Σ, the degrees of freedom are set to be $d = n + 2$ [5] and the scale matrix Ψ is assumed to be diagonal with an $n \times 1$ vector ψ on the main diagonal. Here ψ is an hyperparameter so that its value comes from the maximization of its posterior. On the other hand, the conditional prior for β is a combination of a Minnesota, sum-of-coefficients and dummy-initial-observation priors, which are described in the following subsections.

Minnesota Prior

The Minnesota prior has been introduced by Litterman (1980, 1986) so as to capture three statistical regularities of the macroeconomic time series:

- the existence of a trend;
- the fact that more recent lags of the variables contain more information on the recent value of the series than past values;
- the fact that the lags of a given variable contain more information on its current state than past values of other variables.

If these statistical regularities are applied, a VAR model becomes a multivariate random walk. Each coefficient is then assumed to be an independent, normally distributed random variable.

These features can be described by setting hyperparameters so that:

- the mean of the coefficients of the first lag of every variable is equal to one;
- the mean of the coefficients of all other lags is equal to zero;
- the variance of the coefficients depends inversely on the number of lags;
- the variance of the coefficient of variable j in equation g is lower than those of variable g.

The last two points derive from the concept that assigning a prior with higher variance implies giving more importance to data.

In practice, this set of restrictions can be modelled through a vector of hyperparameters $\Lambda \equiv (\lambda_1, \ldots, \lambda_h)$ and each hyperparameter is assigned the task to describe a specific aspect of the model. A possible specification is the following:

- λ_1 controls the value of the mean of the first lag of every variable and it is set equal to 1;
- λ_2 controls the variance of the lags of variable g in equation g;
- λ_3 controls the variance of the lags of variable j in equation g;
- λ_4 controls the speed of decrease of the variance as the number of lags increase;
- λ_5 controls the variance of the exogenous part;
- λ_0 controls the overall degree of *prior* uncertainty.

[5] This is the minimum value that guarantees to have a finite mean.

So, in this situation, the original estimation problem of $n\,(np+d)$ parameters has been converted into a problem of estimating six hyperparameters.

These hyperparameters determines the mean and the variance of the coefficients' distribution.

The mean vector of the VAR coefficients in equation i is $\beta_i^* = (0,\ldots,0,\lambda_1,0,\ldots,0)$ where λ_1 is in the ith position and their standard deviations are:

$$V_i = \begin{cases} \frac{\lambda_0\lambda_2}{l^{\lambda_4}} & \text{for the } i\text{th lagged endogenous variable,} \\ \left(\frac{\lambda_0\lambda_3}{l^{\lambda_4}}\right)\left(\frac{\sigma_{ii}}{\sigma_{jj}}\right) & \text{for the } j\text{th lagged endogenous variable,} \\ \lambda_0\lambda_5\sigma_{ii} & \text{for deterministic and exogenous variables.} \end{cases}$$

Here $l = 1,\ldots,p$ denotes the number of lags and $({}^{\sigma_{ii}}/_{\sigma_{jj}})$ is the scale parameter.

The Minnesota prior implies that the limiting form of each VAR equation is a random walk with drift.

Under a strict interpretation of the Minnesota prior, the variance-covariance matrix of the error term is diagonal with σ_{ii} determined from data. This simplifies the estimation problem because it is not necessary to specify how the prior distribution of the errors' variance-covariance matrix is related to the prior distribution of the coefficients.

For this reason Giannone, Lenza, and Primiceri (2012) used it in the context of a Normal-Inverse-Wishart distribution so that its first and second moments are:

$$\mathbb{E}\left[(B_l)_{ij}\,|\Sigma\right] = \begin{cases} 1 & \text{if } i=j \text{ and } l=1 \\ 0 & \text{otherwise} \end{cases}$$

$$Cov\left[(B_l)_{ij}\,,(B_k)_{hm}\,|\Sigma\right] = \begin{cases} \lambda_0^2\frac{1}{l^2}\frac{\Sigma_{ih}}{\psi_j/(d-n-1)} & \text{if } m=j \text{ and } k=l \\ 0 & \text{otherwise} \end{cases}$$

Here the indeces l and k refer to lags, i and h refer to equations and j and m refer to variables. The interpretation is therefore that the coefficients of the same variable and lag in different equations are allowed to be correlated and the variance is lower for the coefficients associated with more distant lag, due to the term $\frac{1}{l^2}$, so to shrink their mean to zero.

A shortcoming of the classical Minnesota prior is that it does not allow for unit roots and cointegration which are common features of macroeconomic time series. In order to account for unit roots and cointegration, the Minnesota prior is combined with the sum-of-coefficients prior and the dummy-initial-observation prior.

Sum-of-coefficients prior

The sum-of-coefficients prior has been proposed by Doan, Litterman, and Sims (1984) to account for unit roots and cointegration. This prior is implemented augmenting the dataset with some dummy observations on top of the data matrices. In particular, the artificial observations are n, one for each variable, and have the following structure:

$$\begin{aligned} y^+ &= diag\left(\frac{\bar{y}_0}{\mu}\right) \\ x^+ &= \left[0, y^+, \ldots, y^+\right] \end{aligned}$$

Here $\bar{y}_0$ is an $n \times 1$ vector containing the average of the first p observations of each variable. The matrix y^+ has dimension $n \times n$ while the matrix x^+ has dimension $n \times (1 + np)$. The hyperparameter μ controls the variance of this prior. Inference is produced using the Theil and Goldberger (1961) mixed estimation.

The prior implied by this dummy observations is centered at 1 for the sum of coefficients on own lags for each variable and 0 on other variables' lags. Furthermore, it introduces correlation between the coefficients on each variable in each equation. This prior states that a no-change forecast is a good forecast at the beginning of the sample. The limiting case in which $\mu = 0$ implies the presence of a unit root in each equation ruling out cointegration.

Dummy-initial-observation prior

The dummy-initial-observation prior has been introduced by Sims (1993) and it accounts for cointegration. It is implemented by adding the following artificial observations on top of the data matrices:

$$\begin{aligned} y^{++} &= \frac{\bar{y}_0'}{\delta} \\ x^{++} &= \left[\frac{1}{\delta}, y^{++}, \ldots, y^{++}\right] \end{aligned}$$

Here $\bar{y}_0'$ is an $1 \times n$ vector containing the average of the first p observations of each variable. The matrix y^{++} has dimension $1 \times n$ while the matrix x^{++} has dimension $1 \times (1 + np)$. The hyperparameter δ controls the variance of the prior. This prior introduces correlation between all coefficients in each equation and it states that a no-change forecast for all variables is a good forecast at the beginning of the sample.

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