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# ECB Monetary Policy and Term Structure of Interest Rates in the Euro Area: an Empirical Analysis

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# ECB monetary policy and term structure of interest rates in the Euro area: an empirical analysis

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## Abstract

This paper aims to explore the effects of the ECB monetary policy on the Euro area yield curve. Using cointegration techniques, this paper investigates the long-run relationships among the EONIA and Euro area money market interest rates. Results show that presence of cointegration was rejected for maturities longer than six years, implying that European Central Bank monetary policy actions do not exert significant impact on the entire spectrum of the yield curve. In addition, we also consider the transmission of EONIA interest rate volatility to the money market interest rates using EGARCH models. We find that EONIA volatility is transmitted to short and medium-period interest rates, whereas longer-term rates are not affected.

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## 1. Introduction

One of the main goals of the European Central Bank (henceforth ECB) is to influence the very short-term interest rates in the interbank money market (Hassler and Nautz, 2008). In particular, daily interest rate in the interbank market, the Euro Over Night Index Average (EONIA hereafter)[1], is crucial for signalling the ECB monetary stance, since the EONIA marks the first step of the monetary policy transmission process and the basis on which it acts in order to influence the behaviour of longer term interest rates (Benito et al., 2007). Some authors (Bernanke and Blinder, 1992; Estrella and Hardouvelis, 1991; Mishkin, 1990) argue that monetary policy is a major factor in term structure of nominal interest rate movements. The term structure of interest rates has been considered as a predictor of the future real economic activity such as consumption (non-durables plus services), consumer durables and investments[2] (Estrella and Hardouvelis, 1991): these activities are thought to depend on long-term interest rates. The efficacy of monetary policy is also evaluated by looking at his impact on long-term interest rates. As pointed out by Kozicki and Tinsley (1998), monetary policy affects the real economy since the long-run interest rates reflect the opportunity cost of investment and consumption. In other words, the monetary policy transmission mechanism takes place through the relationship between short-term (instrument) and long-term rates.

The aim of our study is to detect the effects of the ECB monetary policy on the term structure of the Euro area interest rates. Thus far there are not many studies on this issue. Why is noteworthy to explore whether ECB monetary policy has a significant impact on the term structure of Euro area money market interest rates? We may answer to this question arguing that the effectiveness of ECB monetary policy depends on the ability of the Central Bank to influence short term interest rates. By so doing, ECB will be able to obtain its main goals like to maintain price stability as well as safeguarding the value of the Euro.

Another issue we want to investigate in this work is how the volatility of the official interest rate of the ECB is transmitted to Euro area money market interest rates. Given that the ECB is a relatively young institution, there is little empirical evidence documenting whether the transmission of volatility along the term structure of interest rate is significant. Why is interesting to explore also

[1] The EONIA is a measure of the effective interest rate prevailing in the Euro area interbank overnight market. It is calculated as a weighted average of all overnight lending transactions between the most active credit institutions in the Euro area's money market (ECB, 2009).

[2] Roley and Sellon (1995) argue that monetary policy actions are transmitted to the economy through their effect on money market interest rates. By so doing a restrictive monetary policy by Central Banks pushes up both short-term and long-term interest rates, leading to less spending by economic agents such as households and firms. On the other side, an expansive monetary policy stimulate the economy by lowering the interest rates. These authors also point out that if the connection between Central Banks actions and short-term interest rates is quite close, the relationship between monetary policy actions and long-term interest rates appears weaker.

this question? As pointed out by Nautz and Offermanns (2008), Central Banks try to reduce excess volatility of the overnight rate for several reasons. Firstly, high volatility of overnight rates may confuse financial market participants about the policy-intended interest rates, secondly there is a danger that volatility at the short term of the term structure is transmitted to longer term rates with potential distorting effect on investment and consumption decisions of both firms and households.
In order to investigate the first issue we need to introduce the concept of the Expectation Hypothesis (EH hereafter) of term structure of interest rates. The EH states that the long-term interest rates comprise a weighted average of current interest rate and expected future short-term interest rate, plus a constant term premium (Gerlach, 1997). This means that long term interest rate are just based on the expected future short-term interest rates. By influencing the current short-term rate, monetary authorities modify also expected future short-term rates, affecting long-term interest rates as well. Although monetary policy can readily influence short-term interest rates, the connection between monetary policy and long term interest rates appear to be weaker and less reliable (Roley and Sellon, 1995; Camarero et al., 2008). Until now empirical studies have focused on effect of national central banks monetary policies on the yield curve (or the term structure of interest rates). Results of these studies show that the impact of monetary policy on the term structure of interest rates is at best mixed and usually also goes against the EH theory. Among these works, Cook and Hahn (1989a) examine the response of short-tem and long-term rates to changes of the Federal Funds Rates. Results show that changes in the funds rate were followed by large movement in short-term interest rates, moderate movements in intermediate-term rates and small but significant movements in long-term rates. Dale and Haldane (1993) measure the short-run response of UK money market interest rates[3] to monetary policy actions of the Bank of England. Results show a significant effect on interest rates of all maturities considered, although these effects decline as maturity lengthens. Rudebusch (1995) explores the link between the US Federal Reserve monetary policy and the term structure of interest rates. The author shows that the validity of the EH is rejected. Evans and Marshall (1998) find evidence that US monetary policy affects short-term interest rate while long-term rates are much less affected by monetary policy actions. Haldane and Read (2000) examine the response of the term structure of interest rates at the time of monetary policy changes in Germany, Italy, UK and USA over the period 1990-1997. Results show that at the short end of the yield curve, monetary policy in the UK and Italy has greater effect than in the USA and Germany. While looking at the longer end of the yield curve, there is hardy any response in the USA and Germany: this also means a high degree of credibility of the US and German Central Banks, in other words monetary policy actions, when these occurs, convey relatively little information about the future

[3] The movements of interest rates at seven different maturities (1, 3, 6 and 12-months and 5, 10 and 20-years) were considered.

policy actions of the authorities as these are well-understood and credible. This is not the case for Italy and the UK, where there is discernible response in longer-maturity rates, implying greater uncertainty regarding policy targets over the period 1990-1997. Kuttner (2001) estimates the impact of US monetary policy on interest rates at different maturities over the June 1989 - February 2000: results show that unanticipated increased of the Federal Funds Rate tend to increase interest rates at all maturities.[4] Thornton (2004) explores how the actions of the Bank of Japan get translated along the term structure of interest rate of the Japan. Beginning with the consideration that a necessary condition for the EH holding is that the short-term and long term rates to be co-integrated, Thornton (2004) finds that the *Gensaky* rate, used as a proxy of the Bank of Japan monetary policy, is cointegrated only for rates with maturities of 42 months or shorter. In other words results suggest that for the Japan the EH holds only at the short end of the maturity spectrum.[5] Braun and Shioji (2006) find that monetary policy of the Bank of Japan was able to affect both short- and long-term Japanese interest rates during 80's and 90's. However these authors point out that these results depend on specific hypothesis about the effects of restrictive monetary policies.[6]

As pointed out previously, our study aims also to evaluate how the volatility of the ECB affects the Euro area interest rates. In order to focus and further develop this issue, our study builds on earlier empirical works on volatility transmission along the term structure of interest rates. Ayuso et al. (1997) estimate the volatility of money market rates for various European countries before the European Monetary Union (henceforth EMU) took place. Using a sample data spanning from January 1988 to January 1993 as well as a methodology based on Exponential GARCH (EGARCH) models introduced by Nelson (1991), these authors find a significant volatility transmission from national overnight rates to longer-term money market rates for France, Spain and the UK. However, Vila (2002), using a similar methodology, does not find evidence of transmission of volatility from short-term interest rates to longer-term rates in the UK. These different results seem to be due to the different sample period (from April 1994 to June 2001) considered in Vila's work as well as the 1997 reforms of the Bank of England's open market operations.[7]

[4] This author used a dataset of interest rates with the following maturities: 3, 6, 12 months and 2,5,10, 30 years.

[5] As pointed out by Thornton (2004), the main consequence is that the Bank of Japan monetary policy might not be so much effective, given that the actions of the monetary authorities must be predictably transmitted to longer-term rates.

[6] Braun and Shioji (2006) suppose two alternative hypothesis about restrictive monetary policies effect. The first one is the so called "liquidity effect hypothesis" which is based on the consideration that restrictive monetary policy on the one side increase short-term interest rate while on the other side reduce output, prices and money supply. The second hypothesis is the "costly adjustment hypothesis" which argue that monetary policy tightening lower interest rates, as well as money supply, output and prices. The first hypothesis is more consistent with liberalized market (such as the USA) while the second one is more consistent with less-liberalized markets (like the Japanese one).

[7] From March 1997, the Bank of England introduced some changes in its money market operation, these included the introduction of the repo market as well as the regulatory framework for the management's bank liquidity (Tucker, 2004).

Cassola and Morana (2003) investigated whether EONIA volatility is transmitted along Euro area interest rate. They find that ECB announcement of interest rate changes affect strongly short-tem interest rates. Although using data at hourly frequency which contain much more information than data at lower frequency (such as daily, weekly and so on), the main drawback of their work is that the sample data used, from December 2000 to May 2002, is really short. Also Alonso and Blanco (2005) investigated whether EONIA volatility is transmitted along short-term Euro area interest rates. Results show that 1- and 3 month interest rates are particularly affected by EONIA volatility but 12-month interest rates does not. A weakness of their work is that they consider just interest rate with at 1- 3- and 12-month maturity as well as a short sample spanning from January 1999 to November 2003; extending the analysis to longer interest rate would have could evidence the behaviour of these rates to the monetary policy actions of a new institution like the ECB. Also Nautz and Offermanns (2008) examine the transmission of volatility of the EONIA rate along the yield curve. Focusing on the period after the ECB's new operational framework introduced in March 2004[8], these authors find that the EONIA volatility is transmitted along the yield curve when markets are partly confused about the ECB's interest rate decisions.

Against this background, our paper explores the impact of EONIA on the Euro area money markets interest rates through linear- and non-linear time series model as well as using a data set whose initial values coincide with the time the ECB has started to manage the Euro area monetary policy. More in deep, in contrast to previous research, we analyse, through cointegration methodologies, whether a long run relationship does exist among EONIA and term structure of interest rates as well as if these relationships went upon a breakdown due to changes in ECB monetary policy that probably occurred since 2004. Our results show that ECB monetary policy is able to influence short- and medium-term Euro area interest rates. We also surprisingly found that the relationship among the EONIA, used as a proxy of the ECB monetary policy and Euro area interest rates at several maturities went under a number of unique breakpoints especially during August 2007. We believe that the event associated at that time is the subprime credit crisis that, as pointed out also by Cassola et al. (2009), hit the Euro money market in August 2007. A further step to check robustness of results coming from linear regression analysis and cointegration tests was to employ a Principal Component Analysis which confirmed that EONIA rate affect short- and medium term interest rates while longer term rates are unaffected by EONIA's changes. Finally the second aim of our analysis, that is volatility transmission among EONIA and interest rates at

[8] From this date forward, in order to prevent excessive bidding from taking place during the main refinancing period operations, the ECB Governing Council decided to change the timing of the reserve maintenance period and to shorten the maturity of the main refinancing operations to one week (ECB, 2006).

different maturities, was detected through classical EGARCH models. Although these models have been broadly used in order to valuate volatility transmission among variables, our work depart from other studies given that we explore volatility transmission by using interest rate with maturities until 8 years while previous studies do not consider maturities with so long length. Our results show that the transmission of the EONIA volatility tends to decrease as the interest rate maturity increased.

The remainder of the paper is structured as follows. Section 2 is devoted to present the methodology. Section 3 describes the data. Section 4 presents empirical results and section 5 concludes.

## 2. Methodology

The aim of this section is to give a short description of all methodologies used in this work as well as the main reasons which lead us to use them. More specifically, in sub-section 2.1 we describe all methodologies used to detect the relationship among EONIA rate and Euro area term structure of interest rates. On the other side in sub-section 2.2 we describe the methodology employed to detect volatility transmission from EONIA to the Euro area money market interest rates.

### 2.1. Models used to analyse relationships among EONIA and Euro-area interest rates

#### 2.1.1. Linear regression analysis

Assuming that there is an association between the magnitude of monetary policy changes and the response of the term structure of interest rates, we estimate the following linear regression model:

$$\Delta R_{i,t} = c + \alpha_0 \Delta R_{m,t} + \alpha_1 \Delta R_{m,t-1} + \alpha_2 \Delta R_{m,t-2} + \delta_i \Delta R_{i,t-1} + u_t \qquad (1)$$

where $\Delta$ stands for the difference operator, $u_t$ the disturbance term, $\alpha$ is a measure of the *i*-th maturity market rate's response to changes in the monetary policy instrument, and $R_m$ stands for the monetary policy instrument. The lagged difference of the monetary policy instrument was included to capture any anticipation of the policy move. We also have that *i* = 1-week, 1 month, 2-month, 3-month, 6-month, 1-year, 2-year, 3-year, 4-year, 5-year, 6-year, 7-year, and 8-year interest rates maturities. As pointed out above, the main reason for using model in equation (1) is to test whether the *i*-th interest rate with maturity *t* responds to ECB monetary policy changes during the period considered in this work. Similar versions of equation (1) were extensively used by the empirical literature (Thornton, 1998, 2000; Haldane and Read, 2000; Drakos, 2001; Andersson et al., 2006; Kaketsis and Sarantis, 2006) addressing the issue of the effects of monetary policy actions on the term structure interest rates.

### 2.1.2. Engle-Granger cointegration test

After checking the effect of monetary policy changes on interest rates, we try to evaluate whether a long run relationships among monetary policy and interest rates exists. In our view checking the existence of a relation between EONIA and interest rates at different maturities in the Euro area money market, is an important exercise in order to detect how far monetary policy can influence interest rates.[9] In order to test whether markets interest rates are cointegrated with the monetary policy instrument, the Engle-Granger (EG henceforth) cointegration test (Engle and Granger, 1987) will be used. The EG procedure consists in estimating the cointegrating regression by OLS method, obtaining residuals, and applying unit root tests for the residuals. In order to obtain the mentioned residuals, the following OLS regression, that capture any potential long-run relationship among the variables, is performed:

$$X_t = c + \beta Y_t + \varepsilon_t \tag{2}$$

where $X_t$ is interest rate with maturity *i*, while $Y_t$ is the EONIA rate. The residuals from the above equation are considered to be temporary deviation from the long-run equilibrium. The ADF unit root tests are then conducted on the residual obtained from the previous equation based on the following linear equation:

$$\Delta\varepsilon_t = \alpha\varepsilon_{t-1} + \sum_{i=1}^{p} \beta_i \Delta\varepsilon_{t-i} + \omega_t \tag{3}$$

where $\alpha$ and $\beta$ are the estimated parameters and $\omega_t$ is the error term. The cointegration test is performed on the estimated coefficient $\alpha$. The number of optimal lags (*p*) in equation (3) is selected by either Akaike Information Criterion (AIC) or Schwartz Bayesian Criterion (SC). If the *t-statistic* obtained exceeds the critical value the residuals $\varepsilon_t$ from equation (2) are stationary, and then the variables $X_t$ and $Y_t$ are cointegrated.

### 2.1.3. Johansen cointegration test

To check the robustness of the EG methodology results, we decided also to apply the Johansen cointegration methodology. We describe shortly this methodology, more details can be found in Johansen (1988, 1991). Let $Y_t$ a vector a $n \times 1$ vector of non-stationary I(1) variables, the unconstrained Vector Autoregressive (VAR) representation is:

[9] This issue is not trivial given that if monetary policy is not able to influence long term interest rate then other monetary policy tools could be evaluated to obtain this results. In our view empirical results coming out from this experiment could be useful advices for those involved in the management of monetary policy at Central Bank level.

$$Y_t = A_1 Y_{t-1} + \ldots + A_k Y_{t-k} + \varepsilon_t \tag{4}$$

where $\varepsilon_t$ is a $n \times 1$ vector of innovations, and $A_i$ is a $n \times n$ matrix of parameters. Equation (4) can be re-written as a Vector Error Correction Model (VECM), that is:

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-1} + \varepsilon_t \tag{5}$$

where $\Gamma_i = -\sum_{j=i+1}^{p} A_j$ and $\Pi = \sum_{i=1}^{p} A_i - I$. As pointed out by Enders (2004), Granger's representation theorem asserts that if the coefficients matrix $\Pi$ has reduced rank $r < k$, then there exist $k \times r$ matrices $\alpha$ and $\beta$ each with rank $r$ such that $\Pi = \alpha\beta'$ and $\beta' y_t$ is I(0). $r$ is the number of cointegrating relations (the *cointegrating rank*) and each column of $\beta$ is the cointegrating vector. Johansen's procedure is to estimate the $\Pi$ matrix from an unrestricted VAR and to test whether we can reject the restrictions implied by the reduced rank of $\Pi$. Johansen proposed two different likelihood ratio tests of the significance of the reduced rank (that is $r$) of $\Pi$ matrix. The first one is the trace test expressed as:

$$\lambda_{trace} = -T \sum_{i=r+1}^{n} \ln(1 - \lambda_i) \tag{6}$$

The second one is the eigenvalue test expressed as:

$$\lambda_{\max} = -T \ln(1 - \lambda_i) \tag{7}$$

where $T$ is the sample size and $\lambda_i$ is the $i$-th largest canonical correlation. On the one hand, the $\lambda_{trace}$ tests the null hypothesis of $r$ or fewer cointegrating relationships, on the other hand the $\lambda_{\max}$ tests the null hypothesis of $r$ cointegrating relationships against the alternative of $r+1$ cointegrating vectors.

### 2.1.4. Gregory-Hansen cointegration test

A further methodology employed in this work is the Gregory and Hansen (1996) cointegration test. Previous EG methodology and Johansen cointegration test analyse long-run relations. Violation of the stability assumption is especially likely to occur over long periods, which constitute the focus of cointegration studies.[10] Gregory and Hansen (1996) show that structural breaks have

[10] It must be also pointed out that the simulation results of Gregory et al. (1996) show that the power of the Engle-Granger (1987) test of the null of no cointegration is substantially reduced when there is a break in the cointegrating

important implications for cointegration analysis because they deteriorate the power of cointegration tests and lead to the underejection of the null hypothesis of no cointegration. One may conclude, therefore, that cointegration relations do not exists, although they are present with structural changes. For this reason, we employ the Gregory-Hansen methodology that takes account of the possibility of instability in long-run relations. In other words, we want to detect if an eventual long run relationship between EONIA and each interest rate with different maturities has existed over all the entire period considered in this work (that is from 1999 to 2009) or if in these relationships has occurred a break. If these last hypothesis is verified then we can say that monetary policy changes are no more able to influence that interest rates with maturity *i* since the time occurred the break.

Gregory-Hansen methodology proposes a co-integration test that accommodates a single endogenous break in an underlying cointegrating relationship. More in deep, the Gregory-Hansen procedure considers three models (that is the level shift model, the level shift with trend model, and the regime shift model) allowing structural change in the cointegrating relationship. These models are the following:

$$x_t = \mu_0 + \mu_1 \varphi_t + \alpha y_t + \omega_t \tag{8}$$

$$x_t = \mu_0 + \mu_1 \varphi_t + \beta t + \alpha y_t + \omega_t \tag{9}$$

$$x_t = \mu_0 + \mu_1 \varphi_t + \alpha_1 y_t + \alpha_2 \varphi_t y_t + \omega_t \tag{10}$$

All these models permit structural change via the dummy variable $\varphi_t$ which is defined as $\varphi_t = 1$ if $t > \tau$, otherwise $\varphi_t = 0$. The symbol $\tau$ denotes the point in the sample at which a break occurs: the structural breakpoint is determined from the sample based on the information of the smallest *t-statistic*. Before achieving this last information, residuals of the above models are saved and employed in the following Dickey-Fuller equation:

$$\Delta \hat{u}_t = (\rho - 1)\hat{u}_t \omega_t \tag{11}$$

The resulting test statistic for each model is then given at the minimum value obtained for the *t-statistic* of $(\rho - 1)$. In other word, the null hypothesis of no cointegration against the alternative hypothesis of cointegration with a structural break of unknown timing is tested. The timing of structural change under the alternative hypothesis is estimated endogenously.

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relationship. To overcome this problem Gregory and Hansen (1996) extend the EG test to allow for breaks in either the intercept or the intercept and trend of the cointegrating relationship at unknown time (Cook, 2006).

### 2.1.5. Principal Component Analysis

The Principal Component Analysis (PCA) was the last methodology used. The main reason for using these methodology was to check further cointegration methodologies results.[11] The aim of the PCA is to obtain a small number of uncorrelated factors, called principal components (PCs), that best account for the correlations among the interest rates at different maturity. By using the PCA we try to identify the number of common factors affecting market rates across the term structure of interest rates and also whether the relation among these common factors and the monetary policy instrument is statistically significant. We start[12] by defining $s_{it}$ as the standardised *i*-th rate of interest at time *t*. Suppose that all interest rates considered in this work move proportionally, then we have:

$$s_{it} = \beta_{i1} f_{it} \tag{12}$$

for all *i* and *t*, with $\beta_{i1}$, a set of constants to be determined and $f_{it}$ the non-observable first principal component. One seeks to determine those $\beta_{i1}$ and $f_{it}$ which will minimise the residual sum $RS_i$, with:

$$RS_1 = \sum_t \sum_i \left(s_{it} - \beta_{i1} f_{it}\right)^2 \tag{13}$$

Through some algebra, we can show that the previous equation obtain its minimum when:

$$f_{it} = \frac{1}{\lambda_1} \sum_i z_{it} \beta_{i1} \tag{14}$$

where $\lambda_1$ denotes the largest eigenvalue of the matrix $(n_{ih})$. It may, therefore, be shown that:

$$\lambda_k = \sum_i \beta_{ik}^2 \tag{15}$$

where $\lambda_k$ denotes the *k*-th eigenvalue of the matrix $(n_{ih})$ ranked in descending order of magnitude, whereas the factor loadings[13] $\beta_{ik}$ are computed from the corresponding eigenvector. The previous equation implies that $f_{it}$ is a linear function of the observed variables with coefficients proportional to the elements from the eigenvector corresponding to the largest eigenvalue $\lambda_1$. The second principal component may be taken in the same way from resulting residuals.

[11] This way to use PCA as a control tool for checking cointegration results about the relationship among monetary policy changes and interest rates at different maturities was also employed by Drakos (2001)

[12] The exposition of this methodology follow closely that of Drakos (2001).

[13] We define factor loading each correlation coefficient between the *i-th* variable $s_{it}$ and the *k-th* principal component $f_k$.

In order to determine the explanatory power of each PC, two measures are used: the eigenvalue and the cumulative $R^2$ of the PC. The significance of a PC is determined by applying the Kaiser rule of eigenvalue greater or equal to 1 (Kaiser, 1960). The correlations between the variables (i.e. interest rates at different maturities) and the principal components extracted by the Kaiser rule, are also called factor loadings. In some cases, the interpretation of principal components is simplified if the matrix of factor loadings is transformed. Several rotational strategies have been proposed in order to obtain such transformation. The aim of all these strategies is to obtain a clear pattern of loadings, that is, factors that are clearly marked by high loadings for some variables and low loadings for others. Among these strategy we used the varimax rotation given that is the easiest.

### 2.2. Analysing EONIA volatility transmission to the Euro area term structure of interest rates

#### 2.2.1. EGARCH models

The further point we are going to investigate is whether the volatility of the EONIA is transmitted to the money market interest rates. In order to get this result our procedure is based upon the work of Ayuso et al. (1997). Following this procedure, both conditional mean and conditional variance of interest rates with different maturities are estimated jointly. Therefore, all interest rates $i_t$ are modelled in first differences, that is $\Delta i_t = (i_t - i_{t-1})$, and a unit co-integrating vector, $(i_{t-1} - i^*_{t-1})$, is imposed. The model then is:

$$\Delta i_t = c + \phi(i_{t-1} - i^*_{t-1}) + x_t \beta + \varepsilon_t \tag{16}$$

The parameter $\phi$ capture how fast the Euro overnight rate EONIA, $i_t$, returns to its long-run value, the MRO rate $i^*_t$ which is assumed as a proxy of the ECB's key policy rate. The mean equation includes a constant c, while $x_t$ is a vector that contains lags of the dependent variable. We model the conditional variance of the interest rates as an EGARCH process (Nelson, 1991). This specification allows us to deal with non-linearities and asymmetric responses of conditional variances to negative and positive shocks, which seems to be relevant in explaining the behaviour of interest rates at different maturities. In our specification of the conditional volatility we restrict the extent of possible spillovers to those arising from the EONIA to the other rates. In other words, we follow a univariate specification for the conditional variance and include the (log of the) estimated volatility of the EONIA. This procedures, which coincides with the approach followed by Aruso et al. (1997), is supported by the anchor role played by overnight rates for the term structure of interest rates, in the sense that other rates are formed taking into account overnight rates. Thus the model of the conditional variance is the following:

$$\log(\sigma_t^2) = \omega + \beta \log\left(\sigma_{t-1}^2\right) + \alpha\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right| + \gamma \frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \lambda Eonia_t + \varepsilon_t \tag{17}$$

where $\sigma_t^2$ is the variance of the *i*-th interest rate at period *t* conditional to information up to period *t-1* and $\varepsilon_t$ is the unexpected component of the interest rate *i*. If $\gamma$ is greater (lower) than zero, then the response of the conditional variance to a positive shocks (surprise change of the interest rate) at period *t-1* is larger (lower) than the response to a negative shock. The flexible log-linear form of the conditional variance means that we do not have to restrict the coefficients in the conditional variance specification to be-non negative to ensure a non-negative variance. This is important when we want to explore links between EONIA and interest rates at different maturities, given that either volatility transmission, i.e. a positive relation between volatility at different points on the yield curve, or volatility transfer, i.e. a negative volatility relation, are possible at priori (Ayuso et al., 1997). The conditional variance process (eq. 17), together with the conditional mean specification (eq.16), were then jointly estimated using maximum likelihood techniques for a variety of interest rates maturities.

## 3. Data

This work employs market interest rates from the Euro area money market across the term structure of the interest rates from January 2, 1999 to April 20, 2009. The dataset include EONIA interest rate as well as the following interest rates maturities: 1-week, 1-month, 2-months, 3-months, 6-months, 1-year, 2-years, 3-years, 4-years, 5-years, 6-years, 7-years, and 8-years. All data were obtained from *Thomson Financial Datastream*. Table 1 reports summary statistics for short, medium, and long term money markets maturity as well as EONIA. Figure 1a, 2a, and 3a graph all yields at different maturities in appendix A.

**Table 1 – Summary statistics of interest rates**

| | Maximum | Minimum | Mean | St.Dev | Skewness | Kurtosis |
|---|---|---|---|---|---|---|
| 1-week | 5.171 | 0.912 | 3.184 | 0.996 | 0.126 | 1.754 |
| 1-month | 5.186 | 1.157 | 3.237 | 1.012 | 0.159 | 1.643 |
| 2-month | 5.247 | 1.356 | 3.291 | 1.039 | 0.183 | 1.588 |
| 3-month | 5.391 | 1.547 | 3.335 | 1.064 | 0.217 | 1.590 |
| 6-month | 5.437 | 1.711 | 3.380 | 1.070 | 0.220 | 1.619 |
| 1-year | 5.469 | 1.696 | 3.467 | 1.048 | 0.184 | 1.676 |
| 2-year | 5.580 | 1.885 | 3.604 | 0.943 | 0.151 | 1.834 |
| 3-year | 5.66 | 2.194 | 3.761 | 0.860 | 0.158 | 1.967 |
| 4-year | 5.710 | 2.437 | 3.901 | 0.797 | 0.175 | 2.098 |
| 5-year | 5.760 | 2.617 | 4.023 | 0.754 | 0.193 | 2.211 |
| 6-year | 5.810 | 2.747 | 4.134 | 0.725 | 0.213 | 2.297 |
| 7-year | 5.850 | 2.858 | 4.234 | 0.704 | 0.232 | 2.356 |
| 8-year | 5.890 | 2.961 | 4.322 | 0.689 | 0.244 | 2.391 |
| EONIA | 5.750 | 1.340 | 3.118 | 0.963 | 0.371 | 1.931 |

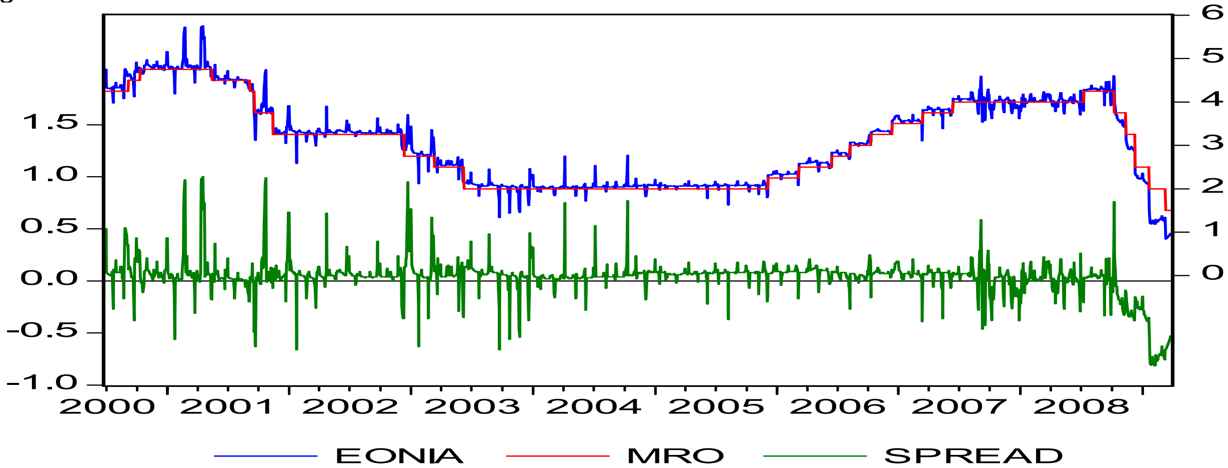
Results of the unit root test for the level and the first difference of time series are reported in table 2. The hypothesis of stationarity is rejected at the 5% level for all series. These results indicates that the series are integrated in the first order and validate the use of models such as cointegration analysis.

**Table 2 – Unit root tests on level and first difference**

| | ADF statistic | *P-value* | PP statistic | *P-value* |
|---|---|---|---|---|
| Level | | | | |
| 1-week | -0.233 | 0.931 | -0.410 | 0.905 |
| 1-month | -0.732 | 0.836 | -0.661 | 0.854 |
| 2-month | -0.825 | 0.811 | -0.732 | 0.836 |
| 3-month | -0.915 | 0.783 | -0.832 | 0.809 |
| 6-month | -0.955 | 0.756 | -0.975 | 0.763 |
| 1-year | -0.744 | 0.833 | -1.067 | 0.730 |
| 2-year | -1.227 | 0.664 | -1.338 | 0.613 |
| 3-year | -1.488 | 0.539 | -1.552 | 0.506 |
| 4-year | -1.601 | 0.481 | -1.697 | 0.432 |
| 5-year | -1.738 | 0.411 | -1.787 | 0.387 |
| 6-year | -1.819 | 0.371 | -1.830 | 0.365 |
| 7-year | -1.827 | 0.367 | -1.845 | 0.358 |
| 8-year | -1.853 | 0.354 | -1.853 | 0.354 |
| EONIA | -1.251 | 0.654 | -1.616 | 0.474 |
| First difference | | | | |
| 1-week | -23.949 | 0.00 | -40.681 | 0.00 |
| 1-month | -10.51 | 0.00 | -44.733 | 0.00 |
| 2-month | 10.333 | 0.00 | -46.480 | 0.00 |
| 3-month | -10.166 | 0.00 | -44.488 | 0.00 |
| 6-month | -10.670 | 0.00 | -48.183 | 0.00 |
| 1-year | -38.405 | 0.00 | -42.278 | 0.00 |
| 2-year | -42.971 | 0.00 | -43.541 | 0.00 |
| 3-year | -44.654 | 0.00 | -44.870 | 0.00 |
| 4-year | -45.983 | 0.00 | -46.123 | 0.00 |
| 5-year | -46.986 | 0.00 | -47.019 | 0.00 |
| 6-year | -48.232 | 0.00 | -48.231 | 0.00 |
| 7-year | -47.114 | 0.00 | -47.121 | 0.00 |
| 8-year | -47.483 | 0.00 | -47.490 | 0.00 |
| EONIA | -20.906 | 0.00 | -76.346 | 0.00 |

As pointed out previously, this work uses the EONIA rate as a proxy of the ECB monetary policy instrument. As we may see in the following figure, the EONIA follows closely the behaviour of the Main Refinancing Operation (MRO hereafter) interest rate, that the key ECB interest rates. The MRO plays a pivotal role in pursuing the aim of  steering interest rate and signalling the stance of ECB monetary policy. From the perspective of signalling the monetary policy stance, the EONIA should move in close distance to the MRO. Figure 1 illustrates the evolution of both the EONIA and MRO rates for the complete sample period; as we can see from that figure, the spread has steadily widened since the introduction of the ECB's new operational framework in March 2004 and stabilized since autumn 2005. While a modest spread between the EONIA and the MRO is not of general concern for monetary policy, a large spread could blur the signalling of the stance of monetary policy and, in extreme cases, may hinder the ECB's stability to steer the overnight rate. Such a loss of control over the short end of the yield curve may have huge costs in terms of credibility and commitment of the ECB We may also note that the EONIA rate shows some spikes normally around the end of the maintenance periods.[14]

**Figure 1 – EONIA and MRO interest rates**




## 4. Empirical results

This section shows results coming up from methodologies described previously. More in deep, in sub-section 4.1 we describe results relatively to the relationship among EONIA rate and Euro area term structure of interest rate, whilst in sub-section 4.2 we describe results relatively to the volatility transmission.

### 4.1. Results from analysing the relationship among EONIA and Euro-area interest rates

#### 4.1.1. Linear regression analysis results

Table 3 summarizes the empirical results for the linear regression model described in eq. (1) of 2.1.1 sub-section. In almost all the cases, the lead and the lag of the policy instrument were significant implying that markets indeed anticipated ECB monetary policy actions. Both the magnitude of the contemporaneous impact of monetary policy changes on markets rate ($\alpha_0$) and the total impact $(\alpha_0 + \alpha_1 + \alpha_2)$ are decreasing with the maturity of the market rate considered. The analysis evidences that monetary policy tools affect short-term rates. Hence, one may infer that ECB monetary policy has the ability to affect the cost of capital and thus, real investments. Are these results in line with those reported in the empirical literature? The finding of table 3 conform to results of several studies (for example Buttiglione et al., 1997; Cook and Hahn, 1989a; Mehra, 1996; Roley and Sellon, 1995), that is the empirical evidence on the quantitative effect of monetary policy on the short- and long-term interest rates finds on average a positive relationship: an increase

[14] The ECB requires credit institutions to hold minimum reserves on accounts with the national central banks: minimum reserves are calculated as an averaging provision for the whole month covered by the maintenance period (Benito et al. 2007). The reserve maintenance period, which is defined by the ECB, is a two-week period usually beginning on a Thursday and ending on a Wednesday over which most depositary institutions must maintain required reserves and over which daylight overdrafts are monitored and charges may be assessed. Indicative calendar of reserve maintenance periods may be found at http://www.ecb.int/events/calendar/reserve/html/index.en.html

in the central bank rates leads to an increase in the interest rates of all maturities. Also more sophisticated empirical analysis of the relationship between monetary policy and interest rates seem to confirm these results. For example studies by Cook and Hahn (1989b) and by Radecky and Reinhart (1994) examined the response of short-term and long-term rates of the US money market to changes in a measure of the Federal Funds Rate. Using a similar approach, Dale (1993) measured the short-run response of UK market rates to monetary policy actions by the Bank of England. Although all three studies find that policy actions have a significant positive effect on interest rates of all maturities, these effects decline as maturity lengthens. Also in this work the estimated response of long-term rates to policy actions tends to be lower than the response of the short-term interest rates. The last result seem to be also confirmed by Evans and Marshall (1998). These authors show empirical evidence that monetary policy primarily affect short-term interest rates, with a diminishing effect on longer-term rates: given these results, they argue that that monetary policy is a nontrivial source of the variability of short-term rates, but it represents a negligible source of variability for long-term rates. In other words this means that much of the response of longer-term rates can be explained by the expectations hypothesis. Given that the same dynamics we find in our results, we may say that the there is some evidence of the existence of the EH also in our results.

**Tabl e 3 - Estimating the effect of monetary policy actions**

| Maturity | c | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $\delta$ | Adj $R^2$ | DW | F-stat |
|---|---|---|---|---|---|---|---|---|
| 1-week | -0.001 | 0.085** | 0.031** | 0.04** | 0.126** | 0.077 | 2.038 | 48.561 |
| | (0.20) | (0.00) | (0.00) | (0.00) | (0.00) | | | [0.00] |
| 1-month | -0.001 | 0.033** | 0.011** | 0.021 | 0.234** | 0.085 | 2.05 | 54.108 |
| | (0.05) | (0.00) | (0.02) | (0.00) | (0.00) | | | [0.00] |
| 2-month | -0.001** | 0.023** | 0.004 | 0.0157 | 0.326** | 0.136 | 2.131 | 91.01 |
| | (0.029) | (0.00) | (0.269) | (0.00) | (0.00) | | | [0.00] |
| 3-month | -0.001** | 0.0195** | 0.0026 | 00013 | 0.388** | 0.178 | 2.169 | 124.73 |
| | (0.035) | (0.00) | (0.42) | (0.00) | (0.00) | | | [0.00] |
| 6-month | -0.001** | 0.02** | 0.006 | 0.017 | 0.285** | 0.105 | 2.108 | 68.434 |
| | (0.033) | (0.00) | (0.092) | (0.00) | (0.00) | | | [0.00] |
| 1-year | -0.001 | 0.027** | 0.013** | 0.016 | 0.203** | 0.051 | 2.019 | 35.231 |
| | (0.07) | (0.00) | (0.02) | (0.004) | (0.00) | | | [0.00] |
| 2-year | -0.0012 | 0.031** | 0.017** | 0.013 | 0.09** | 0.017 | 2.006 | 11.084 |
| | (0.15) | (0.00) | (0.027) | (0.094) | (0.00) | | | [0.00] |
| 3-year | -0.001 | 0.03** | 0.014 | 0.008 | 0.063** | 0.008 | 2.005 | 6.117 |
| | (0.181) | (0.00) | (0.08) | (0.32) | (0.002) | | | [0.00] |
| 4-year | -0.001 | 0.028** | 0.014 | 0.006 | 0.035 | 0.005 | 2.002 | 4.04 |
| | (0.195) | (0.00) | (0.094) | (0.447) | (0.094) | | | [0.00] |
| 5-year | -0.001 | 0.025** | 0.012 | 0.003 | 0.014 | 0.003 | 1.999 | 2.77 |
| | (0.207) | (0.00) | (0.125) | (0.642) | (0.499) | | | [0.02] |
| 6-year | -0.001 | 0.024** | 0.013 | -0.0004 | -0.011 | 0.002 | 1.998 | 2.548 |
| | (0.212) | (0.003) | (0.108) | (0.706) | (0.569) | | | [0.03] |
| 7-year | -0.001 | 0.021** | 0.011 | 0.003 | 0.011 | 0.001 | 1.998 | 2.134 |
| | (0.219) | (0.008) | (0.147) | (0.684) | (0.573) | | | [0.074] |
| 8-year | -0.001 | 0.02** | 0.009 | 0.002 | 0.004 | 0.001 | 1.997 | 1.847 |
| | (0.220) | (0.01) | (0.204) | (0.767) | (0.84) | | | [0.117] |

*Notes.* Standard error in parenthesis. ** statistically significant at 5% level. If the *p-value* just below the F-statistic is essentially zero we reject the null hypothesis at the 5% significance level that all of the regression coefficients are zero.

### 4.1.2. Engle-Granger cointegration test results

The long-run relationship among the EONIA and interest rates at different maturities, is then analysed by EG cointegration test. The first step was to estimate the following equation by OLS method:

$$I_i = c + \alpha EONIA_t + \mu_t \qquad (18)$$

Results (table 4) show that in the long-run the coefficient of the EONIA rate is found to be positive and statistically significant. The EONIA rate explains about 97% of the variation of the one-week maturity as shown by the $R^2$ value. Note, however, that since both the variables are non-stationary in their levels, the standard regression interpretation of the coefficient is no valid. This lead us to the Engle-Granger test of the residuals from this regression. The ADF unit root test was applied on the residuals from this long-run regression in order to examine whether the residual series is stationary or non-stationary. The ADF test on the residuals from the long-run equation is also presented in table 4. The results show that the null is rejected in any case with the exception of long-run relationships between the EONIA and 7- and 8-year maturities relatively to the model without trend. Based on this results, we can conclude that the EONIA and interest rates at different maturities are generally cointegrated.

**Table 4 – Results of the Engle-Granger cointegration test**

| Cointegration equation[a] | $R^2$ | ADF Without Trend | ADF With Trend |
|---|---|---|---|
| 1-Week = 0.081 + 0.991EONIA[8.15][323.3] | 0.975 | -21.834(1) | -22.687(1) |
| 1-Month = 0.124 + 0.994 EONIA [8.42][218.98] | 0.947 | -13.035(1) | -14.384(1) |
| 2-Month = 0.139 + 1.01 EONIA [7.48][176.58] | 0.921 | -10.195(1) | -11.880(1) |
| 3-Month = 0.156 + 1.016 EONIA [7.135][ 151.39] | 0.895 | -8.577(1) | -10.228(1) |
| 6-Month = 0.252+ 1.003 EONIA [9.958][ 128.79] | 0.861 | -7.224(1) | -8.429(1) |
| 1-Year = 0.442+978 EONIA [15.874][114.34] | 0.830 | -6.591(1) | -6.914(1) |
| 2-Year = 0.963 + 0.863 EONIA [31.611][92.291] | 0.761 | -5.646(1) | -5.644(1) |
| 3-Year = 1.408 + 0.776 EONIA [44.915][80.599] | 0.709 | -5.117(1) | -5.225(1) |
| 4-Year = 1.773 + 0.707 EONIA [55.413][71.955] | 0.660 | -4.678(1) | -4.979(1) |
| 5-year = 2.063 +0.655 EONIA [63.422] [65.605] | 0.617 | -4.356(1) | -4.875(1) |
| 6-year = 2.308 + 0.614 EONIA [69.25][60.04] | 0.574 | -4.038(1) | -4.766(1) |
| 7-Year = 2.521 + 0.580 EONIA [73.64][55.23] | 0.533 | -3.760(1) | -4.676(1) |
| 8-Year = 2.704 + 0.552 EONIA [77.260][51.354] | 0.497 | -3.542(1) | -4.614(1) |

*Notes*. [a]It has been reported only equation without trend, equation with trend is available upon request to authors. The number in brackets are the lag lengths which have been selected using Schwarz Criterion. The number in square brackets are *t-statistics*. In ADF test, MacKinnon (1991) critical value are -3.90, -3.34 and -3.05 on model without trend, and -4.33, -3.78 and -3.50 on model with trend for 1%, 5%, 10% meaning fullness levels.

### 4.1.3. Johansen cointegration test results

The expectation hypothesis of the term structure states that the long-term interest rate is determined by the market's expectation of the short-term rate. This implies that market interest rates at different maturity should be co-integrated with the EONIA rate if monetary policy actions are thought to have any effect on the term structure. Table 5 summarizes the results for the cointegration rank of the bivariate system based on Johansen procedure. The first step is to estimate a vector autoregrssion (VAR) model with two variable, that is the EONIA and interest rate with maturity $i$ (as specified in the methodology section). After selecting the appropriate VAR of order $p$, we checked that residual of the estimated models are not white noise. All VAR models so estimated seem to fill this requests given that residuals are not autocorrelated (see Appendix B). After carrying on the cointegration test we can say that the null hypothesis (i.e. no cointegration among each pair of variables) was rejected in all but three cases. These results imply that monetary policy has a significant impact on market rates across the term structure of interest rates in the short- and medium-period.

**Table 5 – Johansen bivariate cointegration results**

| Maturity | $H_0$ | $H_1$ | Tests Statistic | p-value[a] | $H_1$ | Tests Statistic | p-value[a] |
|---|---|---|---|---|---|---|---|
| 1-week | $r = 0$ | $r = 1$ | 71.752** | 0.00 | $r \geq 1$ | 71.575** | 0.00 |
| | $r \leq 1$ | $r = 2$ | 0.176 | 0.674 | $r = 2$ | 0.176 | 0.674 |
| 1-month | $r = 0$ | $r = 1$ | 51.916** | 0.00 | $r \geq 1$ | 51.368** | 0.00 |
| | $r \leq 1$ | $r = 2$ | 0.547 | 0.459 | $r = 2$ | 0.547 | 0.459 |
| 2-month | $r = 0$ | $r = 1$ | 23.451** | 0.0026 | $r \geq 1$ | 22.943** | 0.0017 |
| | $r \leq 1$ | $r = 2$ | 0.507 | 0.476 | $r = 2$ | 0.507 | 0.476 |
| 3-month | $r = 0$ | $r = 1$ | 17.177** | 0.0276 | $r \geq 1$ | 16.613** | 0.02 |
| | $r \leq 1$ | $r = 2$ | 0.564 | 0.452 | $r = 2$ | 0.564 | 0.452 |
| 6-month | $r = 0$ | $r = 1$ | 9.379 | 0.331 | $r \geq 1$ | 8.763 | 0.306 |
| | $r \leq 1$ | $r = 2$ | 0.616 | 0.432 | $r = 2$ | 0.616 | 0.432 |
| 1-year | $r = 0$ | $r = 1$ | 17.716** | 0.022 | $r \geq 1$ | 15.778** | 0.028 |
| | $r \leq 1$ | $r = 2$ | 1.938 | 0.163 | $r = 2$ | 1.938 | 0.163 |
| 2-year | $r = 0$ | $r = 1$ | 26.243** | 0.00 | $r \geq 1$ | 24.139** | 0.00 |
| | $r \leq 1$ | $r = 2$ | 2.103 | 0.147 | $r = 2$ | 2.103 | 0.147 |
| 3-year | $r = 0$ | $r = 1$ | 25.438** | 0.001 | $r \geq 1$ | 23.592** | 0.001 |
| | $r \leq 1$ | $r = 2$ | 1.845 | 0.174 | $r = 2$ | 1.845 | 0.174 |
| 4-year | $r = 0$ | $r = 1$ | 20.506** | 0.00 | $r \geq 1$ | 18.938** | 0.008 |
| | $r \leq 1$ | $r = 2$ | 1.568 | 0.21 | $r = 2$ | 1.568 | 0.210 |
| 5-year | $r = 0$ | $r = 1$ | 17.088** | 0.028 | $r \geq 1$ | 15.761** | 0.028 |
| | $r \leq 1$ | $r = 2$ | 1.327 | 0.249 | $r = 2$ | 1.327 | 0.249 |
| 6-year | $r = 0$ | $r = 1$ | 14.054 | 0.081 | $r \geq 1$ | 12.966 | 0.079 |
| | $r \leq 1$ | $r = 2$ | 1.088 | 0.296 | $r = 2$ | 1.088 | 0.296 |
| 7-year | $r = 0$ | $r = 1$ | 11.654 | 0.174 | $r \geq 1$ | 10.776 | 14.264 |
| | $r \leq 1$ | $r = 2$ | 0.878 | 0.348 | $r = 2$ | 0.878 | 3.841 |
| 8-year | $r = 0$ | $r = 1$ | 10.068 | 0.275 | $r \geq 1$ | 9.351 | 0.258 |
| | $r \leq 1$ | $r = 2$ | 0.716 | 0.397 | $r = 2$ | 0.716 | 0.397 |

*Notes.* [a]MacKinnon-Haug-Michelis (1999) p-values. ** Denotes rejection of the null hypothesis at the 5% level.

### 4.1.4. Gregory-Hansen cointegration test

Table 6, which reports the results of the Gregory-Hansen approach, shows a different picture with regard to long-run relationships. According to Gregory-Hansen approach, the results indicate the presence of a number of bivariate cointegration relations between the EONIA and interest rates over the entire period. More in depth the EONIA rate is cointegrated with interest rate with maturity until 1 year albeit with a break in the cointegration relationship. Overall we find a number of unique breakpoints which are almost all in the period August 2007. The economic event associated at that time is the financial crisis that began on August 9, 2007 and continued into 2008 and 2009. A complete chronology of the crisis might start on February 2007 when several large subprime mortgage lenders started to report losses. But the real start came on Tuesday August 9, when the French bank BNP Paribas temporarily frooze three of its fund that invested in the US subprime mortgages prompting central banks to take steps to calm investors. Indeed, as a direct consequence, overnight interest rates in Europe shot up, and the ECB immediately responded with the largest short-term liquidity injection in its 9 year history, €94.8 billion. The following day, ECB injected further liquidity for an amount of €61.1 billion. Meanwhile, the US Federal Reserve injected $24billion in reserves into the US banking system on Thursday and further $38 billion on Friday (Cecchetti, 2008). The Central Banks supplied these large quantities of reserves in response to increased banks demand. The main reasons of banking system demand was that financial institutions were experiencing large losses as well as strong reduction in the supply of the interbank lending market.[15]

[15] As pointed out by Cecchetti (2008), two reasons might explain the unwilling of banking system to lend. The first one is that banks perceived a substantial increase in credit risk, so they increased the interest rate they were charging. Secondly banks that normally lend faced a combination of uncertainties and constraints related to the size of their own balance sheets.

**Table 6 - Gregory-Hansen cointegration test results**

| Variables | Model | Breakpoint date | GH Test statistic | 5% Critical Value | Reject Ho of no cointegration |
|---|---|---|---|---|---|
| EONIA – 1 week | C | 2007:08:28 | -15.321 | -4.92 | Yes |
| EONIA – 1 week | C/T | 2007:08.28 | -15.319 | -5.29 | Yes |
| EONIA – 1 week | C/S | 2007:08:28 | -15.895 | -5.50 | Yes |
| EONIA – 1 month | C | 2007:08;28 | -11.032 | -4.92 | Yes |
| EONIA – 1 month | C/T | 2007:08:28 | -11.033 | -5.29 | Yes |
| EONIA – 1 month | C/S | 2007:08:28 | -11.112 | -5.50 | Yes |
| EONIA – 2 month | C | 2007:08:27 | -8.847 | -4.92 | Yes |
| EONIA – 2 month | C/T | 2000:12:11 | -9.303 | -5.29 | Yes |
| EONIA – 2 month | C/S | 2007:8:27 | -8.896 | -5.50 | Yes |
| EONIA – 3 month | C | 2007:08:27 | -7.758 | -4.92 | Yes |
| EONIA – 3 month | C/T | 2000:12:12 | -8.306 | -5.29 | Yes |
| EONIA – 3 month | C/S | 2007:08:27 | -7.779 | -5.50 | Yes |
| EONIA – 6-month | C | 2007:08:27 | -5.778 | -5.44 | Yes |
| EONIA – 6-month | C/T | 2007:08:27 | -7.775 | -5.29 | Yes |
| EONIA – 6-month | C/S | 2007:08:27 | -5.779 | -5.97 | Yes |
| EONIA – 1 year | C | 2007:08:27 | -5.778 | -4.92 | Yes |
| EONIA – 1 year | C/T | 2000:12:12 | -7.775 | -5.29 | Yes |
| EONIA – 1 year | C/S | 2007:08:27 | -5.779 | -5.50 | Yes |
| EONIA – 2 year | C | 2000:09:13 | -4.441 | -4.92 | No |
| EONIA – 2 year | C/T | 2000:10:11 | -4.919 | -5.29 | No |
| EONIA – 2 year | C/S | 2000:08:14 | -4.653 | -5.50 | No |
| EONIA – 3 year | C | 2000:09:13 | -4.349 | -4.92 | No |
| EONIA – 3 year | C/T | 2000:09:13 | -4.476 | -5.29 | No |
| EONIA – 3 year | C/S | 2000:08:14 | -4.643 | -5.50 | No |
| EONIA – 4 year | C | 2000:09:13 | -4.196 | -4.92 | No |
| EONIA – 4 year | C/T | 2000:09:14 | -4.321 | -5.29 | No |
| EONIA – 4 year | C/S | 2000:08:14 | -4.5 | -5.50 | No |
| EONIA – 5 year | C | 2000:09:13 | -3.978 | -4.92 | No |
| EONIA – 5 year | C/T | 2000:09:13 | -3.988 | -5.29 | No |
| EONIA – 5 year | C/S | 2000:08:14 | 4.24 | -5.50 | No |
| EONIA – 6 year | C | 2000:09:13 | 3.778 | -4.92 | No |
| EONIA – 6 year | C/T | 2000:09:14 | -3.935 | -5.29 | No |
| EONIA – 6 year | C/S | 2000:09:13 | -3.968 | -5.50 | No |
| EONIA – 7 year | C | 2000:09:13 | -3.552 | -4.92 | No |
| EONIA – 7 year | C/T | 2000:09:13 | -3.661 | -5.29 | No |
| EONIA – 7 year | C/S | 2000:09:13 | 3.679 | -5.50 | No |
| EONIA – 8 year | C | 2000:09:13 | -3.388 | -4.92 | No |
| EONIA – 8 year | C/T | 2000:09:13 | -3.561 | -5.29 | No |
| EONIA – 8 year | C/S | 2000:09:13 | -3.485 | -5.50 | No |

*Notes.* Model specification for bivariate cointegration relationship: C – level shift (change in constant); C/T – level shift with trend (model with a linear trend and change in constant only): C/S – regime shift (model with change in both constant and slope). Critical values are taken from Gregory and Hansen (1996).

### 4.1.5. Principal Component Analysis results

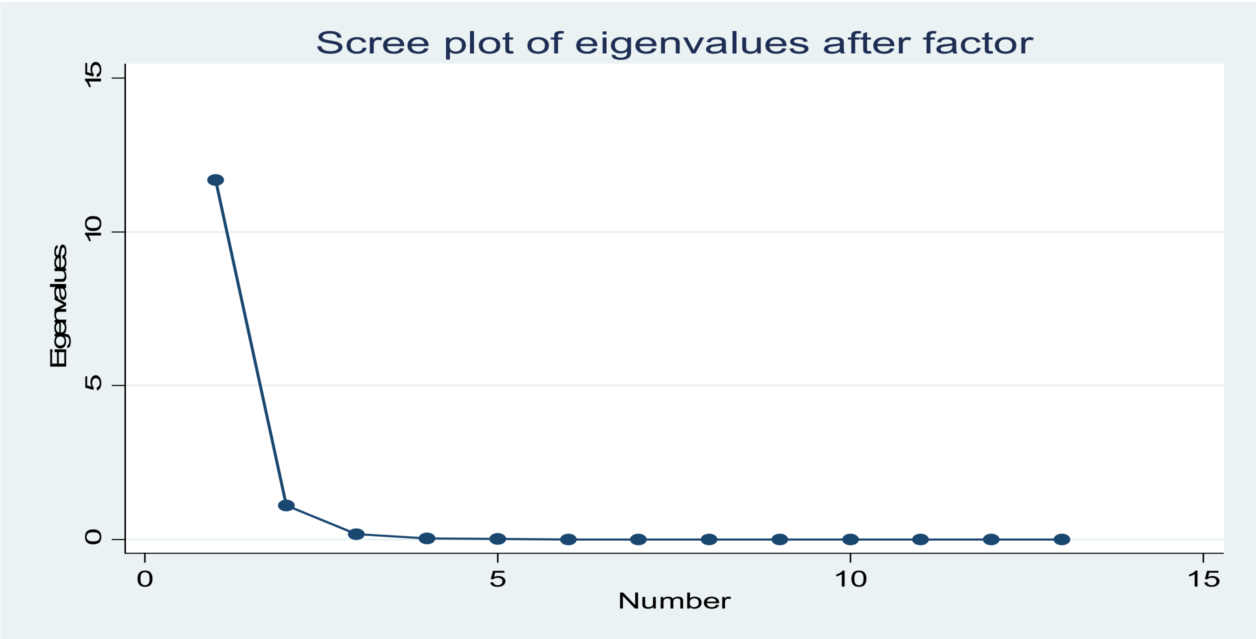
Moving to PCA results, we may remember that only eigenvalues greater than one are of interest (according to the Kaiser rule): by so doing only two factors are retained because both have eigenvalues over 1 (table 7). Total Variance column indicates that the relative weight of each factor in the total variance: the first factor explains 89.8% of the total variance. Cumulative column shows that Factor 1 and Factor 2 account for 98.2% of the total variance: as a result, two PCs have been retained in our analysis. They account for approximately 98.2% of the variability of the original space, which means that the PCA technique enabled us to transform a 13-dimensional space (that is all interest rates include in the first step of the PCA) into a two-dimensional space losing less than 2% of the information contained in the former.

**Table 7 – Principal components factor analysis**

| Factor | Eigenvalues | Total Variance % | Cumulative (%) |
|---|---|---|---|
| 1 | 11.678 | 89,8 | 89.8 |
| 2 | 1.097 | 8,4 | 98.2 |

From the scree plot (fig. 2) we can see that factor 1 and factor 2 account for most of the variance, then the remaining 11 factors all have small eigenvalues.

**Figure 2 – Variation of correlation matrix eigenvalues**




Having determined the number of principal components retained, we are now concerned with the interpretation of the PCs. Hence we computed the factor matrix (also known as factor loadings matrix), whose elements (factor loadings) represent the correlation coefficients between the original variables and the PCs. One common problem in PCA is that the unrotated factor matrix often provides unconclusive interpretations. To solve this problem, we determined the rotated factor matrix. Results (table 8) show that the first PC is powerfully correlated with short- and medium term rates, whereas Factor 2 is more correlated with long-term rates

**Table 8 – Rotated component matrix***

| Maturity | Factor 1 | Factor 2 |
|---|---|---|
| Short-term | | |
| 1-week | 0.881 | 0.424 |
| 1-month | 0.893 | 0.424 |
| 2-month | 0.900 | 0.423 |
| 3-month | 0.901 | 0.424 |
| 6-month | 0.881 | 0.456 |
| Medium-term | | |
| 1-year | 0.826 | 0.537 |
| 2-year | 0.706 | 0.681 |
| Long-term | | |
| 3-year | 0.614 | 0.775 |
| 4-year | 0.546 | 0.832 |
| 5-year | 0.492 | 0.869 |
| 6-year | 0.443 | 0.894 |
| 7-year | 0.393 | 0.914 |
| 8-year | 0.351 | 0.923 |

*Notes.* * Based on the varimax rotation.

The bivariate Pearson correlation coefficients between the monetary policy instrument (that is the EONIA) and the two factors are both significant (table 9). However, the correlation with the second factor is twice lower in magnitude. Therefore if this indirect measure of association is reliable enough, then PCA verifies the results obtained from standard regression models and co-integration analysis.

**Table 9 – Sample correlations**

| | Factor 1 | Factor 2 |
|---|---|---|
| EONIA | 0.827<br>(0.00) | 0.413<br>(0.00) |

*Notes. P-value* in parentheses.

### 4.2. Results from analysing EONIA volatility transmission to the Euro area term structure of interest rates

#### 4.2.1. EGARCH models results

The next results we are going to examine are how the volatility of the EONIA is transmitted to the Euro area money market interest rates. As pointed out previously, the model applied for all interest rates follows closely Ayuso et al. (1997). Estimates of EGARCH models for short- and medium-term interest rates are given in table 10 which reports the results of the estimation of both the mean and volatility equation. Considering the mean equation, we can say that the positive value of the parameters means that movements of official rates were not completely anticipated by the market. By contrast, in the case of the EONIA, the coefficient ($\beta_2$) is not significant when we consider the 6-month, one- and two-year maturities.

**Table 10 – Parameter estimates of EGARCH models for the Short- and Medium-term interest rates**

| Maturity | 1-Month | 2-Month | 3-Month | 6-Month | 1-year | 2-Year |
|---|---|---|---|---|---|---|
| Mean equation | | | | | | |
| c | -2.71E-05 | -0.0003** | -0.0005** | -0.0005** | -0.002*** | -0.003** |
| | (7.22E-05) | (7.83E-05) | (0.0001) | (0.0002) | (0.0007) | (0.001) |
| Φ | -0.0009 | 0.008** | 0.0007** | 0.006** | 0.008*** | 0.007** |
| | (0.0005) | (0.0004) | (0.0005) | (0.0008) | (0.001) | (0.001) |
| $\beta_1$ | 0.337** | 0.400** | 0.453** | 0.314** | 0.206*** | 0.102** |
| | (0.002) | (0.003) | (0.004) | (0.012) | (0.018) | (0.02) |
| $\beta_2$ | 0.002** | -0.003** | -0.003** | -0.0003 | 0.003 | 0.008 |
| | (0.0004) | (0.0009) | (0.0007) | (0.001) | (0.005) | (0.007) |
| Variance Equation | | | | | | |
| ω | -3.98** | -3.169** | -2.377** | -0.525** | -0.117** | -0.116** |
| | (0.122) | (0.108) | (0.079) | (0.042) | (0.016) | (0.024) |
| β | 0.774** | 0.8** | 0.854** | 0.971** | 0.995** | 0.993** |
| | (0.008) | (0.008) | (0.005) | (0.003) | (0.001) | (0.003) |
| α | 1.161** | 0.922** | 0.847** | 0.303 | 0.091** | 0.096** |
| | (0.025) | (0.021) | (0.024) | (0.014) | (0.009) | (0.012) |
| γ | -0.06** | -0.097** | -0.036** | 0.003** | -0.020** | -0.029** |
| | (0.019) | (0.014) | (0.016) | (0.01) | (0.005) | (0.007) |
| λ | 0.384** | 0.220** | 0.135** | 0.023** | 0.002** | 0.0008** |
| | (0.013) | (0.010) | (0.010) | (0.003) | (0.001) | (0.001) |
| Diagnostic Test | | | | | | |
| ARCH LM | 0.302 | 0.125 | 0.790 | 2.215 | 0.008 | 0.045 |
| | [0.582] | [0.723] | [0.374] | [ 0.136] | [ 0.773] | [0.830] |
| Q(10) | 68.264 | 96.108 | 113.47 | 49.320 | 3.411 | 8.301 |
| | [0.00) | [0.00) | (0.00] | [0.00] | [0.970] | [0.599] |

*Notes.* Standard errors are in parenthesis. ** statistically significant at 5% level. The ARCH LM test has been conducted by using 1 lag. Q(10) stands for the Ljung-Box statistic for the 10th order serial correlation. The p-values are in brackets for both ARCH LM and Ljung-Box statistic.

Table 10 also reports the main results of the estimation of the conditional volatility for 1-month, 2-month, 3-month, 6-month, 1 year and 2 year. In the 1-month volatility equation, we find that the parameter of the volatility of the EONIA (that is λ) is positive and statistically significant, suggesting the existence of volatility transmission during the period considered. The value of the coefficient (0.384) indicates that 38% of the Eonia volatility is transmitted to 1-month interest rate maturity during the same day. As we can see for all other interest rate maturities, the transmission of the EONIA volatility tends to decrease as the interest rate maturity is longer.

Estimates of EGARCH models for long-term interest rates are given in table 11. As we may see form the variance equation, EONIA volatility is not transmitted to the volatility of long-term interest rates.

**Table 11 – Parameter estimates of EGARCH models for the Long-term interest rates**

| Maturity | 3-Year | 4-Year | 5- Year | 6 -Year | 7-year | 8-Year |
|---|---|---|---|---|---|---|
| Mean equation | | | | | | |
| c | 0.0001 | -0.003** | -0.003** | -0.003** | -0.002 | -0.001 |
| | (0.0009) | (0.001) | (0.001) | (0.0016) | (0.001) | (0.001) |
| $\varphi$ | -0.002 | 0.004** | 0.002 | 0.002 | 0.001 | 0.0009 |
| | (0.003) | (0.0016) | (0.001) | (0.001) | (0.001) | (0.001) |
| $\beta_1$ | 0.058** | 0.032 | 0.008 | -0.002 | 0.0006 | -0.006 |
| | (0.02) | (0.02) | (0.02) | (0.014) | (0.021) | (0.021) |
| $\beta_2$ | 0.013 | 0.01 | 0.012 | 0.012 | 0.01 | 0.012 |
| | (0.008) | (0.008) | (0.008) | (0.008) | (0.008) | (0.007) |
| Variance Equation | | | | | | |
| $\omega_0$ | -0.112** | -0.122** | -0.131** | -0.203** | -0.131** | -0.140** |
| | (0.02) | (0.028) | (0.031) | (0.038) | (0.033) | 0.036) |
| $\beta$ | 0.992** | 0.991** | 0.989** | 0.981** | 0.988** | 0.987** |
| | (0.003) | (0.003) | (0.004) | (0.005) | (0.004) | (0.004) |
| $\alpha$ | 0.082** | 0.085** | 0.086** | 0.117** | 0.077** | 0.074** |
| | (0.012) | (0.012) | (0.013) | (0.01) | (0.013) | (0.013) |
| $\gamma$ | -0.031** | -0.024** | -0.02** | -0.042** | -0.020** | -0.019** |
| | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) |
| $\lambda$ | -0.0002 | 0.0003 | -0.0002 | -0.002 | -0.0008 | -0.0007 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.0013) | (0.0013) |
| Diagnostic Test | | | | | | |
| ARCH LM | 0.003 | 0.061 | 8.278 | 13.392 | 0.062 | 0.633 |
| | [0.955] | (0.804] | [ 0.602] | [0.0002] | [0.802] | [0.426] |
| Q(10) | 7.563 | 6.421 | 0.227 | 9.134 | 8.762 | 9.578 |
| | [0.671] | [0.779] | [0.633] | [0.519) | [0.555] | [0.478] |

*Notes.* Standard errors are in parenthesis. ** statistically significant at 5% level. The ARCH LM test has been conducted by using 1 lag. Q(10) stands for the Ljung-Box statistic for the 10th order serial correlation. The p-values are in brackets for both ARCH LM and Ljung-Box statistic.

## 5. Conclusion

The aim of this paper was to study the effects of ECB monetary policy on the Euro area money market interest rates. In particular the long-run relationship between the EONIA (used as a proxy for the ECB monetary policy) and market rates across the term structure was under study in order to check whether or not the EH holds. Cointegration was rejected for maturity longer than six years, implying that monetary policy actions do not exert a significant impact on the entire spectrum of the yield curve. Furthermore, principal components analysis was employed in order to explore the number of factors driving nominal rates across the term structure. Empirical results show that two factors account for the variation in nominal rates. At the same time, an additional control shows that the first factor is a dominant driving force of the short-end interest rates, while the other one is the driving force of the long-term interest rates. Further analysis shows that the first factor is strongly correlated with the monetary policy proxy (i.e. the EONIA rate): this means that EONIA tends to influence more short- then long-term rates. In this paper we have also estimated and investigate how the volatility of the EONIA are transmitted to the term structure of the Euro area interest rates using EGARCH models which allow for volatility spillovers from the EONIA to interest rates at different maturities. Our results suggest that a significant proportion of the volatility of the EONIA is transmitted to the short-term interest rates, whereas the volatility of the overnight rate was not generally transmitted to longer-term interest rates.

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## Appendix A

**Figure 1a – Euro area money market short term interest rates**

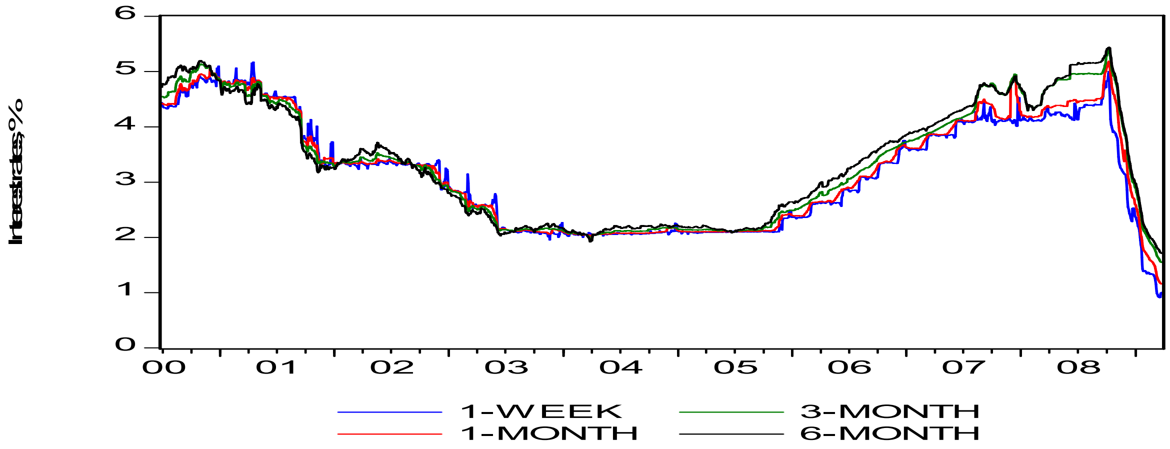



**Figure 2a – Euro area money market medium term interest rates**

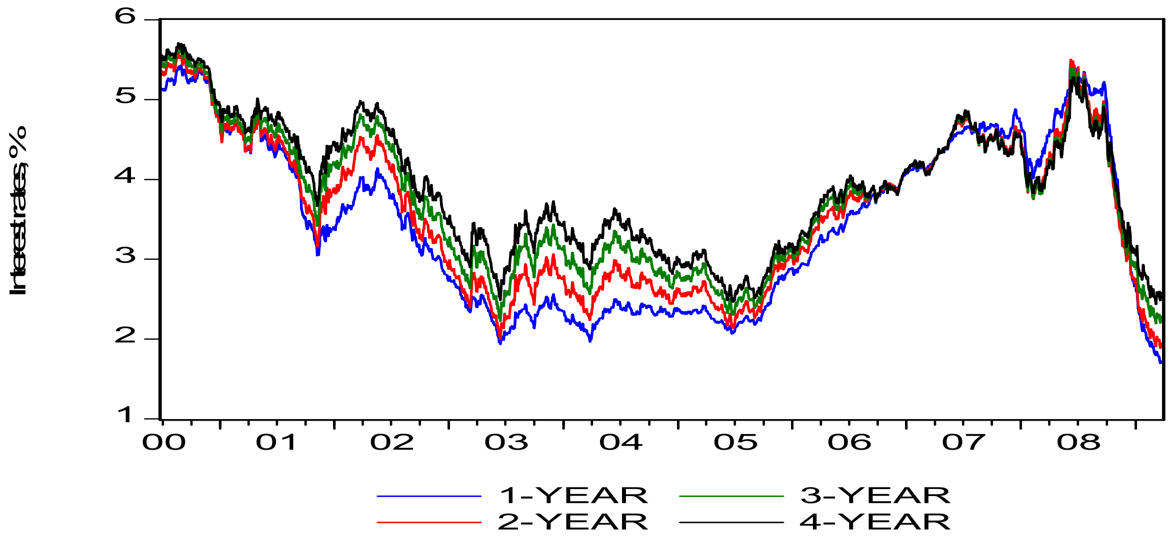
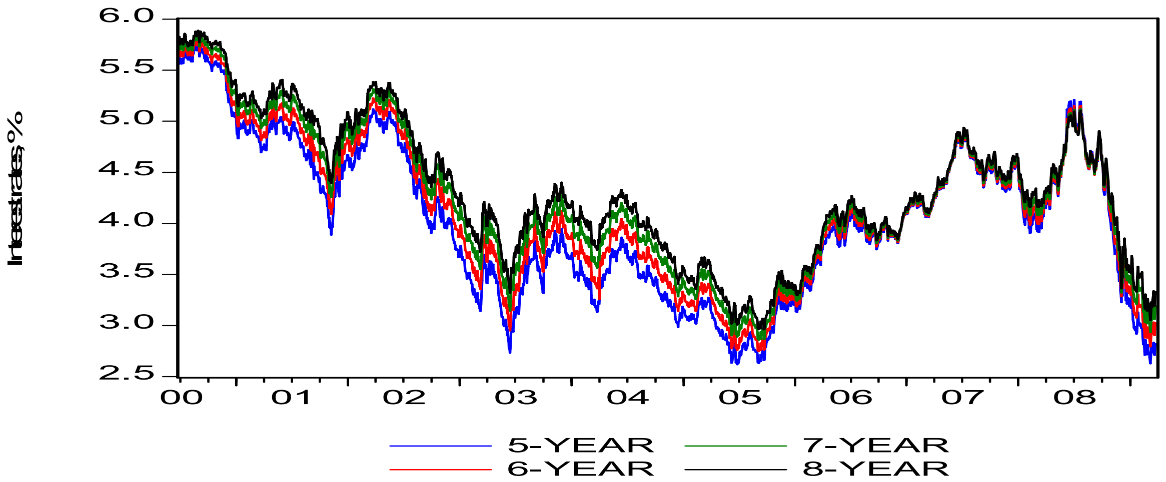
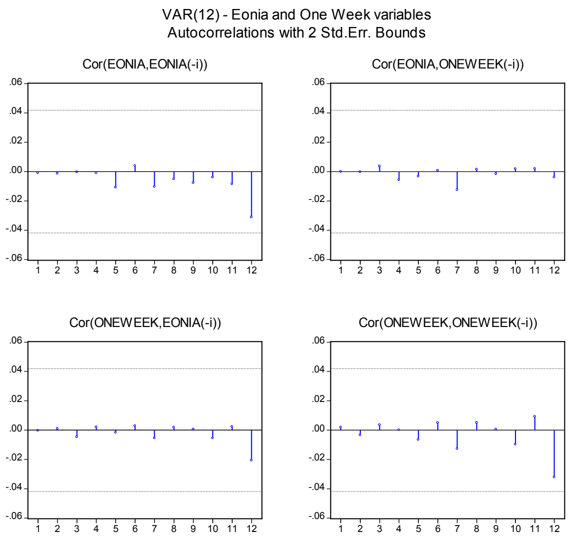



**Figure 3a – Euro area money market long term interest rates**



# Appendix B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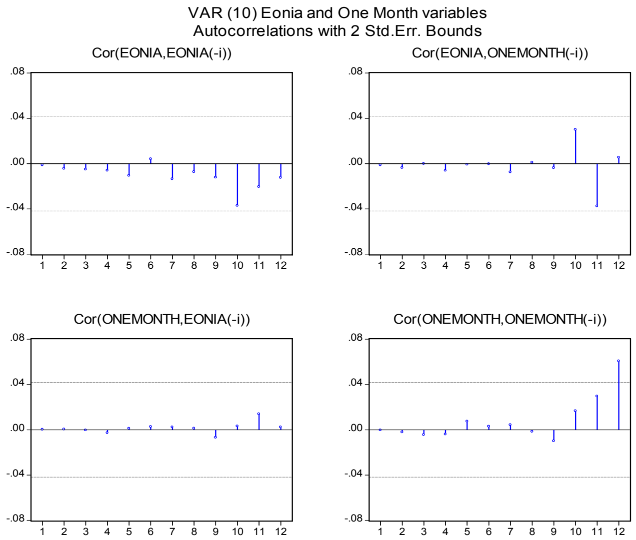
Cor(EONIA,ONEWEEK(-i))
Cor(ONEWEEK,EONIA(-i))
Cor(ONEWEEK,ONEWEEK(-i))


VAR (10) Eonia and One Month variables
Autocorrelations with 2 Std.Err. Bounds
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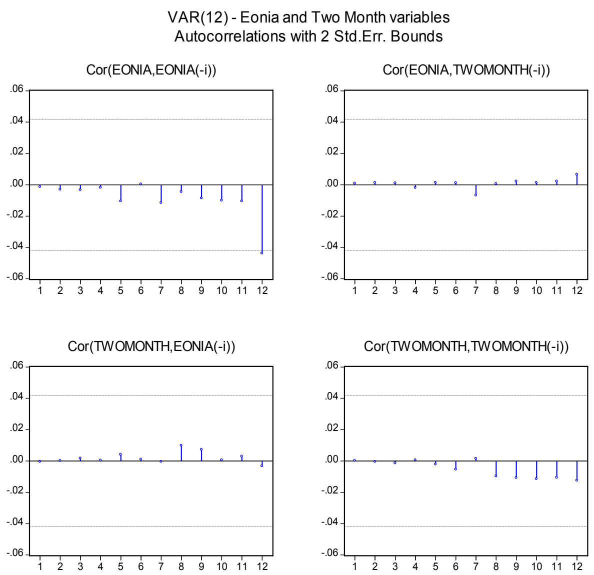
Cor(EONIA,ONEMONTH(-i))
Cor(ONEMONTH,EONIA(-i))
Cor(ONEMONTH,ONEMONTH(-i))


VAR(12) - Eonia and Two Month variables
Autocorrelations with 2 Std.Err. Bounds
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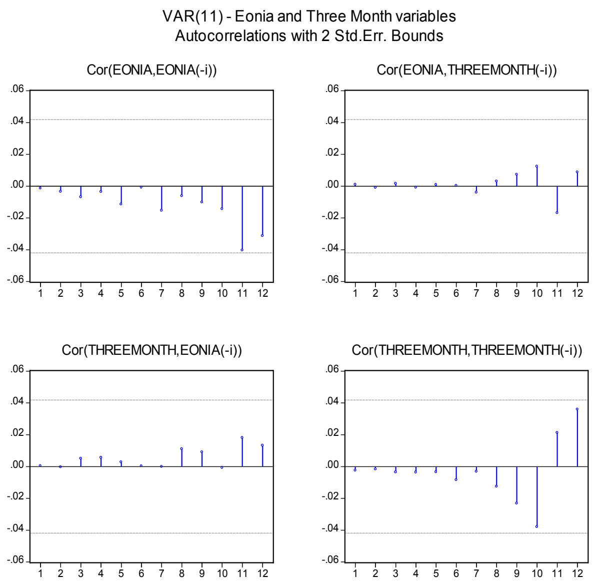
Cor(EONIA,TWOMONTH(-i))
Cor(TWOMONTH,EONIA(-i))
Cor(TWOMONTH,TWOMONTH(-i))


VAR(11) - Eonia and Three Month variables
Autocorrelations with 2 Std.Err. Bounds
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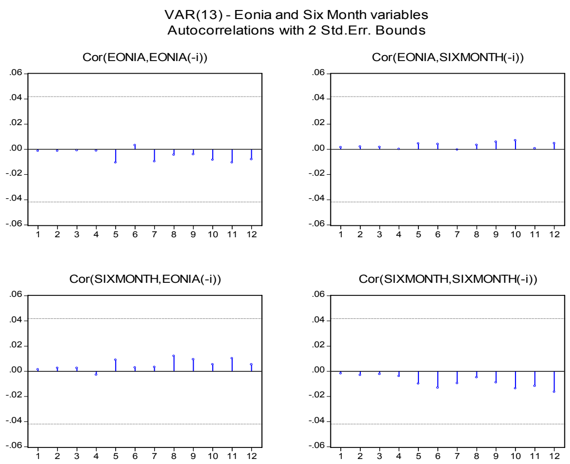
Cor(EONIA,THREEMONTH(-i))
Cor(THREEMONTH,EONIA(-i))
Cor(THREEMONTH,THREEMONTH(-i))


VAR(13) - Eonia and Six Month variables
Autocorrelations with 2 Std.Err. Bounds
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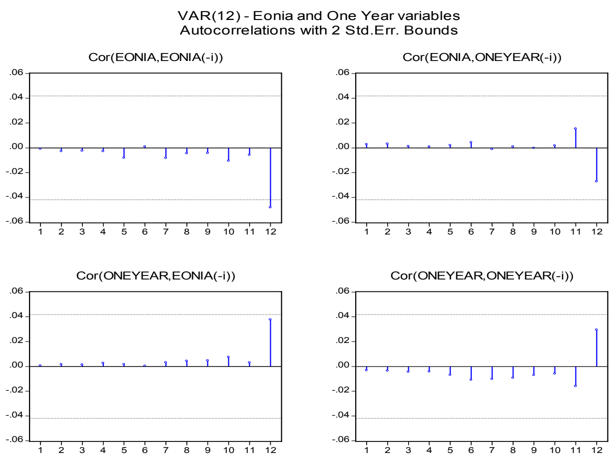
Cor(SIXMONTH,EONIA(-i))
Cor(SIXMONTH,SIXMONTH(-i))


VAR(12) - Eonia and One Year variables
Autocorrelations with 2 Std.Err. Bounds
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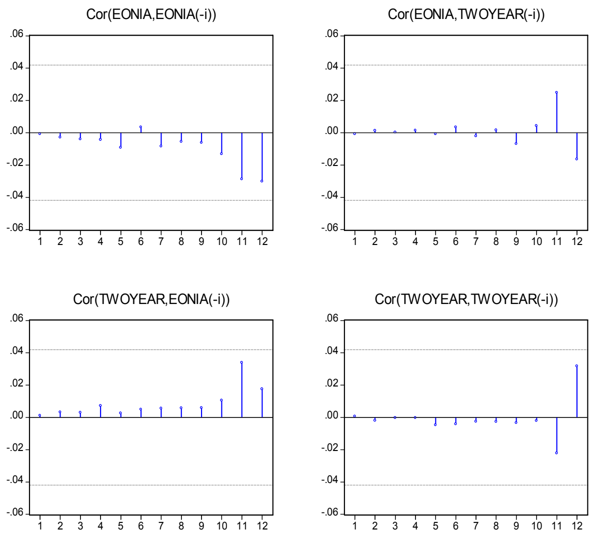
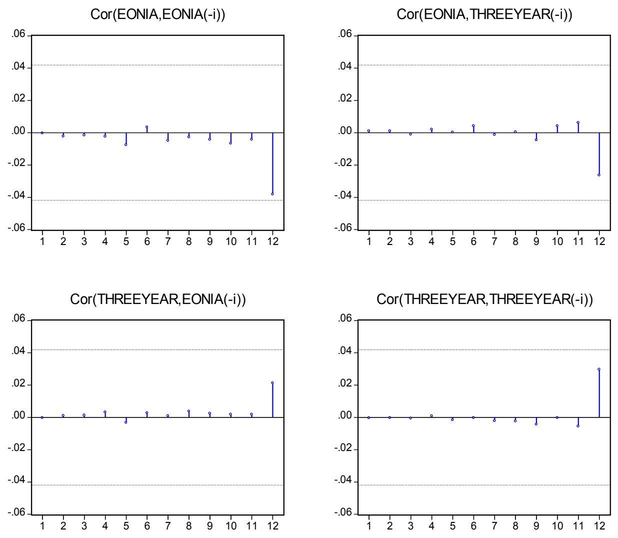
Cor(EONIA,ONEYEAR(-i))
Cor(ONEYEAR,EONIA(-i))
Cor(ONEYEAR,ONEYEAR(-i))

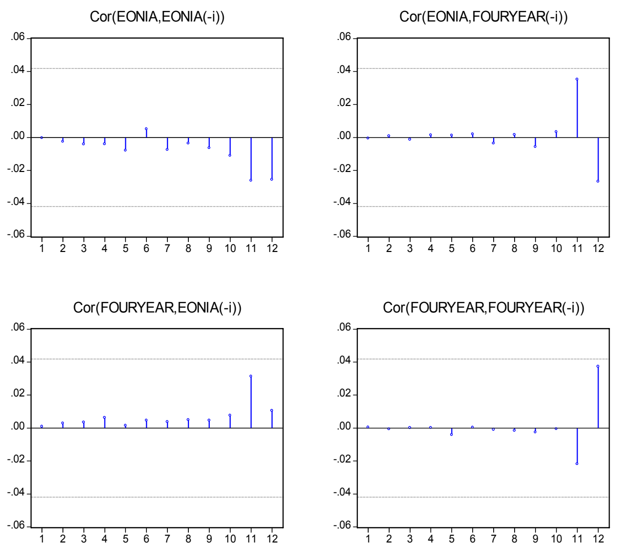
VAR(11) - Eonia and Two Year variables
Autocorrelations with 2 Std.Err. Bounds




VAR(12) - Eonia and Three Year variables
Autocorrelations with 2 Std.Err. Bounds




VAR(11) - Eonia and Four Year Variables
Autocorrelations with 2 Std.Err. Bounds

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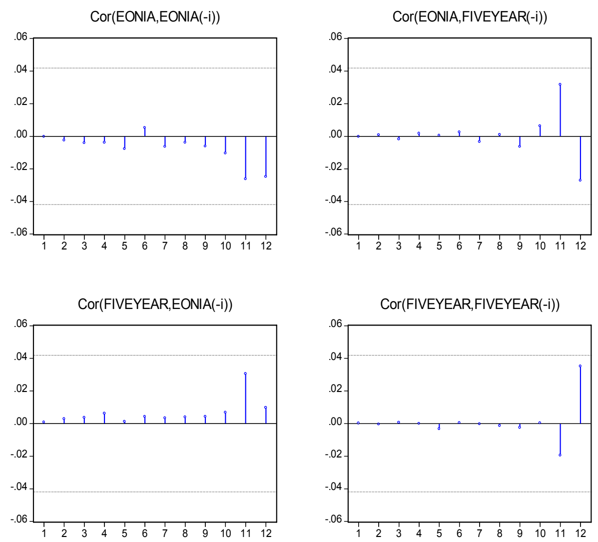
Autocorrelations with 2 Std.Err. Bounds

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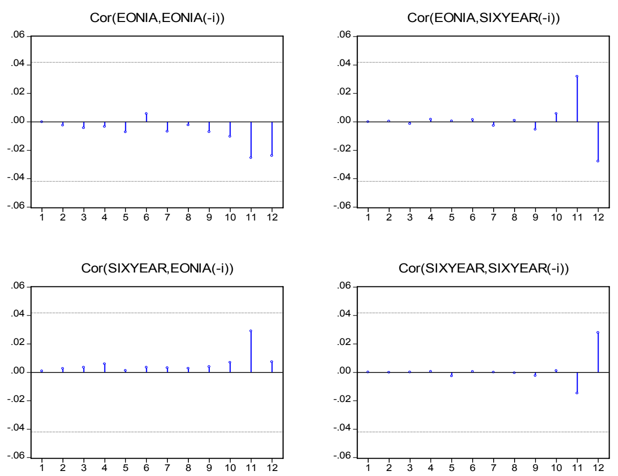
Autocorrelations with 2 Std.Err. Bounds

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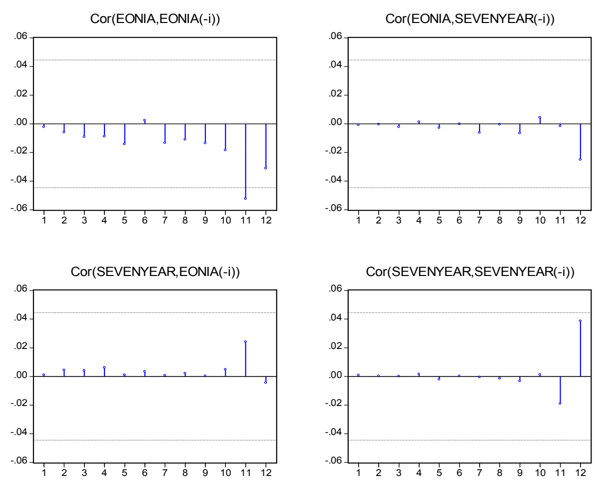
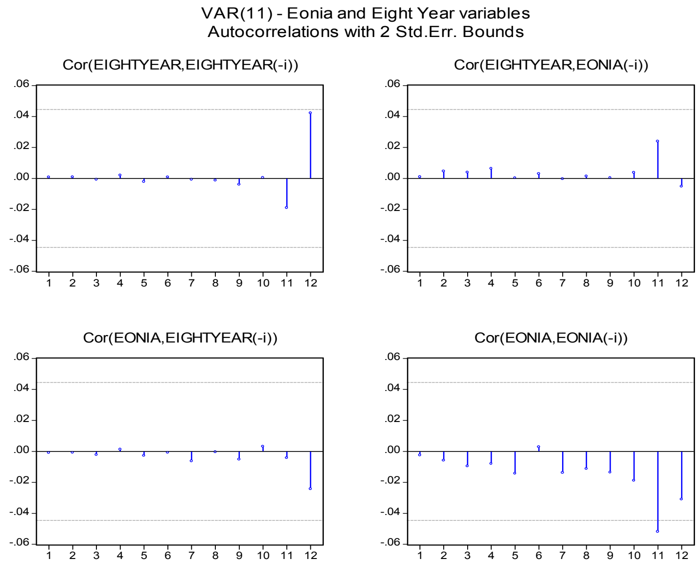
Autocorrelations with 2 Std.Err. Bounds




VAR(11) - Eonia and Eight Year variables
Autocorrelations with 2 Std.Err. Bounds
Cor(EIGHTYEAR,EIGHTYEAR(-i))
Cor(EIGHTYEAR,EONIA(-i))
Cor(EONIA,EIGHTYEAR(-i))
Cor(EONIA,EONIA(-i))
.06
.04
.02
.00
-.02
-.04
-.06
1 2 3 4 5 6 7 8 9 10 11 12