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TESTING THE EXPECTATIONS HYPOTHESIS IN EURO OVERNIGHT INTEREST SWAP RATES

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Abstract

This paper studies how interest rates expectations are formed in the Euro monetary market. Several implications of the Expectations Hypothesis on interest rates are examined both in interbank deposit rates, as well as in Eonia swap rates. Results show that Eonia swap rates better fulfil the Expectations Hypothesis implications and have lower risk premiums than Euribor rates. These results reflect the use by the European Central Bank of Eonia swap rates to measure the market response of its monetary policy actions and its influence on the expectations on future short-term interest rates. The period of financial volatility that started in August 2007 reinforces the ECB's use of Eonia swap rates as a reference for the market expectation formation on future interest rates; however, this superiority already existed before this episode (although it was not so evident).

Keywords: EONIA; Euribor; Swap; expectations hypothesis; Cointegrated VAR models
JEL classification: D84, E43, G13

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1. Introduction

Overnight interest swaps (OIS henceforth) on Eonia[1] is a very liquid market and has constituted a benchmark for the short-term structure of interest rates in Europe since 2000.[2] In an OIS contract, a fixed rate is interchanged at maturity against the accrued overnight rate and both are computed on a notional amount and terms ranging from one week to two years. Traditionally, financial institutions operating in the European interbank market use these contracts to hedge against unexpected interest rate increase (decrease) when they are financing (investing) their daily monetary imbalance in the overnight market by contracting an OIS as paying (receiving) the fixed rate. The use of these contracts has been extended to many institutions, both for hedging and speculation purposes.

The OIS rates and their implied forward rates have become the main reference in the European monetary market to measure market perceptions about ECB monetary policy. The following quote extracted from ECB (2008a, page 76) highlights this issue:

"From a policy perspective, it is important to monitor whether market interest rates reflect a future path of the minimum bid rate that is consistent with the Governing Council's own views and communication. For this purpose, the most accurate indicator is forward rates computed on the basis of the Eonia swap curve. The risk premium embedded in these rates is considered negligible for maturities up to several months, and banks and investors commonly use them for hedging purposes.[…] The expected level of the minimum bid rate is obtained by subtracting the premia corresponding to the Eonia's normal spread over the minimum bid rate. This is typically assumed to be constant over the forecast horizon, except for certain times such as the periods around the end of calendar years, when premia are usually assumed to be somewhat higher. These ECB date-adjusted forward rates have gradually come to be commonly used by private banks and are now regularly reported on wire services."

In this paper, a thorough revision of the most important implications of the Expectation Hypothesis (EH, henceforth) on the OIS rates on EONIA is carried out. We obtain strong evidence for this hypothesis until the financial crisis started in August 2007. When the crisis period is included, the evidence becomes somewhat weaker. The main results can be summed up in the

[1] The *E*uropean *O*ver*N*ight *I*ndex *A*verage is a weighted average of all overnight unsecured lending transactions between the most active credit institutions in the Euro area's money market. Visit www.euribor.org for more details.
[2] The evolution and relative importance of OIS activity in European money market can be consulted at ECB (2009). OIS on Eonia became one of the most liquid segment of the euro money market by 2000 (see also Remolona and Wooldridge (2003))

following points: (i) in the pre-crisis period the forward rates are unbiased predictors only for one-month OIS spot rates for one and two months ahead. This evidence disappears when the crisis period is included in the data set. (ii) Spot and forward rates are cointegrated for all maturities included in the one year horizon, indicating that implied forward rates contain significant information about future spot rates. This evidence persists even when the crisis period is considered. (iii) OIS spot rates form a cointegrated system, indicating that they are all driven by the same economic forces. Furthermore, the stationarity of the spread between short and long OIS spot rates is tested as the EH requires. We obtain evidence for this last result only in the pre-crisis period. (iv) We have tested if the OIS spot rates can be taken as an expectation of the accrued Eonia according the EH. The evidence shows that both variables are cointegrated and most implications of the EH cannot be rejected for interest rates corresponding to one, three, and six months ahead. In this way, one month forward rates in a month is an unbiased predictor of subsequent one month spot rates, and this spot rate is a good predictor of the daily accumulated Eonia rate during the subsequent month. (v) Finally, realised risk premiums in implied forward rates are positive, increase with maturity, and are significantly different to zero. Specifically, mean values for these term premiums for one, three and six months ahead are, respectively, 0.6, 2.87 and 15.1 basis points in the pre-crisis period and 3.6, 16.7 and 73.5 basis points within the crisis period.

For comparative purposes, we have simultaneously tested all the EH implications for Euribor rates. This comparative exercise is only relevant in the pre-crisis period as the credit and liquidity crisis in the European interbank market has dramatically affected unsecured interbank deposit rates after August 2007. In all cases and for this sub-period the results are always weaker for the Euribor rates. The most appealing differences for the pre-crisis sub-period are: (i) any evidence of forward unbiasedness is obtained; (ii) spot and forward rates are not cointegrated for maturities over six months ahead; (iii) the Euribor spot rates form a cointegrated system for periods shorter than six months and in this case the spread between short and longer spot rates is stationary as the EH requires; (iv) Spot Euribor rates cointegrate with the accrued Eonia – but the unbiasedness hypothesis of Euribor rates on subsequent accrued Eonia is rejected in all the considered cases. (v) Finally, from a pair-wise comparison of term premiums contained in Euribors and OIS forward rates it is concluded that unsecured deposit rates contain higher premiums in one and three months maturities, but both term premiums can be considered equal for the six month maturities.

This paper is divided into seven sections. In Section 2, the most important results in the doctrine about the Eonia spread are compiled. In Section 3, the EH and some of its testable

implications are presented. Section 4 contains the data description and some preliminary analysis. Results, conclusions and bibliographical references complete the document.

2. Recent studies on Eonia spread

This paper is not devoted to the study of the Eonia spread over the policy rate; but it is important to sum up the existing results on this spread because it has clear influences on how expectations on future interest rates based on OIS rates are formed. A large spread between the Eonia and the policy rate could blur the message of the stance of monetary policy and can be transmitted to other rates in the term structure and so making it difficult to distinguish between liquidity management considerations in the Eurosystem and expectations on future rates. All the studies carried out on the Eonia spread pay special attention to the changes in the Eurosystem operational framework for the monetary policy implementation that came into effect in March 2004.[3] Since then, this spread has been significantly lower except for the last day of each reserve maintenance period (see ECB (2005)). Linzert and Schmidt (2008) analysed this phenomenon[4] and in their opinion the largest part of this increase can be explained by tighter liquidity conditions (liquidity deficit) and banks liquidity uncertainty.

According to Välimäki (2008) interest rate expectations (as measured by one month in a month forward rate spread) do not have a significant influence on this phenomenon.[5] It can be said that one of the aims of the reforms is accomplished as the influence of rate expectations has disappeared. Nevertheless, Linzert and Schmidt (2008) also find that expectations in the maintenance period (measured as the spread between one-week swap rates and the ECB policy rate) still have a significant influence on the Eonia spread. All these results reflect the results of the seminal paper of Würtz (2003) where expectations about changes in the key policy rate and the

[3] Two important changes were introduced in an attempt to avoid more episodes of underbidding (overbidding) in the main refinancing operations (MRO henceforth) when the policy rate is expected to fall (increase) and so resulting in tight liquidity conditions and increasing overnight interest volatility (see ECB (2003) for more details). The first important change was to adjust the timing of reserve maintenance periods so that the start and the end of these periods are aligned with the settlement day of the MROs following the governing council meeting at which the monthly decision on monetary policy stance is pre-scheduled and their changes, if any, are implemented on the first day of the new reserve maintenance period. Second, the maturity of the main refinancing operations was shortened from two weeks to one week. Together with the above-mentioned changes, this means that MROs no longer straddle reserve maintenance periods. The general opinion sustained with data is that Eonia volatility has significantly declined after the changes to the operational framework in March 2004 – although some episodes of volatility have persisted, especially at the end of the maintenance period with high values of the spread (see Abassi and Nautz (2010), Nautz and Offermanns (2008), Gaspar et al. (2008), ECB (2006a), ECB (2006b)). Previously, in June 2000, the ECB switched from fixed rate to variable rate tenders in its MROs.

[4] Although the mean value decreased from 7.6 to 6.7 basis points, the median increase from 5.0 to 8.0 basis points.

[5] Nautz and Offermanns (2007) found that the Eonia rate significantly adjusted to the term spread except for the last week of the maintenance period in a sample period finishing just before March 2004.

projected liquidity conditions at the end of the maintenance period are the most important variables driving the Eonia spread level and its volatility.

After August 2007, when the financial turmoil started, this spread has turned out to be very volatile around the policy rate and on 15 October 2008 when regular MROs switched to fixed rate tender procedures with full allotment, the spread became systematically negative – thereby reflecting the excess of liquidity in the Eurosystem.[6] Recently, Soares and Rodrigues (2011) show that the average value of the EONIA spread in the first stage of the turmoil (August 2007 – September 2008) was close to zero and it takes a negative value (-56.03 basis points) after the Lehman Brothers fallout and the start of the fixed full allotment policy by the ECB (October 2008 – December 2009).

The spread between Euribor and OIS rates on Eonia is another important issue in our analysis. This spread can be used as an indicator for the overall liquidity and credit risk premia in the money market. The deposit rate is the price for irrevocably obtaining credit and liquidity over a given period of time, without the provision of collateral. Deposit rates contain a counterparty credit risk premium, a liquidity risk premium, and a term premium related to the uncertainty about the future path of short-term interest rates. The Eonia swap rate reflects the same risk premium that is priced into the expected overnight deposit rates, which likewise comprise of both a liquidity and credit element. However, the average risk of lending via short-term overnight deposits is negligible compared with lending via long-term fixed deposits, because the former can be adapted to new circumstances each day.[7] Since the US subprime crisis in August 2007 and the intensification of the financial turmoil after the bankruptcy of Lehman Brothers this spread suffered a drastic widening. As our data period finishes in February 2010, we do not extend this preliminary section to all the subsequent changes in the European monetary system. In any event, the paper conclusions would remain the same as most are obtained using the sub-period finishing just before August 2007.

3. Expectations Hypothesis

Following Cochrane (2001, pp. 352-5) the pure Expectations Hypothesis can be formulated in three equivalent ways: (i) the long-term yields can be obtained by averaging shorter expected

[6] The study of the spreads between Eonia and MROs rates (weighted and marginal) and the MROs and policy rates is a very important part of this analysis, but it is beyond the scope of this paper. Interested readers can consult Eisenschmidt et al. (2009), Perez-Quirós and Rodríguez-Mendizábal (2010), Välimäki (2008) and Würtz (2003)).

[7] A further difference exists in that Euribor rates are fixed at 11 am, while EONIA rate is computed at 6.30 pm. The spread between the two rates, therefore, also reflects changes in the yield curve between these points during the day.

yields; (ii) forward rates equal expected future rates; and (iii) returns on investing in any bond are equal given a holding period. When a constant risk premium is added, the resulting model is still known as the Expectations Hypothesis (EH henceforth).

3.1. EH implications on spreads

According to the EH, the return on an *n*-period investment, $r_{t,n}$, can be obtaining by averaging present and expected *m*-period returns, $r_{t,m}$, plus a constant term premium, $\pi_{n,m}$,

$$r_{t,n} = \frac{1}{k}\sum_{i=0}^{k-1} E_t[r_{t+mi,m}] + \pi_{n,m} \tag{1}$$

where $k = n/m$ is an integer. Following Campbell and Shiller (1991), we can subtract $r_{t,m}$ on both sides of Equation (1) and rearrange terms to obtain the spread between long and short-term returns, $r_{t,n} - r_{t,m}$, as a function of the expected changes in the short-term returns over the *k* periods

$$r_{t,n} - r_{t,m} = \sum_{i=1}^{k-1}\left(\frac{k-i}{k}\right) E_t[\Delta r_{t+im,m}] + \pi_{n,m} \tag{2}$$

Then, if the EH is true, the spread will measure the expected short period rate changes across the longer period. If short-term interest rates are first order integrated processes, and consequently, the first difference is stationary, then the spread will be a stationary process and both rates will be cointegrated with (1, -1) as a cointegration vector. This analysis can be generalised to any pair of short and longer term interest rates. Furthermore, this argumentation can be extended to a collection of *n* interest rates ($r_{t,1}, r_{t,2}, \ldots, r_{t,n-1}, r_{t,n}$) where *n*-1 cointegration relationships must exist. Moreover, EH imposes (1, -1) restrictions in the *n*-1 cointegration relationships as a way of testing stationarity in the *n*-1 spreads.[8] Specifically, for a set of four interest rates (1, 3, 6 and 12 months), the Johansen (1988 and 2001) methodology can be used to jointly test for a set of restrictions implied by the EH; specifically, the matrix of coefficients in the three cointegrating relationships should be:

[8] Dominguez and Novales (2000) and Abad (2004) use the Johansen (1988 and 1991) methodoly to carry out this test. See these references for more details.

$$H_0 : \beta' = \begin{pmatrix} 1 & -1 & 0 & 0 \\ 1 & 0 & -1 & 0 \\ 1 & 0 & 0 & -1 \end{pmatrix} \tag{3}$$

That is, the matrix β' that defines the spreads must be contained in the cointegrated space and must have rank 3. This implication will be used in Section 5.5 to test if 1, 3, 6 and 12-months OIS and unsecured interbank rates are cointegrated systems.

3.2. EH implications on forward rates

With continuously compounded rates of return, implicit forward rates are defined by $(n-m)f_{t,t+m,n-m} = nr_{t,n} - mr_{t,m}$. The EH can be formulated as forward rates equal to the expected future rates plus a risk premium

$$f_{t,t+m,n-m} = E_t[r_{t+m,n-m}] + \Pi_{n,m} \tag{4}$$

Assuming rational expectations,

$$E_t[r_{t+m,n-m}] = r_{t+m,n-m} + \varepsilon_{t+m} \tag{5}$$

where ε_{t+m} is the rational expectations error in forecasting at time t and has a MA(m-1) structure. By introducing Equation (5), Equation (4) can be transformed to the most common expression in the literature

$$r_{t+m,n-m} = \alpha + \beta f_{t,t+m,n-m} + e_{t+m} \tag{6}$$

The rational expectation version of the pure EH implications in forward rates consists in testing the null of H_0 : α = 0 and β = 1 in Equation (6) and e_{t+m} to be uncorrelated with the information known in t.[9] When this hypothesis cannot be rejected, it is said that forward rates are unbiased predictors of the future spot rates. If the EH allows for a constant risk premium, the above null hypothesis will be reduced to H_0 : β = 1. When a significant intercept is obtained after estimating Equation (6), the interpretation of α will be a negative multiple of the underlying risk

[9] When n/m = 2, it can be shown that e_{t+m} should be equal to ε_{t+m}. In the remaining cases, some further hypothesis on how agents form expectations are needed. See Dominguez and Novales (2002) for more details.

premium.[10] If spot and forward rates are first order integrated processes, then Equation (6) can be interpreted as a possible cointegration relationship between current forward and future spot rates. EH on this relationship will imply that both rates are cointegrated with (1, -1) as a cointegration vector. All these EH implications will be tested in OIS and unsecured interbank rates for 1, 3, 6 and 12-months in Sections 5.2 and 5.3, respectively. Furthermore, in Section 5.4, the EH implications in forward rates for both markets will be further tested in all the one-month forward rates contained in the one year period.

3.3. Spot rate as a predictor of the accrued Eonia

Some of the above discussed EH implications can be especially adapted to the OIS on the Eonia market. The reference for the OIS variable rate is computed by accruing the Eonia during the OIS underlying period. Consequently, traded OIS rates can be seen as the expected value of the future accrued Eonia for the underlying swap period. Therefore, when traded OIS rates and immediate accrued Eonia are related, it is possible to test the equivalent return EH implications. Furthermore, the forward unbiasedness EH implication can be tested within the OIS term structure and using the accrued Eonia on the forwarded period. Before writing these particular testable implications, some preliminary technical details must be presented.

An OIS is a fixed/floating interest swap with the floating leg tied to a published index of a daily overnight rate reference, the Eonia in our case. The two parties agree to exchange at maturity, on the agreed notional amount, the difference between interest accrued at the agreed fixed rate and the floating index rate compounded every day over the term of the swap. The following formula is used to compute the accrued variable rate,

$$AE_{t,m} = \left[\prod_{i=t_s}^{t_e-1} \left(1 + \frac{E_i \times d_i}{100 \times 360} \right) - 1 \right] \times \frac{360}{t_e - t_s} \tag{7}$$

where $AE_{t,m}$ is the annualised accrued Eonia between the start, t_s, and the end date, t_e, E_i is the Eonia and d_i is the number of days that E_i is applied.[11] Let N be the notional amount of the swap traded in t, then the final cash flow to a variable rate receiver paying $r_{t,m}$ as a fixed rate would be[12]

[10] For example, when $n/m = 2$, it can be shown that α should be equal to $-2\Pi_{n,m}$. In the remaining cases, some further hypothesis on how agents form expectations are needed. See Dominguez and Novales (2002) for more details.

[11] The Eonia is only computed when the TARGET system is open. The TARGET system is closed on Saturdays and Sundays and on the following public holidays in all participating countries: New Year (January 1), Good Friday, Easter

$$\left(AE_{t,m} - r_{t,m}\right) \times N \times (m/360) \tag{8}$$

The forward unbiasedness EH implication in Equation (6) can be modified in order to relate OIS rates and future accrued overnight rates as follows

$$AE_{t,m} = \alpha + \beta r_{t,m} + e_{t+m} \tag{9}$$

This implication of the EH can be tested in a similar fashion to the Euribor rates, assuming rational expectations, as the long term yields can be obtained by compounding shorter yields. There are other testable implications in which the accrued Eonia could be introduced. Nevertheless, the accrued Eonia will introduce autocorrelation problems that are difficult handle in any econometric experiment. For this reason, we prefer to limit its participation to Equation (9) as we believe this is the most relevant approach for this research.

4. Database and preliminary analysis

Time series used in this paper with the corresponding sources, periods, frequencies, and number of observations are described in Table I. OIS data series are obtained from Bloomberg as the Eonia Swap Index as published in www.euribor.org and computed since June 2005. The econometric analysis presented in this paper is carried out with interest rates transformed to continuous compounds – although the graphics are presented as annualised simple rates in the same

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Monday, Labour Day (May 1), and the first and second days of Christmas (December 25 and December 26). In these days, the OIS computation will use the previously availabe Eonia fixing rate in which the TARGET system is open. Furthermore, we use the standard convention of taking as the starting day of the variable leg computation as t+2; and the modified following convention for the termination date. If no modifications are applied, then $t_e - t_s = m$.

[12] Since 20 June 2005, the market benchmark for this asset is the Eonia Swap Index published daily by the European Bank Federation for the standard swap maturities: 1, 2, 3 weeks and 1 to 12, 15, 18, 21 and 24 months. These rates are quoted on an actual/360 day count convention. The benchmark for 15, 18, 21 and 24-months maturities started to be published on 9 May, 2007. The Eonia Swap Index is the average rate at which, at 11:00 Brussels time, a representative panel of prime banks provide daily quotes, rounded to three decimal places, of what each panel bank believes to be the mid-market rate of Eonia swap quotations between prime banks. These benchmarks can be used to calculate the fair price of any opened position in OIS on Eonia. For this purpose, the following equation can be easily adapted by simply substituting $AE_{t,m}$ for the corresponding implicit forward rate in the Eonia Swap Index term structure and discounting to the valuation point in time. After expiration, the final cash flow cannot be computed until the remaining Eonia rates are known. Nevertheless, the variable leg becomes more predictable and forward rates in the Eonia Swap Index term structure can be used to complete the information necessary to compute fair value. The exposed fair value procedure is based on arbitrage arguments between the term and overnight deposit market. As OIS valuation is not the objective of this paper, we skip any further detail about this question.

way that they are usually expressed in the money markets. Monthly data series are built using information from the first tradable day of the month.

Table I. Data sources, number of observation, and frequencies

	maturities	Period	Daily	Monthly	Source
Eonia	-	03/01/2000-25/02/2010	2649		www.euribor.org
OIS	1 to 12 months	03/01/2000-25/02/2010	2649	122	Bloomberg(*)
Euribor	1 to 12 months	03/01/2000-25/02/2010	2649	122	www.euribor.org

(*) Closing prices, that is the price of the last trade.

Graphical analysis will be useful to understand the main features of our database. We show a sample of some significant data used in the paper, and the remaining time series is omitted to save space. Figure 1 displays the Eonia time series. As we have explained in Section 2, the Eonia is, on average, slightly over the policy rate and jumps quite frequently (mostly due to liquidity management considerations in the Eurosystem). As a result of the financial crisis set off in August 2007, the European Central Bank has several times cut the interest rate on the main refinancing operations until reaching its lowest historical value, 1.00%, at the end of our sample period. Figure 2 reports the three-months OIS rate, the accrued Eonia, and the difference. It can be appreciated how the difference between both rates is quite small – but this difference increases after the financial crisis initiated in August 2007. Finally, Figures 3 and 4 display the three months rates (spot, forward and their difference or realized risk premiums) for the OIS and Euribor rates. From a casual visual inspection it can be inferred that both figures are almost identical. Nevertheless, significant differences are obtained in the following section.

Figure 1. Eonia time series

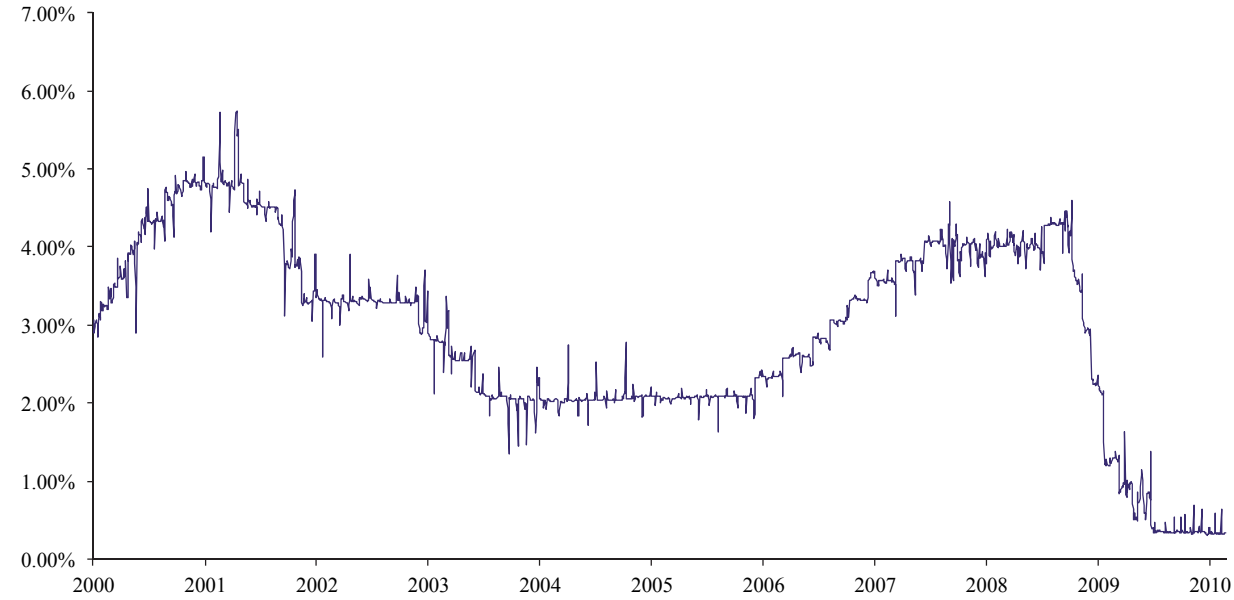

Figure 2. Three months OIS(—),accrued Eonia rates (---) and the difference (⋯)

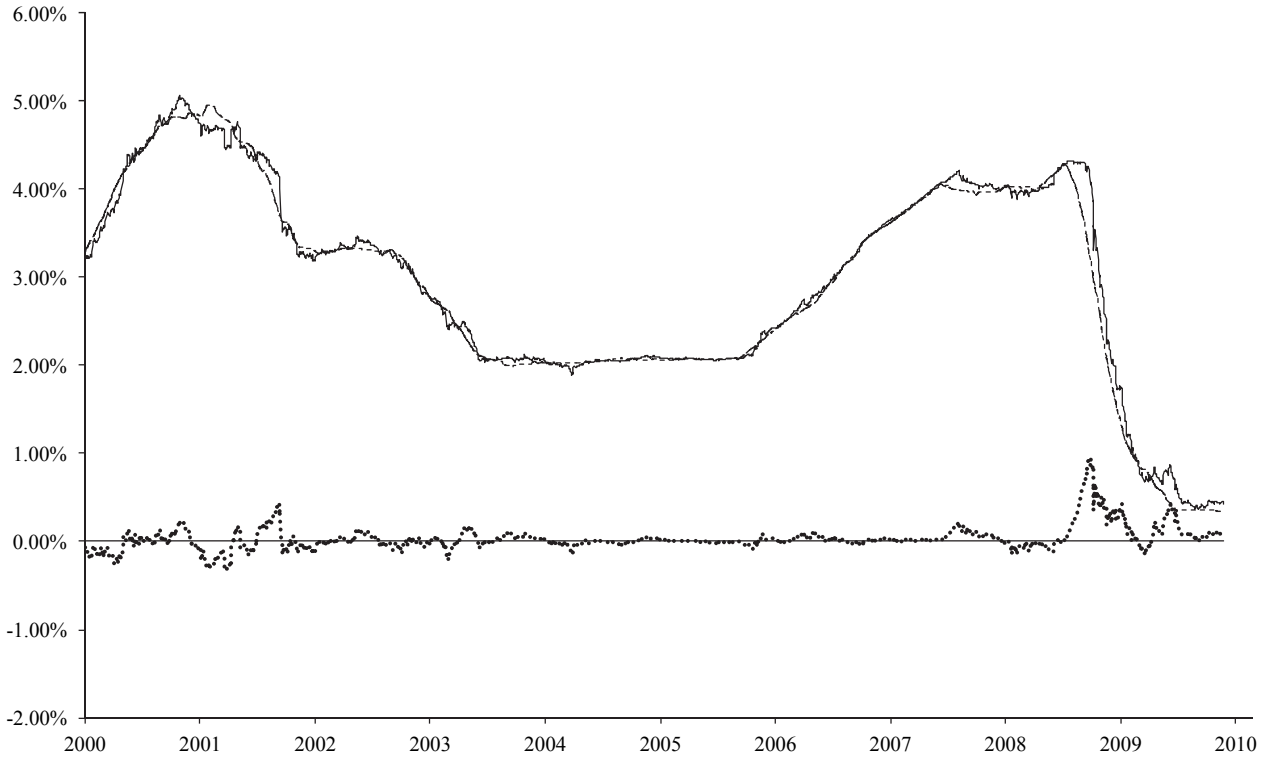

Figure 3. Three month OIS rates(—) , $r_{t+90,90}$, forward rates (---), $f_{t,t+90,m,90}$, and the difference (⋯)

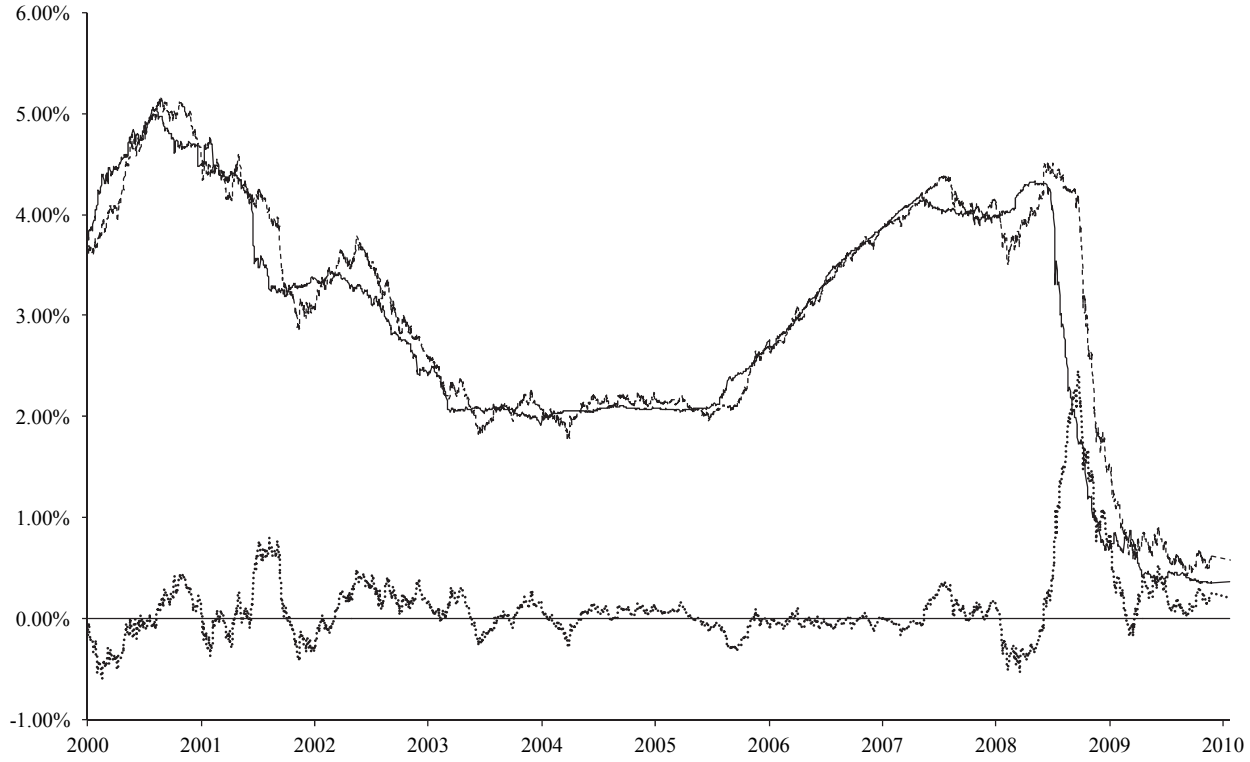

Figure 4. Three month Euribor rates (—), $r_{t+90,90}$, forward rates (---), $f_{t,t+90,m,90}$, and the difference (⋯)

Calendar effects on the European monetary markets

Most papers modelling Eonia behaviour clean the dynamics of several calendar effects by using dummy variables. It will be interesting to test these effects on OIS and Euribor rates before testing the implications of expectations hypothesis on the monetary market term structures. We test the most important calendar effects: the 'end of month' (last day) and the 'end of maintenance period' (one, four or six days) and the different impact of both calendar effects on different subsamples (before and after March 2004). Results, not reported here, show that OIS and Euribor spot rates do not have significant calendar effects at daily frequencies. In any event, we have used monthly frequency in most parts of the paper, so the influence of any calendar effect in our results is minimised.[13]

Unit root tests

As some EH implication tests will be based on cointegration relationships, we need previously to test if all interest rate time series (at daily and monthly frequency) contain a unit root. Results, skipped here to save space, show that all the time series are first order integrated, including implied forward rates time series that will be used later. There is one exception to this generalised result. The presence of a unit root in the accrued Eonia time series for periods greater the six months cannot be accepted at daily frequency, but it cannot be rejected using monthly frequency. In any event, we will use this time series only for 1, 3, and 6 months at monthly frequency to avoid any criticism on this point.[14]

[13] Other calendar effects considered in previous studies are not so important and persistent (cash changeover in January 2002, the day after the terrorist attacks on 11 September 2001, ECB Governing Council meetings). Interested readers are referred to Wurtz (2003), Hassler and Nautz (2008), Nautz and Offermanns (2007), Benito et al. (2007), Durré and Nardelli (2008) and Zagaglia (2010).

[14] The tests carried out are the Augmented Dickey and Fuller (1981), ADF henceforth, and Philips and Perron (1988), PP henceforth. The critical values are those appearing in MacKinnon (1991) for processes without trend but including intercept. The number of lags for the ADF test is chosen by maximising the Schwarz information criterion. The truncation lag in the PP test is chosen using the Bartlett kernel as proposed by Newey and West (1994) using the Eviews 7.0 package.

5. Results

5.1. Spot rates and the accrued Eonia

In this subsection we test two implications of the EH on the relationship between spot and AE rates for 1, 3, and 6 months maturities. Taking Equation (9) as the cointegration relationship between both rates, we test if each pair of rates is cointegrated for each maturity. EH also imposes that the difference between both rates must be stationary. This EH implication will be tested in two ways: (i) imposing the (1, -1) restriction in the cointegration vector following the Johansen (1988 and 2001) methodology; (ii) testing the existence of a unit root in the difference between both rates. Furthermore, we test the forward unbiasedness EH implication by testing $\alpha = 0$ and $\beta = 1$ null hypothesis in the cointegration relationship using the Johansen (1988 and 2001) methodology.

Panels A and B in Table II report the results for OIS rates for the whole and pre-crisis periods, respectively. Similarly, Panels C and D report the results for Euribor rates. With the exception of the whole period for the Euribors rates in Panel C, cointegration between spot and accrued Eonia cannot be rejected at 5% of significance level for 1, 3, and 6 months lengths. Further to this and with the same exception, we also have obtained that rate differences are stationary as unit root hypothesis cannot be accepted at 5% of significance level.[15] The unbiasedness hypothesis of OIS rates regarding the realised *AE* rate cannot be rejected at 5% of significance level at 1 and 3 months and at 1% of significance level in the 6 months length for both sub-periods. In the case of the Euribor rates, this hypothesis is rejected in the three cases in the pre-crisis sub-period. In a similar way, the null $\beta = 1.0$ cannot be rejected in any period and length for the OIS case and in the pre-crisis period for the Euribor rates at 5% of significance level.

From this analysis, we can conclude that OIS rates priced according the EH and Euribor rates were partially priced according to the EH in the pre-crisis period. It is important to point out that the only *AE* rate in which we have not artificially introduced autocorrelation is the 1 month – as we use a monthly frequency. Nevertheless, the conclusions obtained in the 1, 3 and 6 months rates are completely the same. In this sense, we are confident about the obtained results.

[15] There is one exception. The unit root hypothesis in the one month difference panel C is rejected at 5% of significance level.

Table II. Estimating the cointegration relationship spot rates and accrued Eonia rates

	p-*r*; *r*	$\lambda_{trace}(r)^*$	*p*-value	*k*	α	β	$H_0: \alpha = 0$ $\beta = 1$	$H_0: \beta = 1$	ADF/PP statistics on $AE_{t,m} - r_{t,m}$
Panel A. Whole period and OIS rates									
1 m.	2; 0 1; 1	48.083 2.375	0.000 0.705	2	0.041 (2.004)	1.013 (158.99)	3.550 [0.169]	3.421 [0.064]	-5.81/-12.46
3 m.	2; 0 1; 1	23.602 3.374	0.015 0.169	5	0.063 (1.242)	1.012 (63.73)	2.043 [0.360]	0.254 [0.614]	-3.65/-4.79
6 m.	2; 0 1; 1	37.826 6.609	0.000 0.153	4	0.028 (0.696)	1.001 (78.336)	4.095 [0.129]	0.003 [0.955]	-4.05/-3.68
Panel B. Pre-crisis period and OIS rates									
1 m.	2; 0 1; 1	38.252 1.113	0.000 0.921	2	0.044 (1.787)	1.017 (132.99)	4.850 [0.088]	3.728 [0.054]	-4.21/-13.15
3 m.	2; 0 1; 1	50.993 4.492	0.000 0.355	6	0.002 (0.104)	0.999 (181.34)	0.887 [0.642]	0.022 [0.883]	-5.34/-6.70
6 m.	2; 0 1; 1	32.255 6.758	0.000 0.144	4	0.220 (2.865)	1.053 (43.068)	7.285 [0.026]	2.646 [0.104]	-5.98/-4.38
Panel C. Whole period and Euribor rates									
1 m.	2; 0 1; 1	14.510 3.168	0.262 0.559	3	0.154 (1.196)	1.019 (26.032)	(*)	(*)	-3.07/-4.97
3 m.	2; 0 1; 1	9.497 2.857	0.692 0.615	5	3.715 (2.011)	2.281 (4.132)	(*)	(*)	-1.85/-2.38
6 m.	2; 0 1; 1	9.554 1.659	0.687 0.835	4	2.409 (2.546)	1.740 (6.158)	(*)	(*)	-2.32/-2.37
Panel D. Pre-crisis period and Euribor rates									
1 m.	2; 0 1; 1	36.949 1.005	0.000 0.936	2	0.081 (3.114)	1.015 (125.43)	13.327 [0.001]	2.522 [0.112]	-5.69/-12.64
3 m.	2; 0 1; 1	47.290 4.457	0.000 0.360	6	0.059 (2.913)	0.997 (156.05)	28.356 [0.000]	0.174 [0.677]	-5.51/6.06
6 m.	2; 0 1; 1	21.999 3.463	0.027 0.509	8	0.100 (3.072)	1.001 (95.81)	11.568 [0.003]	0.003 [0.960]	-2.47/-3.63

In this table, the maximum likelihood estimate of the equation $AE_{t,m} = \alpha + \beta r_{t,m} + e_{t+m}$ is reported and the trace statistics testing cointegration between both rates using the Johansen (1988) methodology are given. $\lambda_{trace}(r)$ tests the null hypothesis that there are at most *r* cointegration relationships against the alternative that the number of cointegration vectors is greater than *r*. The reported *p*-values are corrected with the small sample Barlett correction developed in Johansen (2002) and the minimum value obtained for the Hannan-Quinn Criteria determines the lag length, *k,* in the VAR system (see Juselius (2009), page 71). The likelihood ratio test (*LRT*) is used in order to test restrictions in the cointegration vector (see Juselius (2009), chapter 10). Critical values for the ADF and PP statistics for the presence of a unit root in $AE_{t,m} - r_{t,m}$ when constant is included are: -3.48, -2.89 and -2.58 at 1%, 5% and 10% of significance levels (Mackinnon(1991)). All the procedures are implemented using RATS 7.0 and CATS 2.0. (*) As cointegration cannot be accepted in this case, we have not computed this test on the values of the cointegration vector. *p*-values and *t*-statistics are displayed between square brackets, [] and parenthesis, (), respectively.

5.2. Forward unbiasedness of implied forward rates in the OIS term structure

A good starting point for the analysis is to carefully observe Figure 3 where the time series for 3 months OIS and forward rates and their differences are outlined. We avoid presenting graphs for the remaining maturities because the main features are repeated in other cases. Forward rates seem to be somewhat delayed, indicating that unexpected movements in the 3 months rates are important and difficult to anticipate. The difference between both rates takes its highest values

during the money market critical period set off in August 2007, indicating that during this period forward rates contain important forecasting errors and, probably also, higher risk premiums. Furthermore, this graph tells us that the difference seems stationary around zero, especially before the turmoil period triggered in August 2007, and positive during the financial crisis period. These facts indicate that forward and OIS rates are probably cointegrated with (1,-1) as a cointegration vector according the EH implications, at least for the pre-crisis period and the three months maturity.

Panels A and B in Table III display the results using the Johansen (1988) methodology for the OIS rates in the whole and pre-crisis period, respectively. In the whole and pre-crisis period cointegration is accepted for 1, 3, and 6 months at 1% of significance level. In the one year maturity case, cointegration is only accepted in the pre-crisis period at 5% of significance level. In the whole period and the three cases in which cointegration cannot be rejected, the null hypothesis of $\beta = 1$ in the cointegration relationship (see Equation (6)) cannot be rejected at 5% of significance level for 1 and 3 months and the significance level decreases to 1% for the 6 months case. Accordingly, for 1 to 6 months the (1, -1) cointegration vector is an acceptable hypothesis. In the pre-crisis period the same conclusion, but with stronger statistical evidence is obtained. Evidence of EH implications on forward rates is obtained by analysing the stationarity of the difference between forward rates and future OIS rates, $f_{t,t+m,n-m} - r_{t+m,n-m}$. Results appearing in the last column in Table III show that in both periods the unit root null hypothesis cannot be accepted in 1, 3, and 6 months maturities at 5% of significance level.[16] The null is rejected for the one year maturity.

From this analysis we can conclude that forward rates are formed according to the EH implications for 1 month, partially according to the EH for the 3 and 6 months maturities and mostly against the EH for the one year case.

[16] There is one exception. The unit root hypothesis in the 6 months difference in panel A cannot be rejected with the ADF test.

Table III. Estimating the cointegration relationship between spot and forward rates with the Johansen (1988) methodology

	p-r; r	$\lambda_{trace}(r)^*$	p-value	k	α	β	$H_0: \alpha = 0$ $\beta = 1$	$H_0: \beta = 1$	ADF/PP statistics on $f_{t,t+m,n-m} - r_{t+m,n-m}$
Panel A. Whole period for the OIS spot rates and its forward rates									
1 m.	2; 0	31.894	0.001	3	0.006	1.019	6.555	3.576	-4.25/-7.88
	1; 1	3.847	0.413		(2.809)	(121.082)	[0.038]	[0.059]	
3 m.	2; 0	21.397	0.033	4	0.062	1.062	6.493	3.3811	-4.53/-3.86
	1; 1	3.378	0.523		(2.912)	(40.247)	[0.039]	[0.066]	
6 m.	2; 0	22.805	0.002	7	0.353	1.179	8.404	4.316	-2.46/-3.02
	1; 1	6.311	0.174		(4.150)	(22.708)	[0.015]	[0.038]	
1 y.	2; 0	14.622	0.255	2	2.713	1.726	(*)	(*)	-1.99/-1.90
	1; 1	3.964	0.430		(1.365)	(3.082)			
Panel B. Pre-crisis period for the OIS spot rates and its forward rates									
1 m.	2; 0	27.127	0.004	4	0.003	1.008	1.518	0.512	-6.14/-10.88
	1; 1	7.316	0.113		(1.337)	(131.834)	[0.468]	[0.474]	
3 m.	2; 0	45.225	0.000	4	0.022	1.016	11.007	1.688	-4.50/-4.32
	1; 1	4.499	0.355		(2.559)	(96.546)	[0.004]	[0.194]	
6 m.	2; 0	44.888	0.000	4	0.178	1.066	14.740	2.235	-3.25/-3.07
	1; 1	4.389	0.369		(2.930)	(28.630)	[0.001]	[0.135]	
1 y.	2; 0	20.990	0.038	1	1.202	1.250	11.512	5.980	-1.50/-1.45
	1; 1	1.493	0.864		(4.139)	(15.277)	[0.003]	[0.014]	
Panel C. Whole period for the Euribor spot rates and its forward rates									
1 m.	2; 0	10.020	0.643	3	0.027	1.075	(*)	(*)	-2.51/-3.97
	1; 1	2.776	0.630		(1.521)	(17.454)			
3 m.	2; 0	10.452	0.602	4	0.239	1.270	(*)	(*)	-3.04/-3.13
	1; 1	1.471	0.867		(2.938)	(13.498)			
6 m.	2; 0	14.507	0.262	7	0.421	1.216	(*)	(*)	-2.36/-2.84
	1; 1	4.369	0.372		(2.912)	(14.652)			
Panel D. Pre-crisis period for the Euribor spot rates and its forward rates									
1 m.	2; 0	29.260	0.002	3	0.004	1.005	48.009	0.298	-5.03/-10.00
	1; 1	2.786	0.628		(1.696)	(127.967)	[0.018]	[0.585]	
3 m.	2; 0	47.618	0.000	4	0.032	1.024	18.571	3.894	-4.82/-4.40
	1; 1	4.191	0.396		(3.734)	(98.518)	[0.000]	[0.048]	
6 m.	2; 0	19.464	0.063	7	0.235	1.102	(*)	(*)	-1.67/-2.89
	1; 1	1.946	0.784		(4.926)	(37.332)			

In this table, the maximum likelihood estimates of the equation $r_{t+m,n-m} = \alpha + \beta f_{t,t+m,n-m} + e_{t+m}$ are reported. For more details, see notes in Table II.

5.3. Forward unbiasedness of implied forward rates in the Euribor term structure

In this subsection we undertake a similar analysis to that carried out in the previous subsection but we now focus on the Euribor rates. We report results for 1, 3, and 6 months maturities as we have limited our analysis to the $m = n$ case and maturities can no longer be obtained from our data set. Figure 4 reports the rates for the 3 months maturities. Comments on Figure 3 written in the previous section can also be applied to this case. Nevertheless, a visual comparison between both figures gives the impression that after August 2007 the difference between forward and future spot rates are somewhat higher in the Euribor rates case, indicating that during this period liquidity and credit risk premiums in the money market are translated to implied forward rates. We will further study this issue in the following sections.

Results for both periods, reported in Panel C and D in Table III, show that at 5% of significance levels both rates only cointegrated for 1 and 3 months in the pre-crisis period.[17] The unbiasedness hypothesis of Euribor rates regarding the realised spot rate is rejected in these two cases at 5% of significance level. The null hypothesis of $\beta = 1$ in the cointegration relationship Equation (6) cannot be rejected at 5% of significance level for the 1 month maturity and the significance level decreases to 1% for the 3-months case. Therefore, for 1 to 3 months the (1, -1) cointegration vector is an acceptable hypothesis. According to the previous results, when the stationarity of the difference between forward rates and future Euribor rates is analyzed, strong evidence is found of stationarity in the 1 and 3 months lengths in the pre-crisis periods. It is interesting to point out that the intercept, α, is significant, positive, and increases with the crisis.

From this analysis we can conclude that before August 2007, the implicit forward rates in Euribor rates were formed partially according to the EH implications for the 1 month case, mostly against the EH for the 3 months case, and absolutely against the EH for the 6 months case. But when the crisis period is included, these rates are no longer cointegrated, and consequently EH is not a valid explanation of how expectations on these rates are formed.

5.4. Testing the EH in successive one month forward rates

The fundamentals in this subsection are based on the arbitrage relationship existing between forward rates and spot rates. In this way, the 1 year rate in t, $r_{t,m12}$, must be equal to the average of the one month spot rate in t, $r_{t,m1}$, and the following eleven consecutive one month forward rates in t, $f_{t,t+mi,m1}$ with i=1 to 11; that is,

$$r_{t,m12} = \frac{1}{12}\left[r_{t,m1} + \sum_{i=1}^{11} f_{t,t+mi,m1} \right] \tag{10}$$

Under the assumption of pure EH and rational expectations, one month forward rates will be equal to the expected future one month rates and, as a result, one-year spot rates can be obtained by averaging consecutive one-month forward rates. If forward rates include a constant risk premium but the EH implication β=1 in Equation (5) is an acceptable hypothesis, we will obtain evidence

[17] The 6 months rates for the pre-crisis period cointegrate at 10% of significance level.

sustaining the EH in a relaxed version. Fama and Bliss (1987) use a similar approach for 1- to 5-year US Treasury bonds.

To throw some light on the differences in the degree of fulfilment of EH implications in the implied forward rates obtained from OIS and Euribors markets, we propose a further analysis on successive 1 month forward rates from one to eleven months ahead. To minimise the influence of autocorrelation in the results, we will carry this analysis using a monthly frequency. Furthermore, we will consider only the pre-crisis sub-period as we have obtained that for the whole period in the previous section Euribor spot and forward rates are not cointegrated and further analysis here is unnecessary. Therefore, attention is now focused in further analysing the fulfilment of EH in both markets just before the crisis began in August 2007.

Panels A and B in Table IV display the results for the OIS and Euribor rates, respectively. In both panels it can be observed that a reliable cointegration relationship exists between successive forwarded rates and the finally observed spot rates. Nevertheless, the significativeness of the stationarity of the difference, examined in the last column, is higher in all cases in the OIS rates; even if it is rejected for the 10 and 11 months ahead difference in Euribor rates. On the other hand, the null hypothesis of $\beta = 1$ in the cointegration relationship Equation (6) cannot be rejected at 5% of significance level in all but one case (the 11-month ahead Euribor rates). Finally, forward unbiasedness cannot be rejected in three cases corresponding to the OIS rates in Panel A: 1, 2 and 6 months ahead. The conclusion is that OIS rates produce more evidence for the EH implications than the Euribor rates.

Table IV. Estimating the cointegration relationship between one month OIS and successive one month forward rates using the Johansen (1988) methodology

Panel A. Pre-crisis period for the OIS spot rates and its forward rates

	p-r; r	$\lambda_{trace}(r)^*$	p-value	k	α	β	$H_0: \alpha = 0$ $\beta = 1$	$H_0: \beta = 1$	ADF/PP statistics on $f_{t,t+m,n-m} - r_{t+m,n-m}$
$m1$	2; 0	27.127	0.004	4	0.003	1.008	1.518	0.512	-6.14/-10.88
	1; 1	7.316	0.113		(1.337)	(131.834)	[0.468]	[0.474]	
$m2$	2; 0	31.186	0.000	3	0.002	1.002	1.584	0.030	-5.71/-6.25
	1; 1	3.906	0.438		(0.613)	(89.242)	[0.453]	[0.861]	
$m3$	2; 0	79.110	0.000	4	-0.002	0.978	8.219	1.551	-4.87/-6.60
	1; 1	2.421	0.364		(-0.563)	(75.846)	[0.016]	[0.213]	
$m4$	2; 0	33.239	0.000	5	0.004	1.001	14.105	0.004	-3.36/-4.92
	1; 1	4.428	0.746		(1.335)	(94.820)	[0.001]	[0.949]	
$m5$	2; 0	62.689	0.000	5	0.006	1.001	17.369	0.004	-3.11/-3.68
	1; 1	6.685	0.148		(1.659)	(74.840)	[0.000]	[0.953]	
$m6$	2; 0	30.875	0.001	4	0.024	1.072	4.536	1.791	-5.98/-4.24
	1; 1	5.394	0.252		(2.178)	(25.597)	[0.104]	[0.181]	
$m7$	2; 0	37.443	0.000	4	0.022	1.051	8.710	1.083	-3.75/-3.38
	1; 1	7.254	0.116		(2.217)	(27.704)	[0.013]	[0.298]	
$m8$	2; 0	52.255	0.000	5	0.027	1.048	15.520	1.234	-2.35/-3.55
	1; 1	5.946	0.202		(2.916)	(30.945)	[0.000]	[0.267]	
$m9$	2; 0	30.853	0.001	4	0.060	1.188	6.377	2.768	-4.54/-3.50
	1; 1	4.136	0.404		(2.555)	(13.141)	[0.041]	[0.096]	
$m10$	2; 0	29.738	0.001	4	0.066	1.179	10.004	2.825	-2.58/-2.65
	1; 1	3.398	0.532		(2.872)	(13.749)	[0.007]	[0.093]	
$m11$	2; 0	38.876	0.000	1	0.095	1.257	7.428	2.167	-2.13/-2.76
	1; 1	3.716	0.468		(2.657)	(10.273)	[0.024]	[0.141]	

Panel B. Pre-crisis period for the Euribor spot rates and its forward rates

$m1$	2; 0	29.260	0.002	3	0.004	1.005	48.009	0.298	-5.03/-10.00
	1; 1	2.786	0.628		(1.696)	(127.967)	[0.018]	[0.585]	
$m2$	2; 0	32.523	0.000	4	0.005	1.001	14.020	0.006	-5.56/-5.92
	1; 1	5.436	0.248		(1.795)	(97.408)	[0.001]	[0.940]	
$m3$	2; 0	44.569	0.000	5	0.009	1.014	19.719	1.235	-4.75/-4.49
	1; 1	4.313	0.379		(3.215)	(97.773)	[0.000]	[0.267]	
$m4$	2; 0	46.305	0.000	5	0.009	1.008	21.122	0.369	-3.35/-3.79
	1; 1	5.559	0.236		(2.870)	(87.367)	[0.000]	[0.543]	
$m5$	2; 0	37.227	0.000	6	0.019	1.039.	15.786	2.610	-2.57/-3.82
	1; 1	8.702	0.061		(4.123)	(61.254)	[0.000]	[0.106]	
$m6$	2; 0	39.494	0.000	4	0.019	1.035	14.815	1.076	-3.90/-3.50
	1; 1	5.190	0.205		(2.614)	(37.821)	[0.001]	[0.300]	
$m7$	2; 0	39.918	0.000	4	0.027	1.053	14.862	1.432	-3.34/-3.24
	1; 1	7.425	0.104		(2.857)	(30.550)	[0.001]	[0.231]	
$m8$	2; 0	39.494	0.000	4	0.038	1.085	14.891	2.401	-2.71/-3.00
	1; 1	6.212	0.181		(3.180)	(24.867)	[0.001]	[0.121]	
$m9$	2; 0	40.143	0.000	3	0.056	1.144	11.143	2.764	-3.03/-2.50
	1; 1	6.039	0.194		(2.966)	(16.793)	[0.004]	[0.096]	
$m10$	2; 0	31.303	0.001	4	0.055	1.125	12.040	1.799	-2.43/-2.50
	1; 1	3.220	0.550		(2.659)	(14.840)	[0.002]	[0.180]	
$m11$	2; 0	44.766	0.000	1	0.130	1.402	9.616	5.052	-2.05/-2.08
	1; 1	6.538	0.158		(3.457)	(10.756)	[0.008]	[0.025]	

In this table, the maximum likelihood estimates of the equation $r_{t+mi,m1} = \alpha + \beta f_{t,t+mi,m1} + e_{t+mi}$ for i=1 to 11, is reported. For more details, see notes in Table II.

5.5. Multivariate cointegration analysis

As we explained in Section 3.1, one implication of EH is that any pair of long and short-term interest rates must cointegrate with (1, -1) as the spread between them must be stationary. This argument can be extended to a collection of n interest rates where n-1 cointegration relationships must exist. As a way of testing the stationarity on the n-1 spreads we will test the restriction appearing in Equation (3) for a set of four interest rates (1, 3, 6 and 12 months) traded in OIS and unsecured interbank deposit markets. A weaker implication of the EH will be that the set of rates examined in each market are cointegrated systems and so share the same common trend.

Panel A and B in Table V report the results for the OIS rates in the whole and pre-crisis periods, respectively. According to the value of the trace statistic we find clear evidence that OIS rates for a cointegrated system and share a unique common trend according the EH implications. Specifically, for each group of n rates considered we cannot reject at 1% of significance level the existence of n-1 cointegration relationships. Further to this, we have tested the stationarity on the spreads restricting the cointegration vector values. The final column reports these results. In the pre-crisis period the null is strongly accepted but in the whole period this hypothesis is weakly accepted at 1% of significance level.

Panels C and D in Table V report results for Euribor rates in the same way. According to the value of the trace statistic we find strong evidence against the EH implication that Euribor rates form a fully cointegrated system for the whole sample period. In the pre-crisis period, we obtain evidence for the cointegration in the first and second subsets of rates, but we reject the cointegration hypothesis for the full set of rates at 5% of significance level. Furthermore, in the two cases where cointegration is a reliable hypothesis we have tested stationarity on the spreads. The final column in Panel D of Table V displays the results. For the 1 and 3 months set we obtain strong evidence of stationarity in the spread. Nevertheless, when the six month rate is added to this group, the stationarity of the spreads is weakly accepted at 10% of significance level – but it will be rejected if we use the 5% significance level as a criteria.

Consequently, results again show strong evidence for the EH in the OIS rates in the pre-crisis period. When the crisis period is included, the evidence is weaker but remains. On the contrary, the Euribor rates only obtain evidence for the EH in the short-run of the curve in the pre-crisis period. All the remaining evidence in the unsecured interbank deposit market is against the expectation hypothesis.

Table V. Multivariate cointegration between OIS rates

maturities	*p-r; r*	$\lambda_{trace}(r)$	p-value	k	*LRT* (p-value)
Panel A. Whole period					
1 and 3	2; 0	50.291	0.000	2	3.919 [0.048]
	1; 1	4.838	0.312		
1, 3, and 6	3; 0	105.461	0.000	2	5.073 [0.079]
	2; 1	36.253	0.000		
	1; 2	5.170	0.275		
1, 3, 6 and 12	4; 0	137.724	0.000	2	9.303 [0.026]
	3; 1	59.193	0.000		
	2; 2	26.795	0.004		
	1; 3	4.514	0.353		
Panel B. Pre-crisis period					
1 and 3	2; 0	55.959	0.000	2	0.104 [0.747]
	1; 1	4.789	0.318		
1, 3, and 6	3; 0	106.337	0.000	2	3.596 [0.166]
	2; 1	51.346	0.000		
	1; 2	4.682	0.331		
1, 3, 6 and 12	4; 0	143.253	0.000	2	1.223 [0.747]
	3; 1	80.443	0.000		
	2; 2	26.617	0.005		
	1; 3	4.103	0.409		
Panel C. Whole period and Euribor rates					
1 and 3	2; 0	7.544	0.935	2	(*)
	1; 1	2.397	0.849		
1, 3, and 6	3; 0	29.291	0.190	2	(*)
	2; 1	6.982	0.892		
	1; 2	2.371	0.705		
1, 3, 6 and 12	4; 0	58.841	0.016	2	(*)
	3; 1	30.016	0.164		
	2; 2	6.717	0.908		
	1; 3	1.457	0.869		
Panel D. Pre-crisis period and Euribor rates					
1 and 3	2; 0	48.783	0.000	2	0.087 [0.769]
	1; 1	4.021	0.421		
1, 3, and 6	3; 0	103.366	0.000	2	5.198 [0.074]
	2; 1	50.555	0.000		
	1; 2	3.992	0.425		
1, 3, 6 and 12	4; 0	134.852	0.000	2	(*)
	3; 1	69.490	0.000		
	2; 2	18.101	0.097		
	1; 3	3.312	0.440		

In this table, the maximum eigenvalue and trace statistics testing cointegration between the first column rates using the Johansen (1988) methodology is reported. $\lambda_{trace}(r)$ tests the null hypothesis that there are at most r cointegration relationships against the alternative that the number of cointegration vectors is greater than r. The reported p-values are corrected with the small sample Barlett correction developed in Johansen (2002) and the minimum value obtained for the Hannan-Quinn Criteria determines the lag length, k, in the VAR system (see Juselius (2009), page 71). The likelihood ratio test (*LRT*) is used in order to test restrictions in the cointegration vector (see Juselius (2009), chapter 10). All the procedures are implemented using RATS 7.0 and CATS 2.0. (*) As cointegration cannot be accepted in this case, we have not computed this test on the values of the cointegration vector.

5.6. Realised risk premiums

Panel A and Panel B in Table VI report the realised risk premiums in the implicit forward rates from Euribor and OIS spot rates corresponding to the pre-crisis and crisis period, respectively. In order to increase the robustness of the descriptive analysis compiled in Table VI we use daily frequency in this subsection.

The most appealing differences between both markets are those related with average values as the other statistics are very similar. Firstly, in both markets average values in realised risk premiums are positive, increase with maturity, and are significantly different to zero. This result indicates that both markets display a positive term premium according to the liquidity preference hypothesis of the term structure of interest rates. Nevertheless, median values are significantly higher in the Euribor rates for 1 and 3 months maturities and equality cannot be rejected for the 6 months maturity. Further to the term premium, the Euribor rates probably include a higher significant counterparty credit risk premium in 1 and 3 months implied forward rates. The equality obtained in the 6 months case probably indicates that for maturities that are longer than 6 months they share a similar term premium. This last result does not imply that both markets share the same risk premium as the comparison is made using intra market realised risk premiums and not across both markets.

From a pair-wise comparison between realised risk premium before and during the crisis period, it can be appreciated that mean values are more than five times higher and the standard deviation more than twice as high in all cases. The huge increase in the counterparty credit risk and liquidity premiums after August 2007 is blamed as the main cause for this increase. Nevertheless, a careful examination of this critical period is beyond the scope of this research.

Table VI. Realised risk premiums (daily frequency).

Panel A. Pre-crisis period (3 January 2000 – 31 July 2007)

	OIS 1 month	Euribor 1month	OIS 3 months	Euribor 3 months	OIS 6 months	Euribor 6 months
Mean × 100 [=0]	0.006 [0.00]	0.0287 [0.00]	0.032 [0.00]	0.049 [0.00]	0.151 [0.01]	0.155 [0.01]
Median × 100	0.004	0.0234	0.012	0.032	0.181	0.192
Kruskal-Wallis	199.99 [0.00]		7.78 [0.00]		0.13 [0.72]	
Standard Deviation × 100	0.085	0.090	0.205	0.205	0.462	0.467
Levene	2.39 [0.12]		0.13 [0.71]		0.10 [0.76]	
Skewness [=0]	1.38 [0.00]	1.24 [0.00]	0.58 [0.00]	0.42[0.00]	0.32 [0.00]	0.29 [0.00]
Excess Kurtosis [=0]	10.73 [0.00]	9.91 [0.00]	1.58 [0.00]	1.37 [0.00]	-0.57 [0.00]	-0.63 [0.00]
Maximum × 100	0.057	0.621	0.796	0.774	1.396	1.353
Minimum × 100	-0.360	-0.344	-0.597	-0.589	-0.775	-0.783

Panel B. Crisis period (1 August 2007 – 25 February 2010)

	OIS 1 month	Euribor 1month	OIS 3 months	Euribor 3 months	OIS 6 months	Euribor 6 months
Mean × 100 [=0]	0.088 [0.00]	0.461 [0.01]	0.351 [0.02]	0.527 [0.03]	0.735 [0.04]	0.744 [0.05]
Median × 100	0.036	0.433	0.167	0.583	0.467	0.566
Kruskal-Wallis	519.09 [0.00]		8.58 [0.00]		1.87 [0.17]	
Standard Deviation × 100	0.174	0.342	0.615	0.815	1.117	1.339
Levene	143.66 [0.00]		56.60 [0.00]		34.70 [0.00]	
Skewness [=0]	2.08 [0.00]	0.97 [0.00]	1.57 [0.00]	1.02[0.00]	1.02 [0.00]	0.83 [0.00]
Excess Kurtosis [=0]	5.30 [0.00]	1.46 [0.00]	1.99 [0.00]	0.55 [0.00]	0.29 [0.13]	-0.45 [0.01]
Maximum × 100	0.891	1.558	2.452	2.785	3.398	3.769
Minimum × 100	-0.239	-0.251	-0.531	-0.632	-1.179	-0.956

This table reports the descriptive statistics of the realised risk premiums in the implied forward rates in the OIS and Euribor spot rates. Realised risk premiums are computed as $f_{t,t+m,n-m} - r_{t+m,n-m}$ considering only the cases in which $m = n - m = 1$, 3 and 6 months. *Kruskal-Wallis* statistics test equality between premium medians for the same maturity in the OIS and Euribor rates. *Levene* statistics test equality between premium variances for the same maturity in both markets. *Skewness* means the skewness coefficient and has the asymptotic distribution N(0; 6/T) under normality, where T is the sample size. The null hypothesis tests whether the skewness coefficient is equal to zero. *Kurtosis* means the excess kurtosis coefficient and has an asymptotic distribution of N(0 ; 24/T) under normality. The hypothesis tests whether the excess kurtosis is equal to zero. Marginal significance levels are displayed as [.] in all the tests.

6. Conclusions

It is important for regulators to understand how economic agents respond to any new piece of information and especially to any action carried out by the regulator. In this sense, an understanding of the exact measure of money market response to central bank initiatives is important in order to better design and implement central bank monetary policy. As we have said in the introduction, the ECB and money markets actors use implicit OIS rates on EONIA to obtain a precise measure of how expectations on future interest rates are formed. The consensus approach is to use the forward rate implicit in the OIS rates less the EONIA spread on the key policy rate to obtain the expected policy rate in the short run.

This paper is the most complete assessment made of EH implications on the OIS rates for Eonia.[18] Most of the results support a relaxed version of the EH in this market, but the evidence

[18] As far as we know, there is only one precedent in the financial literature that studies EH implications in the same asset. In Durré et al. (2003) the unbiasedness hypothesis in implied one month forward rates for one, three, six and nine

becomes somewhat weaker when the crisis period triggered in August 2007 is included in the sample. We obtain evidence for the existence of term premiums in the forward rates implicit in the OIS rates. The term premiums are positive on average and increase with the time to maturity. Specifically, mean values for these term premiums for one, three, and six months ahead are, respectively, 0.6, 2.87 and 15.1 basis points in the pre-crisis period; and within the crisis period these values increase to 3.6, 16.7 and 73.5, respectively. This result is important in order to obtain an exact indicator of monetary market agent expectations on interest rates. In this sense, the one month premium in the pre-crisis period can be considered negligible, but the same cannot be said for three and six months premiums. The use of this result in order to obtain a more precise expectation indicator should wait until money markets come back to a situation similar to that existing before August 2007.

months ahead are studied for the period beginning January 1999 and ending in June 2002. Evidence is found for cointegration in all the horizons – yet the $\beta = 1.0$ null is only accepted for the one month horizon. The risk premium quantification obtained, computed from the intercept value in a restricted cointegration relationship, varies between 1, 2, 4 and 13 basis points for the one, three, six and nine months, respectively. As the authors recognise, their results should be interpreted with caution given the limited sample period.

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