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Determinants of the EONIA spread and the financial crisis*

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Abstract

The financial markets turmoil of 2007-09 impacted on the overnight segment, which is the first step of monetary policy implementation. We model the volatility of the EONIA spread as an EGARCH. However, the nature of the EGARCH considered will be different in the period before the fixed rate full allotment policy of the ECB (2004 - 2008) where we follow the approach of Hamilton (1996) and in the period afterwards (2008 - 2009) where a conventional EGARCH seems sufficient to capture the behaviour of volatility. The results suggest a greater difficulty during the turmoil for the ECB to steer the level of the EONIA spread relative to the main reference rate. The liquidity effect has been reduced since 2007 and in particular since the full allotment policy at the refinancing operations. On the other hand, the liquidity policy and especially the provision of long-term liquidity followed was effective in reducing market volatility. Liquidity provision conditions were also found to have influenced the EONIA spread only since the financial market turmoil. Fine-tuning operations contributed to stabilize money market conditions, especially during the turmoil. The EGARCH parameter estimates also suggest a structural change in the behaviour of the EONIA spread in reaction to shocks.

JEL codes: E43, E52, G21

Keywords: money market, EONIA, monetary policy implementation, financial markets turmoil

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1 Introduction

Nowadays, monetary policy is implemented in developed economies by setting a reference level for a short-term interest rate. The ECB Governing Council is responsible for setting the official interest rates in the euro area, which serve as a benchmark for interbank market interest rates. This corresponds to the first step of the monetary policy transmission mechanism. The expectations theory, one of the explaining theories of the yield curve argues that an investment with a longer maturity should generate the same return as a shorter term investment plus a forward investment for the remaining maturity. This implies that the long-term interest rate should reflect the current level of the shorter-term interest rate and its expectations over the maturity of the long-term investment. Thus, ultimately, it is the shortest maturity interest rate, *i.e.*, the overnight interest rate, and the expectations on this rate that determine the remaining interest rates. It is therefore important to understand how the Eurosystem influences the market interest rate, *i.e.*, the benchmark overnight interest rate for the euro area, the Euro Overnight Index Average rate (EONIA).

The financial turmoil that began in 2007 had a significant impact on the functioning of the money market. Interest rates in this market increased substantially and volatility soared. Longer-term money market interest rates began to incorporate larger liquidity and credit risk premia. The overnight segment turned more volatile and contingent to conditions of interbank market functioning. This situation may have altered the Eurosystem's ability to intervene in the interbank market and steer interest rates in line with monetary policy stance.

Our aim in this paper is to analyse the EONIA spread against the main ECB reference rate. Under "normal" market functioning conditions, the EONIA should fluctuate around the main ECB reference rate. Given that most empirical studies focus on the period prior to the new operational framework, it is relevant to reassess the EONIA spread determinants under "normal" conditions and the eventual changes under market stress situations, both in the money market and in financial markets in general. This paper is organized as follows: in section 2 we recall the main features of the euro area money market and the monetary policy implementation framework of the Eurosystem. In section 3, we describe the recent evolution of the EONIA, focusing mainly on the financial turmoil that began in 2007 and on the most relevant events to explain the behaviour in the money market. In section 4, we explain the methodology and the data used and section 5 presents the main estimation results. Section 6 concludes.

2 The euro area money market and the implementation of monetary policy

According to the ECB (2004), "*monetary policy exerts significant influence over short-term nominal market interest rates. By setting interest rates, monetary policy influences the economy, and ultimately the price level, in a number of ways.*" The monetary policy transmission mechanism begins then with the setting of official interest rates. The European Central Bank (ECB) provides funding or receives deposits from market participants at these rates, which then serve as benchmark to interbank market interest rates. Longer maturity money market rates, such as the 3- and 6-month Euribor, which are widely used as an index for interest rates on bank loans in several euro area countries, are influenced by expectations over shorter term interest rates, and by liquidity and credit risk premium. Therefore, changes in official interest rates impact banks funding costs and bank loans interest rates. Since the central bank reference rates are transmitted along the yield curve and other asset prices, the central bank is able to influence investment and consumption decisions and, ultimately, consumer prices.

The Eurosystem influences short-term interest rates since it sets the price of the monetary base, of which the Eurosystem is the sole supplier.[1] The Eurosystem has at its disposal several means of intervention in the market for reserves. The main refinancing operation (MRO) is the most important open market instrument. In these operations, which are conducted every week, the Eurosystem provides liquidity with one-week maturity, according to its forecast for the aggregate liquidity needs of the euro area banking system. Between 2000 and 2008, banks interested in obtaining funding through the MRO would have to submit bids in the pair bid amount-interest rate. The bids are satisfied by decreasing order of bid rates, which cannot be below the minimum bid rate defined by the ECB. Since October 2008, following worldwide financial markets stress, notably in short-term funding markets, the Eurosystem adopted a fixed rate full allotment (FRFA) tender procedure. This meant that counterparties began bidding only the amount of primary liquidity they would need, obtaining the full amount and paying the interest rate defined by the ECB equal for all participants.[2]

The Eurosystem also provides reserves at a longer term via its longer-term refinancing operations (LTRO). These operations are conducted monthly and have a 3-month maturity. With these operations the Eurosystem does not aim at steering longer maturities interest rates but only to provide liquidity for a longer period of time in order to smooth the banking system's funding needs. Therefore, LTRO are conducted as pure variable rate tender, *i.e.,* there is no limit on the interest rates that banks can propose. During the financial turmoil, some changes were introduced in this instrument: the Eurosystem conducted operations with 6- and 12-month maturity, increased the frequency of 3-month operations and, similarly to the MRO, since October 2008, adopted the fixed rate full allotment tender procedure.

Another available type of open market operation is the fine-tuning operation (FTO). Contrary to the MRO and LTRO, these are not regular nor pre-scheduled operations. They aim at managing the liquidity situation and steering interest rates in the money market, in particular to smooth the effects on interest rates from unexpected liquidity fluctuations. The majority of the FTO conducted so far had overnight maturity and same day value. Since March 2004, several changes were introduced in the operational framework[3] (ECB, 2003) and although the frequency of FTO increased these operations did not become a regular feature. In the new operational framework, the last MRO is allotted one week before the end of the maintenance period, which means that during the last week liquidity imbalances (liquidity forecast errors) accumulate.[4] When these imbalances reach a significant value, they originate pressure on short-term market interest rates, and consequently, the frequency of FTO's increases.[5]

The Eurosystem also has at the disposition of counterparties two standing facilities, the deposit and the marginal lending facilities. The rates of these facilities are set at a "penalty" level, in order to induce institutions to use this instrument only in case of late, large and unexpected individual liquidity shocks. The facilities have overnight maturity and therefore aim at limiting the volatility of overnight rates. Counterparties have no incentive to trade above the marginal lending facility rate or below the deposit facility rate, as there is no limit on

[1] There are several reasons for banks to demand monetary base, such as the public demand for currency, the need to clear interbank balances and the obligation to meet minimum reserve requirements with the central bank.

[2] At the beginning of phase III of the Economic and Monetary Union (EMU), MRO were also conducted as a fixed rate tender, but the ECB defined the allotment amount. In June 2000, the procedure was changed to a variable rate tender.

[3] The period since these changes were introduced is called the new operational framework (NOF).

[4] One of the changes introduced with the NOF was to coincide the beginning of the maintenance period with the MRO allotment day immediatelly following the ECB Governing Council meeting for which the monetary policy stance discussion is scheduled.

[5] The operational framework still foresees the existence of structural operations, with the aim of shifting the structural liquidity position of the Eurosystem. These operations are not relevant for the money market behaviour at the very short-term and were never used so far.

the use they can make of the facilities.[6] Therefore, and as can be observed from Figure 1, the standing facilities rates form a fluctuation corridor for the market overnight rate (ECB, 2008).

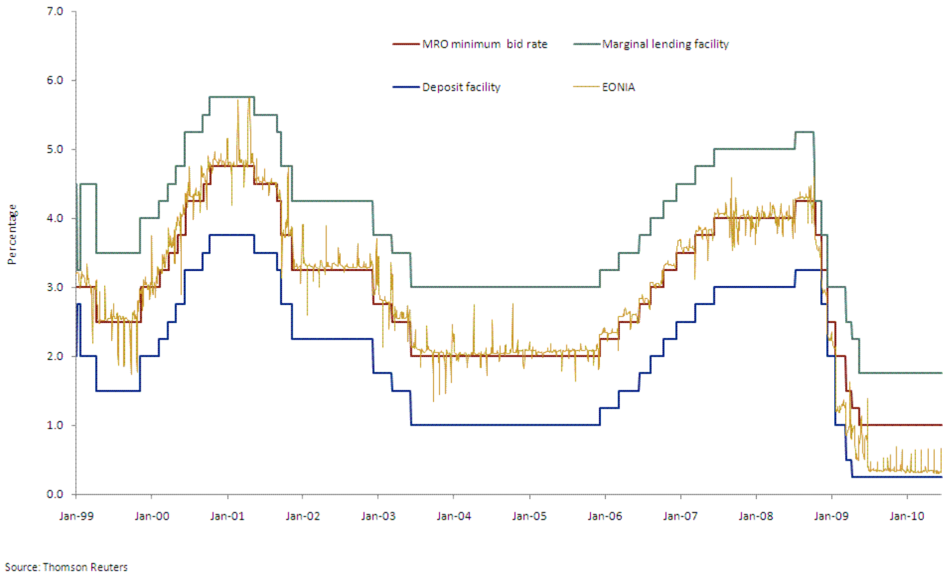

Figure 1: EONIA and ECB reference interest rates

Eurosystem counterparties must fulfill reserve requirements, *i.e.*, hold non-negative current accounts with the respective national central bank during the reserve maintenance period (around one month), in such a way that the daily average current accounts is at least the amount of the reserve requirements. Reserves are remunerated in order to avoid an implicit taxation on banks.

The Eurosystem does not have an explicit interest rate target, contrary to some central banks, such as the Federal Reserve Bank or the Bank of England; see Federal Reserve System (2005) and Bank of England (2008). Its aim is to steer market interest rates at very short maturities. Nonetheless, the design of the monetary policy operational framework implies that the overnight market rate usually fluctuates around the middle of the corridor given by the standing facilities rates. The EONIA rate is the benchmark overnight rate for the euro money market.[7]

According to Perez-Quirós and Mendizábal (2006), the main features of the operational framework that explain EONIA's behaviour are the averaging provision of reserve requirements and the existence of an interest rates corridor. These features, together with balanced liquidity supply, lead the EONIA to typically fluctuate around the middle of the corridor. However, reserve fulfillments in the different days of the maintenance period are not perfect substitutes. As the end of period approaches, the overnight market rate tends to rise, deviating from the martingale, as one would expect. Perez-Quirós and Mendizábal's (2006) model replicates this behaviour using features of the Eurosystem's operational framework without the need to introduce market frictions or non-competitive behaviour.

Empirical studies on the behaviour of the EONIA confirm the importance of the monetary policy operational framework. The most important factors driving the spread can be

[6] With the exception of the collateral that counterparties have to post as a guarantee when they use the marginal lending facility.

[7] The EONIA (Euro Overnight Index Average) is the average of the rates at which major euro area banks traded during the day weighted by the transactions amount; see http://www.euribor-ebf.eu/euribor-eonia-org/about-eonia.html for more information.

related with liquidity conditions, policy rate expectations and calender and end-of-period effects (Wurtz, 2003, Bindseil *et al.*, 2003, Moschitz, 2004, Nautz and Offermanns, 2006, Linzert and Schmidt, 2008 and Välimäki, 2008). Firstly, monetary policy influences the EONIA by setting the interest rate level for primary liquidity. For the period before 2004, Nautz and Offermanns (2006) found a strong link between the EONIA and the policy rate, except at the end of the maintenance period. Liquidity conditions are closely related to the liquidity provision by the central bank, which weighs on the level and the volatility of the EONIA (Wurtz, 2003, Moschitz, 2004). Linzert and Schmidt (2008) found that tighter liquidity conditions and uncertainty regarding liquidity conditions (related with the allotment uncertainty at refinancing operations) pressure the EONIA spread relative to the main ECB reference rate upwards. The authors conclude that the ECB is only able to reduce the value of the spread when its liquidity policy induces excess liquidity conditions at the end of the maintenance period. From a structural point of view, there seems to exist evidence for a positive relation between the structural liquidity deficit, which is partly defined by the ECB, and the value of the EONIA spread (Linzert and Schmidt, 2008, Välimäki, 2008).[8]

The standing facilities interest rate range and the degree of asymmetry relative to the main reference rate also influence the market interest rate. A reduction in the amplitude of the corridor allows the EONIA to be more stable and closer to the policy rate (Perez-Quirós and Mendizábal, 2006). In a recent paper, Perez-Quirós and Mendizábal (2010) argue that, if banks have a strong preference for liquidity due to expectations of tight liquidity conditions in the future, the corridor amplitude only has an impact on the demand for reserves if the corridor is asymmetric relative to the main reference rate.

Another important feature of the Eurosystem's monetary policy operational framework is the obligation of counterparties to deliver financial assets as collateral in the refinancing operations. According to Neyer and Wiemers (2004), the market interest rate becomes higher than the policy rate when (among other factors, such as, total liquidity needs of the banking sector and transaction costs in the interbank market) there are opportunity costs of holding collateral which can differ across banks. Thus, banks with lower opportunity costs of holding collateral will obtain more funding from the central bank and act as intermediaries for the remaining banks.

The behaviour of the EONIA also depends on some features of the money market functioning unrelated to monetary policy. At the end of the month, quarter and year, banks usually increase their demand for reserves due to expected increases in payment activities occurring in the last day of the month and due to end of month balance sheet management activities (Bindseil *et al.*, 2003). Most studies confirm the relevance of these calender effects on the behaviour of the EONIA (Wurtz, 2003, Moschitz, 2004, among others). In the same token, on the last day of the reserve maintenance period, counterparties have to fully comply with reserve requirements, which pressures market transactions. The impact on the EONIA usually depends on the aggregate liquidity conditions and on the distribution among market participants.

3 Recent evolution of the EONIA spread

The behaviour of the EONIA has changed significantly since the onset of the financial crisis in August 2007 (Figure 1). Figure 2 shows in a clearer way the evolution of the EONIA spread relative to the MRO minimum bid rate since the implementation of the NOF and Table 1 presents the descriptive statistics (in basis points (b.p.)). As previously mentioned,

[8] The liquidity deficit is given by the total amount of reserve requirements plus the autonomous factors, not related to monetary policy, such as banknotes in circulation and government deposits. In the Eurosystem, the liquidity deficit is relatively stable, since a large part of it is given by reserve requirements and demand by banknotes.

the new operational framework implied significant changes in the operational framework, and consequently, the way the overnight market works. Thus, our analysis will only consider the period from March 2004 onwards. Throughout this paper, the results relative to the NOF correspond to the period from March 2004 to August 2007. The period of the financial crisis starts on August 2007 and the full allotment period begins in October 2008. The sample ends in December 2009.

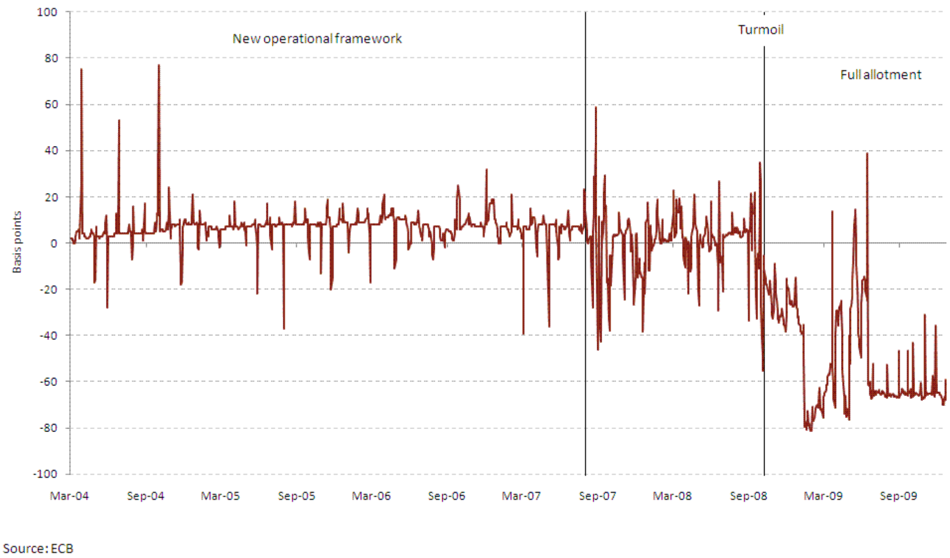

Figure 2: Evolution of the EONIA spread since the start of the new operational framework

	Full sample	NOF	Turmoil	FRFA
Mean	−6.53	6.79	0.42	−51.03
Median	5.00	7.00	2.95	−64.10
Maximum	77.00	77.00	58.80	38.60
Minimum	−81.40	−39.00	−55.40	−81.40
Std. Dev	26.26	6.72	13.68	21.86
Skewness	−1.46	1.42	−0.71	0.91
Kurtosis	4.09	38.29	6.28	3.13

Table 1: Descriptive statistics of the EONIA spread

The EONIA spread was relatively stable from 2004 until the onset of the financial markets turmoil in 2007. The average spread was around 7 b.p. with the occurrence of occasional spikes, which were mostly linked to the reserves maintenance period calender. Since August 2007, the situation changed quite substantially and the spread turned much more volatile. The behaviour of the EONIA spread within the maintenance period also changed substantially.

The descriptive statistics in Table 1 show the different behaviour of the EONIA spread in the periods before and during the financial turmoil. From the amplitude of the spread interval (maximum - minimum) one can confirm the expected increase in the dispersion of the spread since the beginning of the turmoil. The value for the skewness suggests a larger asymmetry in the period before the turmoil than during it. The value for the period before the turmoil is positive (1.42), implying a positive asymmetry, i.e, a distribution with a longer right tail. The value for the skewness for the financial crisis period is close to zero (-0.23), suggesting a symmetric distribution, but reflecting an opposite situation before and during the FRFA. The kurtosis of the distribution allows us to conclude in favour of a platykurtic distribution (a distribution flatter than the normal distribution) for the financial crisis period, suggesting a larger frequency of deviations in the EONIA spread. In the period before the turmoil, the distribution is leptokurtic (taller and more concentrated than the normal), which hints at the higher stability in the spread during this period.

Figure 3 shows the average and the one standard deviation interval of the EONIA spread for the same day of the maintenance period. Prior to the crisis, one observed a stable and positive spread up to the last few days of the maintenance period, during which the spread could vary substantially. Notice that this pattern is at odds with Perez-Quirós and Mendizábal's (2006) model predictions of a slightly increase in the overnight interest rate over the maintenance period, regardless of the liquidity conditions. During the turmoil and before the FRFA, the spread oscillated around zero with an increased volatility. Following the FRFA policy, the spread has been on average negative and very volatile all through the maintenance period. We will now present in more detail the major events occurring during the financial crisis that may contribute to explain the evolution of the EONIA spread.

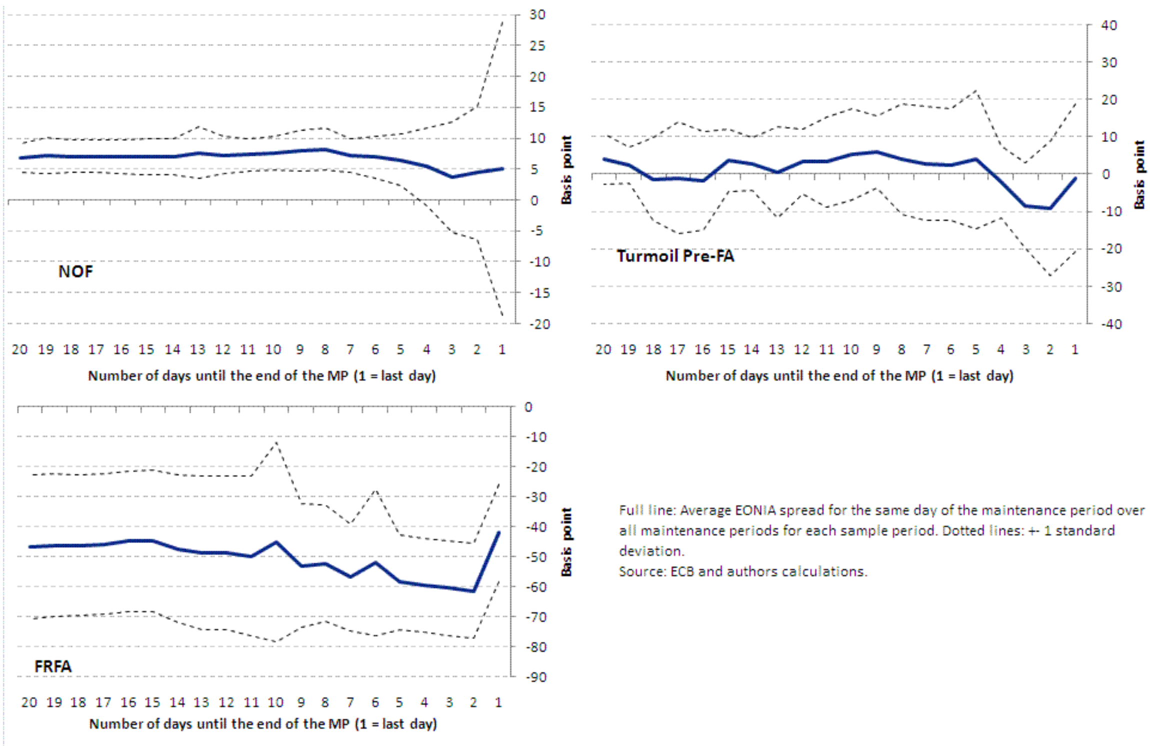

Figure 3: Average EONIA spread over the reserve maintenance period.

Brunnermeier (2009) presents an analysis of the factors which led to the financial crisis. In the summer of 2007, investors began a process of strong reassessment of risk related to revaluations in the market for securitization exposed to the US subprime market. In August, these fears spread to the euro area banks and money markets. The uncertainty about the true value and exposure of banks to asset-backed securities, among other assets, lead in a first phase to a liquidity crisis. While market participants were uncertain about their own liquidity needs, given the context of higher volatility, they were also revising upwards their counterparties credit risk in a context of asymmetric information and uncertainty about banks balance sheets. This translated into an increased demand for liquidity. Banks demand for central bank liquidity increased and showed a preference for reserve frontloading, *i.e.*, to hold more deposits with the central bank than necessary at the beginning of the maintenance period as a precautionary measure (Figure 4). The bidding behaviour in the Eurosystem refinancing operations also changed and there was an increase in tender bid rates and in its dispersion (Eisenschmidt *et al.*, 2009). The increase in the demand for liquidity was also visible in the rise of the amounts that were reported to be traded among EONIA panel banks in the second half of 2007. There was also a reduction in the availability to trade in the money market at the remaining maturities. Consequently, interest rates of the unsecured money market segment jumped, as well as, volatility (ECB, 2009b). Anedoctal and survey evidence (ECB, 2009a) confirms the strong decrease registered in the unsecured money market activity, especially at longer maturities. Despite the shift in preference from longer to shorter maturities, there seems to be no relevant impact on interest rates. Zagaglia (2008) reports that before the turmoil, there was evidence of spillovers of volatility from longer maturities of the money market to overnight rates, but this no longer occurs during the turmoil.

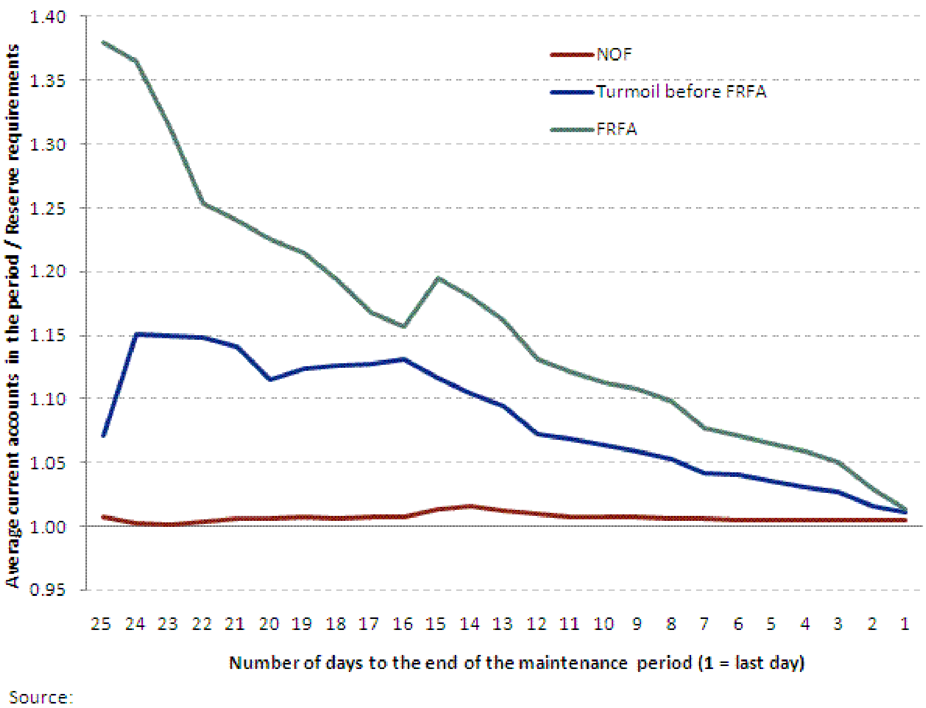

Figure 4: Average reserve fullfilment path of Eurosystem reserve requirements.

The immediate response of the Eurosystem was to increase the liquidity provision with the aim of containing excessive deviations of short-term market interest rates from policy rates (ECB, 2009b). As a consequence, the value of the EONIA spread remained relatively limited and around zero.

In September 2008, there was a sharp deterioration of the financial markets following the Lehman Brothers investment bank fallout, reaching the second phase of the financial crisis, the systemic risk phase. Money markets worldwide froze and unsecured market interest rates skyrocketed. Demand for primary liquidity increased substantially and the use of Eurosystem standing facilities rose to unprecedented levels. In a situation where credit risk rose substantially, market participants almost ceased to trade between each other and the central bank took the role of intermediator. The response by central banks was quite significant. The most relevant measure taken by the Eurosystem was to switch all liquidity providing tenders to a procedure of fixed rate tender with full allotment of the amount bid by banks. In this way, banks were able to secure all their funding needs via the ECB. The ECB also broadened the list of eligible collateral so that collateral requirements did not became binding. The number and frequency of refinancing operations also increased.[9] Aiming at reducing volatility in shorter-term market interest rates, in October 2008 the ECB narrowed the standing facilities interest rate corridor from 200 to 100 b.p., keeping it symmetric around the MRO rate.

As a consequence of the measures taken, money market liquidity conditions became relatively ample. Aggregate liquidity was now determined by the demand side and banks were able to get increased funding at regular operations and depositing it later in the day at the deposit facility. Thus, money market activity, including the overnight segment, diminished. The EONIA moved below the MRO rate and kept systematically closer to the deposit facility rate. Broadly speaking, the measures were effective in limiting the turmoil in funding markets. Therefore, in December 2008 the ECB decided to re-widen the interest rate corridor back to 200 b.p. This was expected to reduce ECB intermediation by increasing the banks opportunity costs of trading in the market. Nonetheless, given that the fixed rate full allotment procedure of refinancing operations was kept, the excess liquidity and the high recourse to the deposit facility remained. The lower level for the deposit facility rate may have contributed to a further decrease in the EONIA spread, by keeping EONIA closer to the deposit facility rate. Perez-Quirós and Mendizábal (2010) argue that the symmetry in the corridor, regardless of the amplitude, does not impact the demand for reserves when banks have a preference for liquidity for precautionary reasons, and therefore, central banks should intervene in the liquidity provision and the asymmetry degree of the corridor.

One can argue that the central bank has the ability to influence interest rates when liquidity risk premium prevails, as seems to have occurred in the first phase of the crisis (Nobili, 2009 and Frank and Hesse, 2009). However, the ability of central banks to influence interest rates when credit risk premium prevails is most likely low. According to Nobili (2009), following the Lehman Brothers fallout, the liquidity risk premium responded favourably to Eurosystem policy measures and the credit risk component became then the main responsible for the evolution of the money market rates. Frank and Hesse (2009) and Christensen *et al.* (2009) also conclude in favour of the success of central banks measures on easing stress in unsecured money markets.

In May 2009, money market conditions were more stable. Some additional measures, not directly related to the situation in the overnight segment, were taken. The Eurosystem expanded further its non-conventional measures aiming at easing funding conditions in the banking system and promoting credit to the rest of the economy ("enhanced credit support" phase). The standing facilities corridor was narrowed again to 150 b.p. in order to avoid the deposit rate being at the zero lower bound while keeping the corridor symmetric around the MRO rate. The Eurosystem also decided to purchase covered bonds and to provide further longer-term liquidity to counterparties via 1-year refinancing operations. The first 1-year operation, conducted at the end of June 2009, met a great demand, implying that about half of the liquidity provided by regular operations was through the 1-year operation. This operation provided a substantial liquidity buffer and seems to have allowed for a greater stabilization of the money market conditions.

4 Data and methodology

In this study the determinants of the EONIA spread are analysed, in particular, the effects of the financial crisis. Only few empirical papers have looked at the behaviour of the EONIA since the new operational framework. The period analysed in this paper starts in March 2004

[9] Given that the strains were also felt in the dollar and swiss franc funding markets, the ECB also provided liquidity to Eurosystem counterparties in these currencies. See, for instance, ECB (2009b) for more details.

and ends in December 2009.

The liquidity effect indicates the capacity of the central bank to influence the level of interest rates through changes in the supply of reserves. From a monetary policy point of view, it is important to understand this effect and how it may have changed with the turbulence of the financial markets. Given that one of the relevant components for the evolution of the money market interest rates and, in particular, the EONIA, was the liquidity premium, one may expect that the ability of the Eurosystem to influence the interest rates has changed. The Eurosystem does not completely determine the supply of reserves since it began with the full allotment procedure at the refinancing operations; this may have implied a lower liquidity effect.

Market turbulence was also affected by the credit risk component. The effect on the overnight segment is not clear. On the one hand, this segment is not subject to credit risk considerations, and on the other, the larger preference for short-term maturities in detriment of long-term ones due to credit risk, may imply an indirect effect on the overnight segment. If this is the case, it may indicate that monetary policy loses ability to influence interest rates.

Besides these two effects, it is also important to analyse other characteristics of the overnight segment of the money market, such as calendar effects and effects of the maintenance period (Wurtz, 2003, Perez-Quirós and Mendizábal, 2006, Moschitz, 2004, among others).

The methodology used follows previous studies, in particular the seminal work of Hamilton (1996) for the fed funds rate. The EONIA spread with regards to the MRO rate, which we define as s_t, is modelled considering that the conditional variance follows two regimes. This feature of the conditional variance is modeled using an exponential general autoregressive conditional heteroskedastic (EGARCH) model as proposed by Nelson (1991), but with the particularity of the two regimes introduced by Hamilton (1996). In order to accommodate this characteristic, the innovations are assumed to follow a distribution which consists of the combination of two normal distributions which differ in the variance. However, for the FRFA period, we found that a conventional EGARCH is more appropriate.

Hence, the EONIA spread, s_t, is described as:

$$s_t = \mu_t + h_t v_t$$

where μ_t is the conditional mean, h_t the conditional standard deviation and v_t are random shocks which follow a normal distribution with zero mean and variance $p + (1-p)\sigma^2$. In other words, the distribution of the shocks is given as,

$$g(v_t) = p \frac{\exp\left(-\frac{v_t^2}{2}\right)}{\sqrt{2\pi}} + (1-p)\frac{\exp\left(-\frac{v_t^2}{2\sigma^2}\right)}{\sqrt{2\pi}\sigma}$$

where with probability p, the innovations follow a distribution with low volatility, in which the variance is normalised to one, and with probability $(1-p)$, a distribution with high volatility, whose variance is σ^2. Hamilton (1996) was one of the first to use this distribution in this context in order to capture the tails and the infrequent spikes which are found in the fed funds rate. The equation for the conditional mean of the spread is given as,

$$\mu_t = c + \rho s_{t-1} + \beta' x_t + \phi' D_t$$

where c is a constant, s_{t-1} the first lag of the spread, x_t a vector of explanatory variables and D_t a vector of dummy variables. The conditional variance of the EONIA spread, h_t^2, is given by the expression,

$$\log\left(h_t^2\right) - \gamma z_t = \delta\left[\log\left(h_{t-1}^2\right) - \gamma z_{t-1}\right] + \alpha\left(|v_{t-1}| - E|v_{t-1}| + \varkappa v_{t-1}\right)$$

where z_t corresponds to a set of explanatory and dummy variables. Considering the logarithm of the conditional variance ensures that it always assumes positive values, independently of the sign of the coefficients, avoiding in this way the need to impose restrictions on the model parameters in order to guarantee that the unconditional variance is positive. The parameter $\varkappa$ allows for the existence of asymmetric effects, i.e., positive surprises may have different impacts than negative surprises. If $\varkappa = 0$, negative surprises have the same impact on volatility as positive surprises. If $\varkappa < 0$ ($\varkappa > 0$), negative (positive) surprises have a larger impact on volatility. If $\varkappa < -1$ ($\varkappa > 1$), positive (negative) surprises reduce volatility while negative (positive) ones increase volatility (Hamilton (1994)).

In the mean, as well as, in the variance equation, explanatory variables look to capture liquidity effects, credit risk effects, interest rate expectation effects (both within the maintenance period as well as in between) and the conditions of primary liquidity provision. The dummy variables look to capture calendar effects, end and start of the maintenance period effects, fine-tuning operations and changes of official interest rates.

5 Results

5.1 The period up to the full allotment policy

Tables 2 and 3 present the estimation results of the model based on a sample from March 2004 to September 2008 when the ECB started the full allotment policy at the liquidity-providing reverse operations.[10] The explanatory variables included in the model are (i) the expected spread in the maintenance period, measured by the spread between the one week EONIA swap and the current MRO rate[11] and (ii) the liquidity imbalance in relative terms, given by the ratio between the sum of daily excess reserves accumulated over the maintenance period and the use of the deposit facility net of the use of the marginal lending facility, and the amount of reserve requirements. One may expect that the impact of liquidity imbalances is different in the last week of the period, when banks are more sensitive to liquidity variations, in comparison to the rest of the maintenance period. The dummy variables included are: $D_1 = 1$ for the first day of the reserve maintenance period; $D_2 = 1$ for the last day of the month; $D_3 = 1$ for the last day of the quarter; $D_4 = 1$ for the days in which the ECB Governing Council decided for a change in official interest rates; $D_5 = 1$ for the days in which the ECB conducts a liquidity absorbing fine-tuning operation; $D_6 = 1$ for the days of the last week of the maintenance period; $D_7 = 1$ for the two last days of the month.

From Figure 3 we observe that over the reserve maintenance period the EONIA spread volatility seems to have changed, while its mean continued relatively stable, slightly positive and decreasing in the last days of the maintenance period. Two remarks should be taken into account. The mean spread is lower during the turmoil than before, to which the excess liquidity created from monetary policy allotments may have contributed. The mean also seems to be more volatile, but we also have a lower number of maintenance periods (14 compared to 41 before the turmoil). The estimated model takes this dynamics into account, allowing for different behaviour of the variance in the two periods.

In line with what would be expected, we do not find significant changes in the mean behaviour in the EONIA spread with the start of the financial turmoil. We observe a slightly positive

[10] Estimations were done in Gauss 10.0.3 based on an adaptation of the code of Hamilton (1996), available on his website http://dss.ucsd.edu/~jhamilto/software.htm#fed.

[11] The source used for the overnight swaps were the Reuters quotes to June 20, 2005 and the EONIA swap index of the European Federation of Banks from that date onwards.

Mean equation			
Variable	Coefficient	St. Error	z-stat
C	0.7272	0.1139	6.3844
s_{t-1}	0.7235	0.0262	27.6146
D_1: first day MP	2.1450	0.3479	6.1662
D_2: end of month	2.2869	0.2188	10.4497
D_3: end of quarter	4.3540	0.1937	22.4785
D_4: change in policy rate	−2.9505	0.7970	−3.7020
D_5: liq. absorbing FTO	3.8187	0.7197	5.3058
Rel. ex. liq. last week MP	−147.5670	27.5717	−5.3521
Rel. ex. liq. remaining MP	−25.1357	1.3039	−19.2767
Expected spread within MP	0.1965	0.0226	8.7021

Source: Authors' calculations.

Table 2: Parameter estimates for the mean equation for the period prior to the full allotment policy (2-normal mixture distribution)

average spread, in line with theoretical predictions, given the tender procedure followed during this period. Indeed, the Eurosystem followed a variable rate tender procedure with a minimum bid rate at the MRO, which imposed the main policy rate as the benchmark for the lowest cost of primary liquidity. Therefore, under normal market conditions it would be expectable that market participants would cover this primary cost by trading slightly above the policy rate. From Figure 3, it seems that there may have been a decrease in the average spread during the turmoil. However, we do not find such an effect to be statistically significant. During this period, the ECB began a reserve frontloading policy (larger allotment amounts at the first MRO of the maintenance period), leading to an excess liquidity situation that was adjusted at the end of the maintenance period. Liquidity conditions are likely to explain this small decrease.

The results also confirm the expectations regarding the calender and end-of-maintenance period effects. The EONIA spread tends to increase 2 b.p. in the last business day of the month, and an additional 4 b.p. in the last business day of the quarter. Volatility also tends to increase at the end of the month. This result is in accordance with previous studies and relates mainly to the increase in payments and activities of balance sheet management (Bindseil *et al.*, 2003, Wurtz, 2003, Moschitz, 2004, Benito *et al.*, 2006 and Linzert and Schmidt, 2008). The effect of the maintenance period is captured in the mean at the beginning of the period, with a 2 b.p. increase, and in the last week of the period with an increase in volatility. This effect is not consensual in the literature. Regarding the euro market and for a sample prior to the one considered here, Perez-Quirós and Mendizábal (2006), Bindseil *et al.* (2003) and Wurtz (2003) do not find a significant effect, while Moschitz (2004) concludes that the EONIA volatility increases at the end of the period. Hamilton (1996) and Bartolini (2000) verify that, for the fed funds rate, the effect of the maintenance period is relevant for both the mean and variance.

To a certain extent, the effect of fine-tuning operations on the EONIA spread corresponds to what would be expected. The spread tends to increase when there is a liquidity absorbing fine-tuning operation, but liquidity providing fine-tuning operations do not have a significant effect on the spread.

Interest rate expectations for the maintenance period are not significant in the new operational framework (which is in line with the results of Linzert and Schmidt, 2008). However, in the days in which the ECB Governing Council decides to change the official interest rates, the mean spread shows a significant fall. This is a robust result, but to a certain extend unexpected, which may be related to an adjustment by market participants to the new policy rate.

Regarding the effects of policy changes, results in the literature are not consensual. While Wurtz (2003) does not find a significant effect on volatility after changes in the official interest rates, Moschitz (2004) concludes that the EONIA volatility increases in the days in which the ECB Governing Council meets. Both studies refer to similar sample periods.

Expectations on interest rates within the maintenance period are important for the behaviour of the EONIA spread. It seems that market participants partly incorporate shorter expectations over the EONIA spread into the current level of the spread. According to Linzert and Schmidt (2008), the one week ahead expected spread is positively correlated with the current spread. Although this variable is statistically significant, this does not completely rule out the possibility that market participants may be anticipating changes in the official interest rates, given that this variable captures this effect in the last week of the maintenance period. If this would be true, then the new operational framework would not have completely isolated the EONIA from the expectations of policy rate changes. The effect of expectations on volatility is not statistically relevant.

It is possible to find a significant liquidity effect in the period under analysis. Given the average minimum reserve requirements of 172.5 billion euro during the period up to the beginning of the full allotment policy, the results suggest that a liquidity imbalance of around 1.2 billion euro would imply a variation in the spread of 1 b.p. in the last week of the maintenance period. Over the rest of the maintenance period a six times bigger imbalance on aggregate liquidity would be necessary to observe the same effect, *i.e.*, a 6.9 billion euro imbalance would be needed to get a 1 b.p. impact on spread. This result is in accordance with the literature (Friedman and Kuttner, 2010), although with a slightly smaller impact than the results estimated in other papers. Wurtz (2003) only finds a significant effect of the liquidity conditions of the EONIA in the last two week days of the period. The results of Ejerskov *et al.* (2008) imply that an imbalance of one billion euros implies a variation in the spread of 25 b.p. in the last week of the period and only 2 b.p. in the remaining part of the period. Moschitz (2004) also finds an end-of-period effect, where an imbalance of the same magnitude generates a variation of the EONIA of 7.7 p.b.

We find that liquidity conditions are also relevant for the volatility behaviour and that there is a distinct reaction before and during the turmoil. Until August 2007, excess liquidity in the last week of the maintenance period contributed to substantially reduce volatility. Given that during this period, the ECB used to follow a balanced liquidity provision, especially at the end of the period, this meant that market participants would favor a small liquidity surplus, probably for precautionary reasons since the costs of non-compliance are elevated. During the rest of the maintenance period, the effect was of an opposite sign, but also of much smaller magnitude. This different effect over the maintenance period disappeared with the start of the turmoil and the total impact was smaller. During the turmoil, a one billion increase in the excess liquidity induces a 9 per cent increase in volatility and we do not find a significantly different impact at the end of the period. It seems that the higher preference for liquidity led to a reduced impact on volatility from liquidity imbalances.

The model was also estimated with 5-year iTraxx Europe senior financial CDS composite spread as a proxy for the banking sector credit risk. This variable was very stable and close to zero until the start of the turmoil, therefore any effect from credit risk would only be expectable after August 2007. However, we did not find a significant effect for this variable, which meant that, at least in the first phase of the crisis, the overnight sector remained isolated from credit risk considerations, both directly and indirectly (via a possible increase in rates due to an increased demand following a shift in market participants preferences from longer to shorter maturities).

Relatively to the estimates of the EGARCH parameters, we also found a significant difference between the results for the two periods, which confirms our suspicions of a relevant change

Variance equation			
Variable	Coefficient	St. Error	z-stat
D_6: last week of MP	1.2487	0.1737	7.1902
D_7: end of month (2 days)	1.0477	0.2473	4.2368
Rel. ex. liq. last week MP before turmoil	46.6976	6.5131	7.1697
Rel. ex. liq. remaining MP before turmoil	−173.4230	22.5898	−7.6770
Rel. ex. liq. turmoil	16.4369	6.2434	2.6327
δ_1	0.4192	0.0504	8.3209
α_1	0.6014	0.0493	12.2089
$\varkappa_1$	−0.0592	0.0570	−1.0387
p_1	0.7397	0.1519	11.1007
σ_1	6.1273	0.5867	10.4433
δ_2	0.7549	0.0721	10.4687
α_2	0.1911	0.0467	4.0926
$\varkappa_2$	0.0121	0.0503	0.2398
p_2	0.4821	0.1106	8.7195
σ_2	5.2724	0.5687	9.2713
Maximum likelihood (log)	−2334.6967		

Source: Authors' calculations.

Table 3: Parameter estimates for the variance equation for the period prior to the full allotment policy (2-normal mixture distribution)

in the overnight market volatility with the start of the turmoil. The variance turned to be more persistent with the turmoil (δ_2 is larger than δ_1), but innovations have less impact (α_1 is larger that α_2). The coefficient that captures possible asymmetry effects ($\varkappa$) is not significant. The probability of observing spikes in the innovations is relatively low when compared with previous studies for the euro area (Moschitz (2004), Perez-Quirós and Mendizábal (2006), Gaspar *et al.* (2004)), namely for the period prior to the turmoil. However, the period analysed in these studies precedes the introduction of the new operational framework, a period in which the behavior of the EONIA was more volatile throughout the maintenance period. Our estimates suggest that, before the turmoil, less than one in every four observations are drawn from a distribution with a larger variance. The variance of this distribution is about six times larger than that of the distribution with the normalized variance. This indicates that spikes in the innovations are relatively infrequent but may reach very high levels, which is consistent with the evolution of the EONIA in this period. With the start of the financial turmoil, there was an increase in the frequency of spikes to one in every two observations, but the variance of the distribution of the extreme values became slightly smaller than before.

5.2 The period of the full allotment policy

As mentioned earlier, in October 2008 the ECB began its FRFA policy, which led to a strong increase in aggregate excess liquidity in the Eurosystem (Figure 5). This policy had as a consequence a significant decrease in the EONIA, putting it close to the deposit facility interest rate (Figure 1). The EONIA spread since 2004 measured against the MRO rate seems to behave as a non-stationary series if this period is included. In our analysis given the in-depth contextual changes, we consider that the beginning of the FRFA constitutes a break in the series of the spread. Given the policy procedures during this period and the implied high levels of excess liquidity, we consider that the relevant policy rate became the deposit facility rate instead of the MRO rate. During this period there were also changes in the facilities interest rate corridor whose impact is mitigated by this measure of the spread.

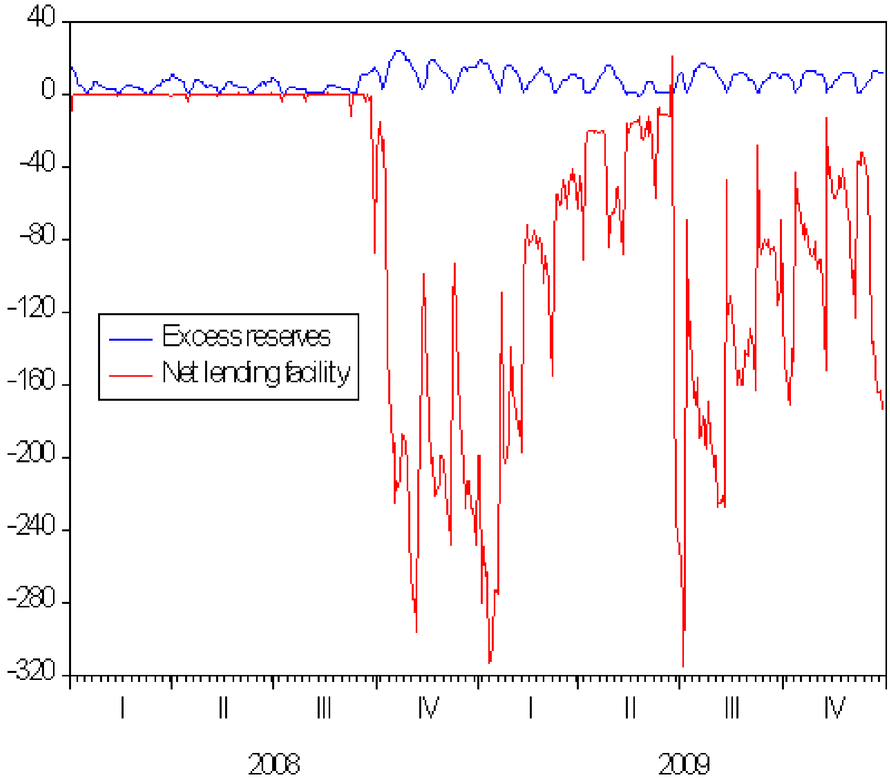

Figure 5: Eurosystem's net recourse to the marginal lending facility (marginal lending minus deposit facilities) and accumulated excess reserves over the maintenance period (in billion euro).

Figure 6 shows the EONIA spread measured against the minimum bid rate and against the deposit facility. Now, the spread is strictly positive and we do not observe the sharp drop in January 21, 2009, coming from the rewidening of the corridor from 100 b.p. back to 200 b.p. Given the high volatility of the spread during this relatively short period and that our main interest focuses on liquidity, risk and policy factors, we demean the series using several date dummies, including end-of-month, end-of-period, some outliers and the period after the first 1-year LTRO (see Table 5 in the appendix). The demeaned series is presented in figure 6.

Over this period, we find a significant difference in the behaviour of this market relative to the previous period, as shocks seem to be more even (not necessarily smaller). Table 4 presents the estimation results. Unlike in the previous section, we do not find significant evidence of the existence of two regimes and therefore we proceed with estimation of a conventional EGARCH(1,1) model.

The value of the constant is symmetric to the average spread relative to the MRO rate (the average demeaned spread is null), which might suggest that out of the factors found to be significant, the EONIA would probably be, on average, around the MRO rate. The main factors affecting the EONIA spread continue being related to liquidity. As the ECB provides more aggregate liquidity, the spread tends to decrease. We clearly find a non-linear effect from the excess liquidity captured in the estimated coefficients of the recourse to the deposit facility in the mean equation. In other words, as the excess liquidity increases, the marginal impact on the spread tends to vanish. For the period following the settlement of the 1-year LTRO, the spread is slightly more sensitive to the excess liquidity. The coefficients of the recourse to the deposit facility suggest that a recourse of 73 billion euro before the 1-year LTRO and of 42

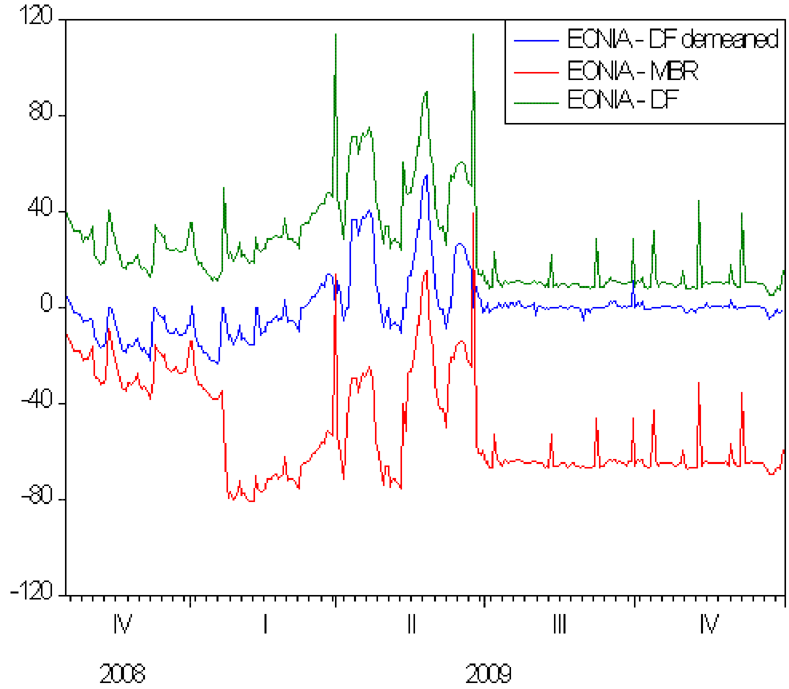

Figure 6: Different ways to measure the EONIA spread during the full allotment policy.

billion euro after it eliminate the positive constant value. From this level on, any impact from an increase in liquidity is marginally neutral. The recourse to the marginal lending facility is not significant to explain the spread, which is in line with what we would expect, given the high level of aggregate excess liquidity and the very low use of the marginal lending facility.

Until the more stable period following the 1-year LTRO, there continued to exist a significant end-of-period effect and much more significant than before. From the allotment of the 1-year LTRO onwards, this variable ceased to be relevant. During this period, there was always an excess liquidity situation which led the ECB to conduct a liquidity absorbing fine-tuning operation at the end of every MP, turning the aggregate liquidity conditions in these days more predictable.

It is also worth noting that the spread was more persistent before the 1-year LTRO settlement. In fact, this operation was quite effective in containing the evolution of the EONIA spread, which turned to be mostly explained by liquidity considerations.

Regarding volatility, as already mentioned, we do not find evidence of the two switching regimes in variance. It seems that the EONIA spread was less subject to occasional relative extreme shocks than before the full allotment period. We also find a significant change with the settlement of the 1-year LTRO. The only variables we found relevant to help explain the variance are dummy calender effects, namely an end-of-month for the second half of 2009. Contrary to the previous period, we did not find any significant liquidity effect on the variance. Conditional variance before the 1-year LTRO seems to be non-stationary and we did not find any effect that may explain this behaviour. Indeed, the conditional variance seems to be explained only by an increasing trend that was only stopped with the 1-year LTRO (see figure 10). We do not find statistically significant asymmetry effects, but unexpected shocks have a strong impact on the variance of the EONIA.

The expected spread within the MP was not found significant for this period, contrary to the previous period. This may be partially due to the increased uncertainty surrounding the evolution of the spread. The CDS spread was also tested and was not significant. Therefore, we can again affirm that it seems that credit risk considerations did not contaminate the overnight

	Coefficient	Std. Error	z-Statistic	Prob.
Mean equation				
C	52.1316	16.2176	3.2145	0.0013
s_{t-1}	0.8619	0.0216	39.9372	0.0000
$^*s_{t-1}$	0.3555	0.0799	4.4488	0.0000
Easter	17.6494	1.5660	11.2704	0.0000
$\ln(DepFac)$	−7.3354	2.7880	−2.6311	0.0085
$^*\ln(DepFac)$	−8.8916	2.8205	−3.1525	0.0016
$[\ln(DepFac)]^2$	0.2393	0.1241	1.9283	0.0538
$^*[\ln(DepFac)]^2$	0.3752	0.1233	3.0443	0.0023
$\ln(MLFac)$	−0.0633	0.1448	−0.4369	0.6622
$^*\ln(MLFac)$	0.0566	0.0542	1.0455	0.2958
End-MP	16.8359	2.3518	7.1588	0.0000
*End-MP	−0.1929	0.3288	−0.5866	0.5575
Variance equation				
End month	0.0867	0.9899	0.0875	0.9302
*End month	2.7965	0.4051	6.9039	0.0000
End-MP	1.7383	1.1729	1.4820	0.1383
*End-MP	−0.7378	0.9390	−0.7857	0.4320
δ	1.0106	0.0063	160.9743	0.0000
$^*\delta$	0.7078	0.1249	5.6673	0.0000
α	0.0223	0.0601	0.3707	0.7108
$^*\alpha$	0.9820	0.2431	4.0388	0.0001
$\varkappa$	11.9456	32.2373	0.3706	0.7110
$^*\varkappa$	0.0883	0.1576	0.5602	0.5753
Log likelihood	−683.0458		Akaike info criterion	4.4765
Avg. log likelihood	−2.1684		Schwarz criterion	4.7386
Number of Coefs.	22		Hannan-Quinn criter.	4.5812

*For the period following the first 1-year LTRO

The constant refers to the full period during the full allotment policy.

Table 4: Parameter estimates for the period of the full allotment policy (normal distribution)

segment.

6 Conclusions

The financial markets turmoil, initiated in 2007, brought a high degree of uncertainty and volatility to the financial markets, from which the overnight segment did not remain isolated. Since monetary policy implementation starts in this market segment, it is important to understand how far the ability of the central bank in steering the market according to its objectives may have changed with the financial crisis. This study looks to answer this question.

We consider a methodology used in previous studies on the reference overnight interest rate for monetary policy purposes, either the EONIA for the euro area or the fed funds rate for the US. The EONIA spread is modelled assuming that the conditional variance obeys two regimes, following the EGARCH model for the behaviour of the conditional variance proposed by Nelson (1991) with the particular features of two regimes introduced by Hamilton (1996). Given the structural changes introduced in 2004 with the new operational framework, we only model the EONIA spread since then. For the period since the implementation of the fixed rate full allotment policy by the ECB, we found a conventional EGARCH (1,1) to be more suitable to explain the behaviour of the EONIA spread.

The results suggest that prior to the financial markets turmoil the EONIA spread was quite stable, reacting to calender and end-of-maintenance period effects and subject to a strong liquidity effect in the end of the period. The beginning of the turmoil in August 2007 did not impact on the mean behaviour. Instead, the EONIA spread became more volatile. We observe a significant change in the variance behaviour with the start of the turmoil. Volatility became much more persistent and subject to more frequent although less extreme shocks. Moreover, liquidity conditions do not matter significantly for the variance during the turmoil, while previously excess liquidity conditions would contribute to an increased volatility in the last week of the period, but to lower volatility over the remaining weeks. This suggests that market participants, under "normal" market conditions, did not see the weeks of the maintenance periods as equivalent, preferring a balanced liquidity situation at the end of the period which guaranteed a more stable EONIA spread. However, with the turmoil, this effect disappeared and we only continued to observe an equivalent liquidity effect on the level of the EONIA spread.

The series of the EONIA spread seems to show a break associated with the Lehman Brothers fallout and the start of the fixed rate full allotment policy by the ECB. Given the high excess aggregate liquidity in the banking system, it seems that the main reference rate for the EONIA switched from being the MRO policy rate to the deposit facility rate. Therefore, over the period from October 2008 until December 2009, a "new spread" was assumed as the EONIA rate relative to the rate of the deposit facility.

The evolution of the mean spread and the variance also shows significant changes relative to before the crisis. A liquidity effect continued to be observed, although much less significant than before, which may be due to the increased preference for liquidity that we find from anecdotal information and also to a non-linear effect associated to the existence of an interest rate corridor. Indeed, we find a significant non-linear effect from excess liquidity. This may suggested that the ECB full allotment policy contributed significantly to reduce the upwards pressure on overnight rates, but had no relevant impact on volatility. Indeed, the variance of the EONIA seemed to show a sustained increasing trend which was only stopped with the first 1-year LTRO. More than the fixed rate full allotment policy, it seems that it was this operation that contributed significantly to stabilize the EONIA and restore the effect from monetary policy implementation. Indeed, the lower persistence in both the mean spread and in the variance suggest this. As a counterpart, the relevant policy rate for this market switched to the lower level of the interest rate corridor.

Given that market segmentation was one of the likely prevailing features of the behaviour in the money market during the crisis, it would be interesting to study the impact it may have had on the EONIA spread. Indeed, there is some evidence suggesting that banks preferred to get more primary liquidity in regular operations and deposit the excess in the deposit facility instead of trading in the market. This behaviour would probably make central banks' task of steering the overnight rate more difficult.

7 Appendix

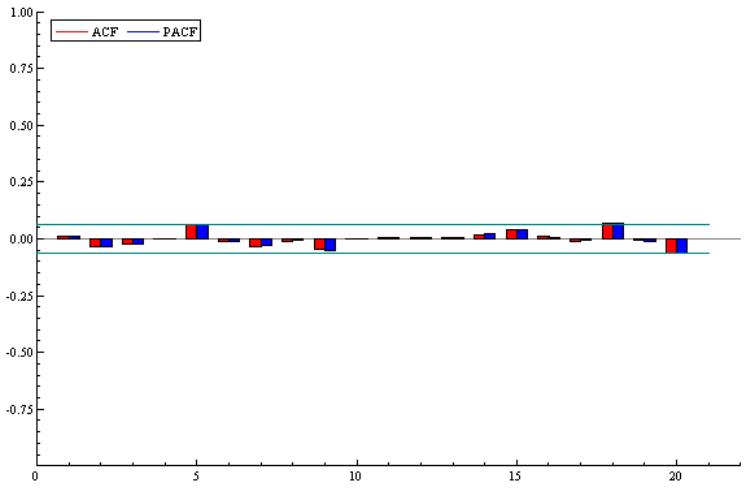

Figure 7: Standardized residuals autocorrelation for the model estimated prior to the full allotment policy.

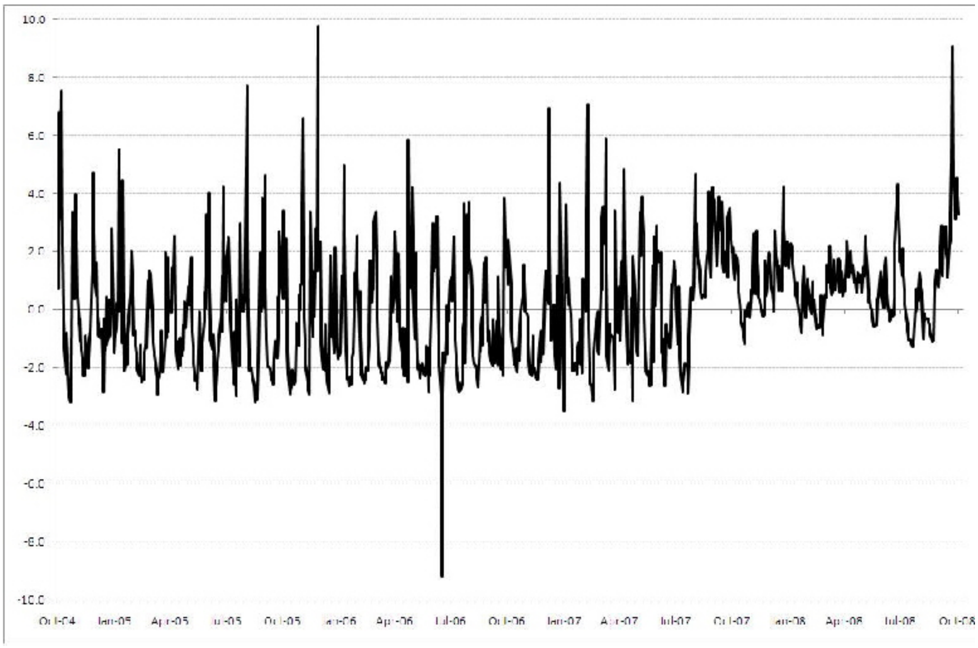

Figure 8: Logarithm of the variance of the model estimated for the period prior to the full allotment policy.

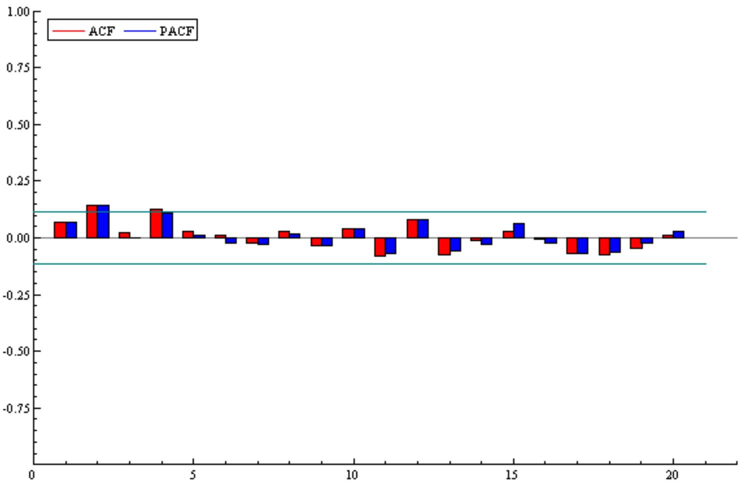

Figure 9: Standardized residuals autocorrelation for the model estimated for the full allotment policy period.

Sample: 10/14/2008 12/31/2009
Included observations: 318

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	34.3816	1.0496	32.7553	0.000
End-month	5.2008	5.1250	1.0148	0.3111
End-quarter	2.7195	8.3893	0.3242	0.7461
D24-06-09	79.2184	13.4180	5.9039	0.0000
D31-03-09	71.2981	15.0038	4.7520	0.0000
1Y LTRO	−24.8692	1.5983	−15.5595	0.0000
End MP Nov08	6.6184	13.4180	0.4933	0.6222
End MP Dec08	−15.2816	13.4180	−1.1389	0.2557
End MP Jan09	−19.6816	13.4180	−1.4668	0.1435
End MP Feb09	−5.2816	13.4180	−0.3936	0.6942
End MP Mar09	−0.8816	13.4180	−0.0657	0.9477
End MP Apr09	16.2184	13.4180	1.2087	0.2278
End MP May09	25.7184	13.4180	1.9167	0.0563
End MP Jun09	14.3184	13.4180	1.0671	0.2868
End MP Jul09	13.0876	13.4328	0.9743	0.3307
End MP Aug09	12.7876	13.4328	0.9520	0.3419
End MP Sep09	18.9876	13.4328	1.4135	0.1586
End MP Oct09	22.4876	13.4328	1.6741	0.0952
End MP Nov09	34.4876	13.4328	2.5674	0.0108
End MP Dec09	29.6876	13.4328	2.2101	0.0279
Start MP Nov08	4.4184	13.4180	0.3293	0.7422
Start MP Dec08	0.3184	13.4180	0.0237	0.9811
Start MP Jan09	15.4184	13.4180	1.1491	0.2515
Start MP Feb09	−9.8816	13.4180	−0.7364	0.4621
Start MP Mar09	0.1184	13.4180	0.0088	0.9930
Start MP Apr09	26.4184	13.4180	1.9689	0.0499
Start MP May09	13.5184	13.4180	1.0075	0.3146
Start MP Jun09	20.3184	13.4180	1.5143	0.1311
Start MP Jul09	1.6876	13.4328	0.1256	0.9001
Start MP Aug09	−0.6124	13.4328	−0.0456	0.9637
Start MP Sep09	−1.3124	13.4328	−0.0977	0.9222
Start MP Oct09	2.1876	13.4328	0.1628	0.8707
Start MP Nov09	−0.6124	13.4328	−0.0456	0.9637
Start MP Dec09	0.5876	13.4328	0.0437	0.9651
R-squared	0.5723	Mean dependent var		25.1682
Adjusted R-squared	0.5226	S.D. dependent var		19.3612
S.E. of regression	13.3769	Akaike info criterion		8.1257
Sum squared resid	50819.3	Schwarz criterion		8.5279
Log likelihood	−1257.99	Hannan-Quinn criter.		8.2863
F-statistic	11.5172	Durbin-Watson stat		0.1527
Prob(F-statistic)	0			

Table 5: OLS estimates for the EONIA spread agains the deposit facility. All variables are one day dummies, expect 1Y LTRO which is a dummy for the period since the 1-year LTRO was settled.

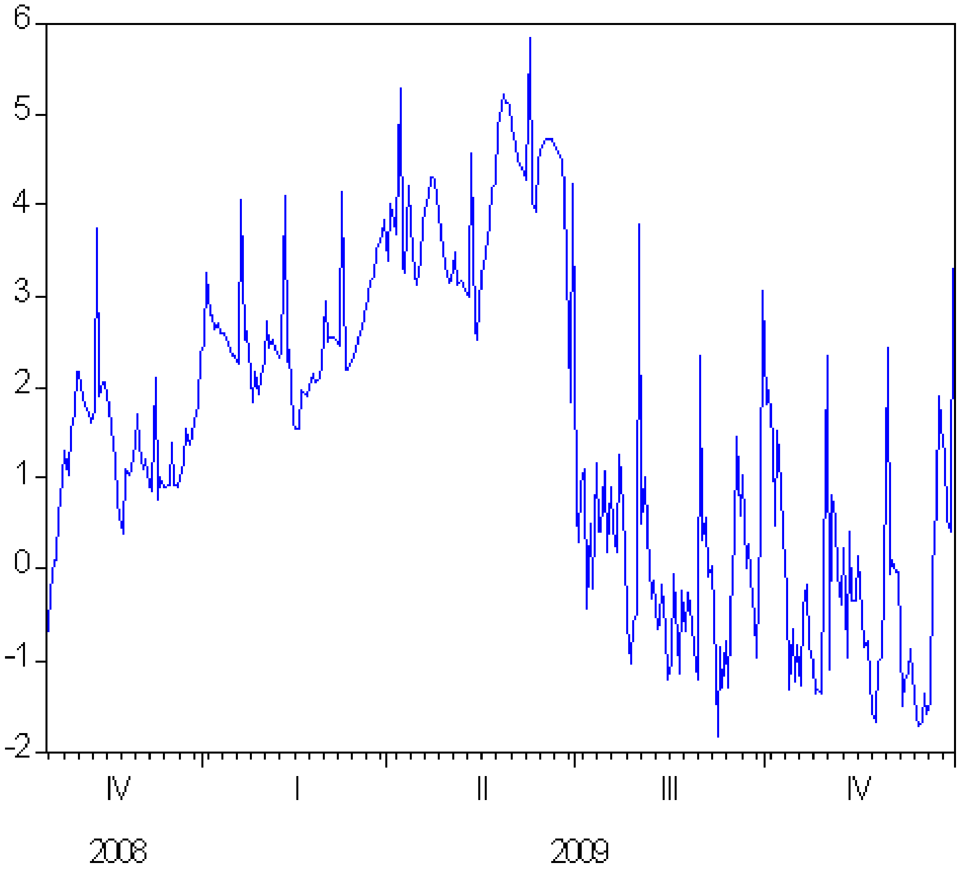

Figure 10: Logarithm of the variance of the model estimated for the period prior to the full allotment policy.

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