DETERMINANTS OF THE EONIA SPREAD AND THE FINANCIAL TURMOIL OF 2007-2009*

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1. INTRODUCTION

Nowadays, monetary policy is implemented in most advanced 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 is the first step in 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 an investment with a shorter term 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 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 over 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 a larger liquidity and credit risk premia. The overnight segment turned more volatile and contingent to conditions of interbank market functioning. This situation might have altered Eurosystem's ability to intervene in interbank market and steer interest rates in line with monetary policy stance.

Our aim 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. The article 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 in 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 interest rates on bank loans. Central bank reference rates are transmitted along the yield curve and other asset prices. Consequently, 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 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 money market stress, the Eurosystem adopted a fixed rate full allotment 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 has no aim of steering longer maturities interest rates but only to provide liquidity for a longer period of time in order to smooth the banking system 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

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(1) Reasons for banks demanding monetary base are for example, 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.

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. Contrary to MRO and LTRO, these are not regular and 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 fine-tuning operations conducted so far had overnight maturity and same day value. Since March 2004, when several changes were introduced in the operational framework[3] (ECB (2003)), the frequency of fine-tuning operations increased, but it did not imply that these operations turned into a regular feature. Since the new operational framework, the last MRO is allotted one week before the end of the maintenance period, which meant that during the last week liquidity imbalances (liquidity forecast errors) accumulated.[4] If imbalances reach a significant value, then the pressure on short-term market interest rates will show up. Hence, given the aim of fine-tuning operations, their frequency increased naturally.[5]

Besides these open market operations, the Eurosystem has at the disposal of counterparties two standing facilities, the deposit and the marginal lending facilities. The rates of the facilities are set at a "penalty" level, in order to induce institutions to use this instrument 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 the use they can make of the facilities.[6] Therefore, standing facilities rates form a fluctuation corridor for the market overnight rate; as can be observed from Chart 1.[7]

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 account 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.[8]

The Eurosystem aims at steering 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

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(3) The period since these changes were introduced is called 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.

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

(7) See ECB (2008) for more details on the monetary policy operational framework.

(8) See Federal Reserve System (2005) and Bank of England (2008).

Chart 1

EONIA AND ECB REFERENCE INTEREST RATES
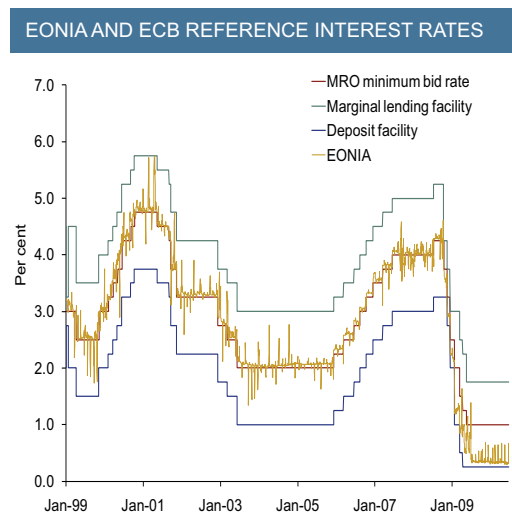
Source: Thomson Reuters.

the benchmark overnight rate for the euro money market.[9]

Acording 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 fulfilments 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 related to 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), 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 upwards relative to the main ECB reference rate. 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 more struc-

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(9) 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.

tural 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)).[10]

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 Eurosistem'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 turns higher than the policy rate when there are opportunity costs of holding collateral which can differ across banks (besides other factors, such as, total liquidity needs of the banking sector and transaction costs in the interbank market). Thus, banks with lower opportunity costs of holding colateral 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 the month balance sheet management activities (Bindseil *et al.* (2003)). Most studies confirm the relevance of these calender effects for the behaviour of the EONIA (Wurtz (2003), Moschitz (2004), among others). In the same token, in the last day of the reserve maintenance period, counterparties have to fully comply with reserve requirements, which pressure 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

The behaviour of the EONIA has changed significantly since the onset of the financial crisis in August 2007 (Chart 1). Chart 2 shows in a clearer way the evolution of the EONIA spread relative to the MRO minimum bid rate since the implementation of the new operational framework and Table 1 presents the descriptive statistics (in basis points (b.p.)). As previously mentioned, 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.[11]

The EONIA spread was relatively stable from 2004 until the onset of the financial markets turmoil in

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(10) 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 for banknotes.

(11) Throughout this article, the results relative to the NOF correspond to the period from March 2004 to August 2007. The period of the financial crisis goes from August 2007 until the end of December 2009. The full allotment period begins in October 2008 and goes until 2009.

Chart 2

EVOLUTION OF THE EONIA SPREAD SINCE THE
START OF THE NEW OPERATIONAL FRAMEWORK
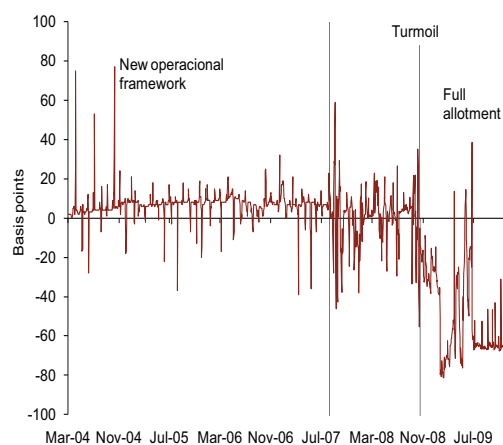
Source: ECB.

2007. The average spread was around 7 b.p. with the occurence of ocasional spikes, which were mostly linked to the reserves maintenance period calender. Since August 2007, the situation changed substantially and the spread turned much more volatile. The behaviour of the EONIA spread with-in the maintenance period also changed considerably.

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 during 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. 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.

Chart 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.[12] During the turmoil, the spread has been on average negative and very volatile all through the maintenance period. We will present next, in more detail, the major events occurring during the financial crisis that may contribute to explain the evolution of the EONIA spread.

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(12) Notice that this pattern is already at odds with Perez-Quirós and Mendizábal's (2006) predictions of a slightly increase in the overnight interest rate over the maintenance period, regardless of the liquidity conditions.
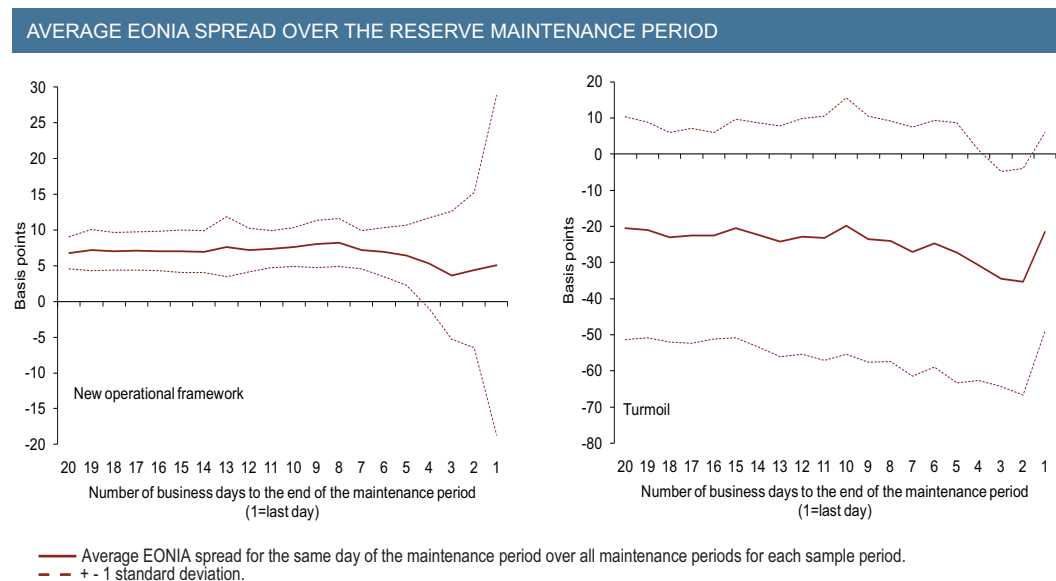
Table 1

DESCRIPTIVE STATISTICS OF THE EONIA SPREAD			
	Full sample	**March 2004-August 2007**	**August 2007-December 2009**
Mean	-6.53	6.79	-25.43
Median	5	7	-18.3
Maximum	77	77	58.8
Minimum	-81.4	-39	-81.4
Std. Dev.	26.26	6.72	31.55
Skewness[a]	-1.46	1.42	-0.23
Kurtosis[b]	4.09	38.29	1.66

Source: Authors' calculations.
Notes: [a] The normal distribution typically used as a reference, is symmetric and the value of this statistics is null. [b] The kurtosis of the normal distribution has a value equal to 3.
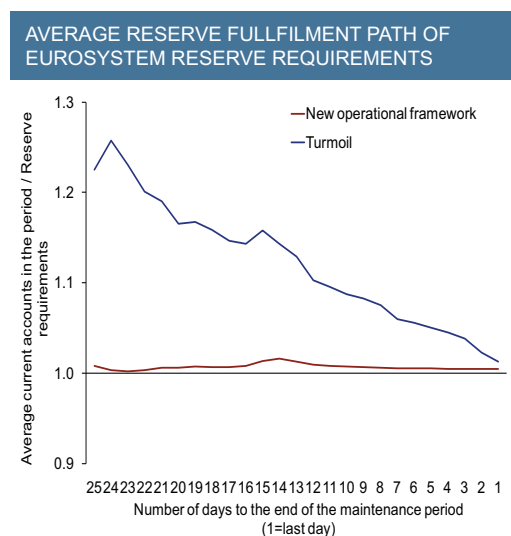
Brunnermeier (2009) presents an analysis of the factors which led to the financial crisis. In the summer of 2007, investors began a process of strong reassessment of risk related to revaluations in the market for securitization exposed to the US subprime market. In August, these fears spread to euro area banks and to money markets. The uncertainty about the true value and the exposure of banks to, especially, asset-backed securities 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 increased demand for central bank liquidity 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 (Chart 4). The bidding behaviour in the Eurosystem's refinancing operations also changed and there was an increase in tender bid rates and in its dispersion (Eisenschmidt

Chart 3

AVERAGE EONIA SPREAD OVER THE RESERVE MAINTENANCE PERIOD

Average EONIA spread for the same day of the maintenance period over all maintenance periods for each sample period.
+ - 1 standard deviation.

Sources: ECB and authors calculations.

Chart 4

AVERAGE RESERVE FULLFILMENT PATH OF
EUROSYSTEM RESERVE REQUIREMENTS

Source: ECB.

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.[13]

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 skyrocked. 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 the collateral requirements did not became binding. The number and frequency of refinancing operations also increased.[14] Aiming at reducing volatility in

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(13) 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.

(14) Given that the strains were also felt in 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.

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, reduced. 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 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 interes rates when liquidity risk premium prevails, as seems to have occurred in the first phase of the crisis (Nobili (2009), 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 Eurosistem policy measures and the credit risk component became then the main responsible for the evolution of 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 and ends in December 2009.

The liquidity effect indicates the capacity of the central bank to influence the level of the interest rates through changes in the supply of reserves. From the viewpoint of monetary policy, 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 might have implied a lower liquidity effect.

Market turbulence was also affected by the credit risk component. The effect over the overnight segment is not clear. On the one hand, this segment is not subject to credit risk considerations. 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 in the overnight segment. If this is the case, it may indicate that monetary policy loses ability to influence the 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 and maintenance period effects (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 EGARCH (Exponential General Autoregressive Conditional Heteroskedastic) 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 considered to follow a distribution which consists of the combination of two normal distributions which differ in the variance.

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,

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

where with probability p, the inovations 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,

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

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

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

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 $\aleph$ allows for the existence of asymmetric effects, *i.e.*, positive surprises may have different impacts than negative surprises. If $\aleph = 0$, negative surprises have the same impact on volatility as positive surprises. If $\aleph < 0 \left(\aleph > 0\right)$, negative (positive) surprises have a larger impact on volatility. If $\aleph < -1 \left(\aleph > 1\right)$, 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[15]

The period before the financial markets turmoil

Tables 2 and 3 present the results of the model parameters for the mean and conditional variance, respectively, for the period from March 10, 2004 to August 8, 2007. 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[16] 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

Table 2

PARAMETER ESTIMATES FOR THE MEAN EQUATION FOR THE PERIOD BEFORE THE TURMOIL (from 10 March 2004 to 08 August 2007)			
Variable	Coefficient	St. Error	z-stat
Mean equation			
C	0.3521	0.0865	4.0698
s_{t-1}	0.7695	0.0287	26.8025
D_1: end of month	1.9022	0.1108	17.1733
D_2: end of year	1.0253	1.102	0.9304
D_5: change in policy rate	-6.425	0.4466	-14.3864
D_6: liq. absorbing FTO	4.5716	1.003	4.5579
D_7: liq. providing FTO	0.4424	1.5967	0.2771
Expected spread within MP	0.1976	0.0238	8.2865
Rel. ex. liq. last week MP	-55.3724	17.0214	-3.2531
Rel. ex. liq. remaining MP	-18.5803	6.9588	-2.6701

Source: Authors' calculations.
Note: *z*-stat is equivalent to the *t*-test.

Table 3

PARAMETER ESTIMATES FOR THE VARIANCE EQUATION FOR THE PERIOD BEFORE THE TURMOIL (from 10 March 2004 to 08 August 2007)			
Variable	Coefficient	St. Error	z-stat
Variance equation			
D_1: end of month	-1.0797	0.2643	-4.0852
D_3: last day of MP	2.108	0.1888	11.1682
D_4: penultimate day do PM	4.0673	0.3441	11.8212
D_5: change in policy rate	-1.6375	0.7038	-2.3267
Expected spread within MP	-0.0233	0.0196	-1.1908
δ	0.0753	0.046	1.6364
α	0.4883	0.0324	15.0685
$\aleph$	0.0887	0.0546	1.6249
p	0.7712	0.1047	17.5348
σ	10.1139	0.9001	11.2359
Maximum likelihood (log)	-1736.9495		

Source: Authors' calculations.
Note: *z*-stat is equivalent to the *t*-test.

(15) 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.

(16) 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.

different in the last week of the period, when banks are more sensitive to liquidity variations, in comparison to the rest of the maintenace period. The dummy variables included are: D_1=1 for the last week day of the month; D_2=1 for the last week day of the year; D_3=1 for the last day of the reserve maintenance period; D_4=1 for the penultimate day of the maintenance period; D_5=1 for the days in which the ECB Governing Council changes the official interest rates; D_6=1 for the days in which the ECB conducts a liquidity absorbing fine-tuning of and D_7=1 for the days in which the ECB conducts an liquidity providing fine-tuning operation.

As expected, the mean of the EONIA spread is influenced by the calendar effects and tends to increase 2 b.p. in the last business day of the month, and additionally 1 b.p. in the last business day of the year. This result is consistent 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 not significant for the mean behaviour, but volatility increases at the end of the maintenance period. This effect is not consensual in the literature. Regarding the euro market and for a sample previous 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 *et al.* (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 extend, 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 over 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 a significant fall in both the mean and variance of the spread is observed. This is a robust result, but to a certain extend unexpected. With this regard, the results in the literature are not consistent. 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, for similar samples in both studies. A possible explanation for our results may be related with a process of adjustment over those days, after an increase of the volatility of the spread prior to expected changes in the official interest rates.[17]

Expectations on interest rates within the maintenance period are important for the behaviour of the EONIA spread. According to Linzert and Schmidt (2008), the one week ahead expected spread is positively correlated with the current spread. The effect of expectations on volatility is not statistically relevant.[18]

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(17) Effectively, changes in official interest rates are generally correctly antecipated by market participants.

(18) Although this variable is statistically significant, this does not completely rule out the possibility that market participants may be antecipating changes in the official interest rates, given that this variable captures this effect in the last week of the maintenance period.

It is possible to find a significative liquidity effect in the period under analysis. The results suggest that a liquidity imbalance of half of the amount of the minimum reserves would imply a variation in the spread of less than 30 b.p. Recall that the average of minimum reserves over this period rose to 155 billion euro. Over the rest of the maintenance period a three times bigger imbalance of aggregated liquidity would be necessary to observe the same effect. This result is in accordance with the literature (Friedman and Kuttner (2010)), although the estimated coefficients are smaller than the results in other papers. Wurtz (2003) only finds a significant effect of the liquidity conditions in 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 7.7 b.p. of the EONIA.

Relatively to the results for the EGARCH parameters, the coefficient that captures possible asymmetry effects ($\wp$) is not significant. The probability of observing spikes in the innovations is relatively low when compared to previous studies for the euro area (Moschitz (2004), Perez-Quirós and Mendizábal (2006), Gaspar *et al.* (2004)). However, the period analysed in these studies preceeds 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 less than one in every five observations is drawn from a distribution with a larger variance. The variance of this distribution is about 10 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.

The financial markets turmoil period

Tables 4 and 5 present estimation results for the conditional mean and variance equations, respectively, for the period from August 9, 2007 to December 31, 2009. The explanatory variables included in this period and which were not included in the previous sample are (i) the CDS spread, given by the CDS index itraxx senior financials published by Markit, whose constituting entities closely represent the EONIA panel banks, and is used as a proxy for credit risk and (ii) the bid-to-cover ratio, given by the ratio between the total bid amount and the allotted amount at the MRO[19]. Since the implementation by the ECB of the full allotment tender procedure, it is no longer necessary to use this variable. The additional dummies used are: D_8=1 in the two last and first business days of the maintenance period; D_9=1 in the last day of the quarter; D_{10}=1 since the allotment of the first LTRO with one year maturity, and D_{11}=1 for June 24, 2009, when a very high value of the spread was registered as a consequence of a one day lag between the maturity of the MRO and the placement of a very large amount of the one year operation.

Relatively to the value of the constant in the mean equation, two conclusions are possible: either the variables modeled do not capture completely the evolution in negative levels of the mean spread, or a structural change has occurred under balanced liquidity conditions affecting the mean spread. The

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[19] Since the model uses daily data, the bid-to-cover ratio is kept constant over the week (at the same level of the last operation).

coefficient of the lag of the spread is close to one, which suggests a high degree of persistence as well as a change in persistence when compared to the period previously analyzed.[20]

Calendar effects are still significant in explaining the mean behaviour of the spread, but market participants seem now to be more sensitive to these effects. In fact, during the crisis, the EONIA spread rose on average 6 b.p. in the last business day of the month, which compares to less than 2 b.p. in

Table 4

PARAMETER ESTIMATES FOR THE MEAN EQUATION FOR THE PERIOD DURING THE TURMOIL (from 09 August 2007 to 31 December 2009)			
Variable	Coefficient	St. Error	*z-stat*
Mean equation			
C	-1.2006	0.4476	-2.6823
s_{t-1}	0.9881	0.0046	214.0279
D_1: end of month	6.0344	1.2358	4.8829
D_9: end of quarter	2.6306	1.7265	1.5237
D_3: last day of MP	13.8033	2.7594	5.0023
D_5: change in policy rate	-0.8943	0.2221	-4.0273
D_6: liq. absorbing FTO	5.1641	1.5486	3.3346
D_7: liq. providing FTO	-4.4297	1.2389	-3.5754
D_{11}: 24/06/2009	46.1302	3.5294	13.0704
Rel. ex. liq. last week MP before full allot.	-22.7857	14.3875	-1.5837
Rel. ex. liq. last week MP during full allot.	-0.6708	0.1665	-4.029
Rel. ex. liq. remaining MP	-0.3048	0.2659	-1.1466
CDS spread	0.0061	0.002	3.0432
Bid-to-cover ratio before full allot.	0.5199	0.2635	1.9733

Source: Authors' calculations.
Note: *z*-stat is equivalent to the *t*-test.

Table 5

PARAMETER ESTIMATES FOR THE VARIANCE EQUATION FOR THE PERIOD DURING THE TURMOIL (from 09 August 2007 to 31 December 2009)			
Variable	Coefficient	St. Error	*z-stat*
Variance equation			
D_1: end of month	2.0831	0.341	6.1085
D_8: first and two last days of the MP	2.577	0.289	8.9157
D_6+D_7: fine-tuning operation	0.5627	0.6549	0.8592
D_{10}: 1-year LTRO	-0.893	0.4272	-2.0903
Rel. ex. liq. last week MP before full allot.	-6.8412	12.2038	-0.5606
Rel. ex. liq. last week MP during full allot.	-1.5254	0.4606	-3.3122
Rel. ex. liq. remaining MP	1.7944	0.3745	4.7917
Bid-to-cover ratio before full allot.	0.4849	0.1847	2.625
δ	0.7809	0.0565	13.8216
α	0.2051	0.0653	3.1407
$\aleph$	0.1377	0.1664	0.8277
p	0.6519	0.1278	10.7086
σ	6.6221	0.4919	13.4625
Maximum likelihood (log)		-1797.8009	

Source: Authors' calculations.
Note: *z*-stat is equivalent to the *t*-test.

[20] Hassler and Nautz (2008) showed that the persistence of the EONIA spread increased with the new operational framework, which suggests a reduction in the ability of the ECB to control the EONIA. However, the results refer to the period before the financial crisis.

the previous period. This larger sensitivity is still more pronounced at the end of the maintenance pe-riod, with an increase of 14 b.p. in the last day of the period, independently of the liquidity conditions. These effects also have a significative impact and are more pronounced than before on the volatility of the EONIA spread; the logarithm of the variance increases about 2 b.p. in the last weekday of the month and in the days around the reserve maintenance period shift.

A reduction effect of the spread, although of a milder magnitude, is still observed on the days the Governing Council decides to alter the official interest rates.[21] On the other hand, the impact of fine-tuning operations is more pronounced during the financial crisis. Fine-tuning operations seem to have a symmetric impact, given that liquidity absorbing operations increase the spread by 5 b.p. whereas liquidity providing operations tend to reduce it by 4.4 b.p. Furthermore, the conduction of fine-tuning operations does not seem to have a relevant impact over the behavior of volatility.

The liquidity effect was substantially reduced in the financial crisis and particularly since the ECB initiated the full alotment procedure.[22] The effect continues to be more pronounced in the last week of the maintenance period, as was also the case in the previous period, which is also in line with previous studies (Wurtz (2003), Ejerskov *et al.* (2008), Moschitz (2004), among others). Taking into consideration that the average value of reserve requirements during the crisis and before the full alotment policy was 204 billion euros, the results suggest that a liquidity imbalance of about 9 billion euros would be necessary to generate a 1 b.p. change in the EONIA spread in the last week of the maintenance period.[23] Since the ECB began with the full allotment procedure at refinancing opera-tions, the variable representing the liquidity conditions looses economic meaning. In contrast, Akram and Christophersen (2010) conclude that, for the Norwegian overnight market, total liquidity is more important during the crisis in order to pressure downwards interest rates. The effect of liquidity imbal-ances in the variance has also changed with the financial crisis. The imbalances of the last week of the maintenance period are not statistically significant before the implementation of the full allotment procedure, but the large excess liquidity created since then contributed to reduce the logarithm of the variance by 1.5 b.p.

The results for the liquidity effect suggest two conclusions. On the one hand, the liquidity effect is very likely nonlinear. When the deviations with respect to the balanced supply of reserves increase, the impact on the EONIA is lower, particularly in the case of the Eurosystem where there is a limit on rates given by the standing facilities rates. Given the high excess of liquidity (Chart 5), it is expectable that increasing liquidity provision will have a small marginal effect. On the other hand, during the finan-cial crisis, EONIA spread may simply have become less sensitive to changes in aggregate liquidity conditions. Given the preference for liquidity in a context of a high counterparty risk and where, as a consequence, a market segmentation situation emerges, the "depth" of the market shrinks, making

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(21) The impact is smaller, although still significant, if one considers a dummy for the days on which a decision over the official interest rates is scheduled at the Governing Council meeting.

(22) The EONIA spread fell when this procedure started. However, the dummy variable for this period is not significant as long as the regression includes a variable that captures aggregate liquidity conditions.

(23) When the model is estimated using only daily accumulated excess reserves over the maintenance period, the conclusion is qualitatively the same. In this case, a reduction of 1 b.p. of the spread is hit with excess reserves of 3.5 billion euro in the last week of the maintenance period before the full allotment policy.

Chart 5

RELATIVE DAILY LIQUIDITY IMBALANCES
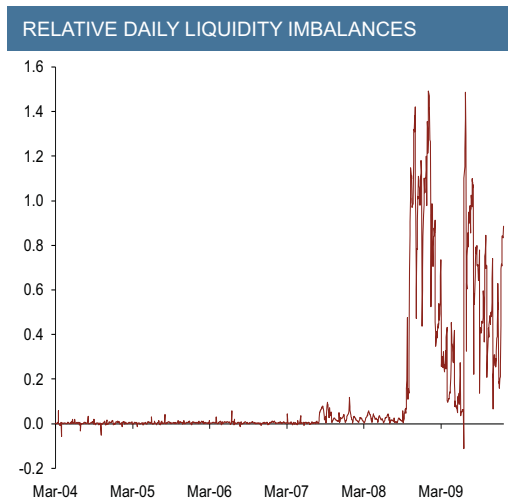
Sources: ECB and authors' calculations.

prices less sensitive to quantity variations.

Additionally, it seems that full allotment at refinancing operations was effective in reducing the end of period money market volatility, although not at controlling the interest rates. This result may be related to the fact that market participants systematically expect the realization of a fine-tuning operation in the last weekday of the maintenance period in order to re-balance aggregate liquidity conditions, although this variable did not reveal statistically significant.[24] Hence, they could avoid trading in the market to adjust their liquidity position. Without availability for trading, the rate remains inflexible. However, during the rest of the maintenance period, the existence of liquidity imbalances generates additional volatility in the EONIA spread, which did not happen before the crisis. The high level of liquidity imbalance and its volatile evolution may contribute to explain this change. The simulated model of Cassola and Huetl (2009) shows that larger volatility in liquidity was not responsible for the observed developments in the overnight market during the crisis, which concurs with our findings. This behavior of the spread would require market segmentation and credit constraints.

The bidding behavior and the allotment results at the MRO also reveal important for the behavior of the conditional mean and variance, contrary to what occurred before the turmoil. As expected, the co-efficient of the bid-to-cover ratio is positive and statistically significant. The larger the amount bid that was not satisfied (larger bid-to-cover ratio), the larger is the share of liquidity needed by banks that has to be satisfied in the market, which, as a consequence, creates upward pressure on the EONIA spread and in the volatility of this market segment. Linzert and Schmidt (2008) also find a positive effect of the bid-to-cover ratio, but smaller and referring to the period before the crisis.

The CDS spread itraxx senior financials has a slightly positive but significant coefficient in the mean equation of the EONIA spread. The expected sign of this variable is not entirely clear, given that the

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(24) In order to capture these expectations, we also included a dummy variable equal to one in the last day of the maintenance period if the ECB performed a fine-tuning operation in the end of the previous maintenance period (Linzert and Schmidt (2008)). However, this variable proved statistically insignificant.

overnight market is not subject to credit risk due to the maturity, but may suffer contagion effects from other unsecured market segments, which are exposed to credit and counterparty risks. For example, a substitution effect may occur due to a reduction in the activity at longer maturities given that an increase in perceived risk may lead to a greater demand for transactions at shorter maturities. This effect may explain the obtained results. However, the impact is relatively small, given that an increase of 100 b.p. in the CDS spreads only increases the EONIA spread by 0.6 b.p. Akram and Christophersen (2010) also conclude that the measures associated to credit risk are more important for the behavior of the overnight interest rates of the norwegian market during the crisis than before.

No significant effect was found regarding the expectations relatively to the evolution of the spread beyond the current maintenance period, which confirms that, even during the crisis, the overnight segment remained isolated from the official interest rate expectations. The variable for the expectations regarding the evolution of the spread within the maintenance period introduced autocorrelation in the residuals, and was therefore excluded from the model. We have also tested whether changes in the corridor of the standing facilities rates have an impact on the spread, but no statistically significant effect was found both in the conditional mean and variance. This result is in line with the findings of Perez-Quirós and Mendizábal (2010), who argue that an asymmetric corridor would be necessary in order to impact on the demand for reserves.

The provision of a long-term liquidity buffer had a strong impact on the market through the reduction of volatility.[25] When the ECB conducted the first operation with a one year maturity, the logarithm of the variance of the EONIA spread decreased by 1 b.p. The results suggest that during the financial crisis, monetary policy was more effective in the reduction of market volatility than in controlling interest rates.

Finally, with regards to the EGARCH parameters, it is observed that variance persistence increased during the crisis, but the reaction to shocks was more controlled. It seems that market participants reacted less to shocks to the EONIA spread over this period. The parameter that captures asymmetric effects is still not significant. About one in every three observations are drawn from the distribution with the highest variance (about 6.6 times more than the variance from the regime with low volatility). In comparison with the period previous to August, 2007, the discrepancy between the two regimes and the frequency of extreme observations diminished.

6. CONCLUSION

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 remaine 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 might have changed with the financial crisis. This study looks to answer this question.

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(25) As an alternative, the liquidity provided at regular operations weighted by maturity was used as an explanatory variable, but did not improve the quality of the model.

We consider a methodology widely 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. The behaviour of the EONIA has also changed substantially with the financial markets turmoil; therefore, we estimate the model in two periods separated by August 2007. This study has the advantage of using a relatively common technique to assess a time period for which there are only few empirical studies available.

The results suggest a greater difficulty during the financial markets turmoil on the ECB steering the level of the EONIA spread relative to the main reference rate. The liquidity effect was reduced since 2007 and especially since the full allotment policy at the refinancing operations. This reduction is probably related to the non-linear response of the interest rate to changes in quantity, which is likely to be highly determined by the existence of the interest rate corridor. On the other hand, the liquidity policy followed was effective in reducing market volatility. This effect has probably resulted from the provision of a substantial liquidity buffer, both in terms of quantity and maturity. The liquidity provision conditions were also found to have influenced the EONIA spread, but only during the financial market turmoil, which might be due to the elevated stability in liquidity provision before that period. The effect of fine-tuning operations is in line with its objectives, although the impact is more pronounced during the turmoil.

The banking system credit risk seems to have pressured the EONIA spread upwards during the crisis, but the effect is not economically significant. The EGARCH parameters results also suggest a structural change in the behaviour of the EONIA spread in reaction to shocks. Before the turmoil, extreme shocks were less regular but more extreme in comparison with more common shocks. During the turmoil, the discrepancy between the two regimes and the frequency of extreme observations reduced, and the persistence in both the conditional mean and variance increased.

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 might 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.

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