Volatility Transmission in the European Money Market*

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Abstract

The European overnight rate (Eonia) is the operational target of the European Central Bank (ECB) that signals the monetary policy stance and anchors the term structure of interest rates. This paper empirically investigates the transmission of Eonia volatility to longer-term money market rates. Distinguishing between seasonal Eonia volatility due to e.g. calendar effects and non-seasonal volatility which may be closer related to uncertainty about the policy intentions of the ECB reveals a significant volatility transmission even for the twelve-month rate. We also examine how the ECB's new operational framework introduced in March 2004 has influenced the Eonia and the transmission of volatility along the yield curve.

Keywords: Volatility transmission; Operational framework of central banks; Interest rate dynamics

JEL classification: E43; E52

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1 Introduction

The interbank money market for overnight lending is the key channel through which monetary policy is executed. Overnight rates, like the US Federal funds rate or the European Eonia[1] rate, are the operational targets of central banks that do not only signal the monetary policy stance, but also anchor the term structure of interest rates. As a consequence, central banks try to avoid excess volatility of the overnight rate for two reasons. First, confusing financial market participants about the policy-intended interest rate level, high volatility of overnight rates hampers the communication of the monetary policy stance and, thus, decreases the transparency of monetary policy. And, second, there is a danger that volatility at the short end of the term structure is transmitted along the yield curve to longer term interest rates with potential distorting effects on investment and consumption decisions. This paper provides new evidence on how volatility of the Eonia rate affects longer-term interest rates in the Euro area.

With a view to the perceived risks of high interest rate volatility, central banks increasingly have adopted monetary policy instruments designed for smoothing overnight interest rates. In particular, the European Central Bank (ECB) recently reorganized its operational framework in order to mitigate the disturbing impact of rate change expectations on the Eonia rate.[2] Specifically, the ECB shortened the maturity of its main refinancing operations and synchronized the timing of the reserve maintenance periods with the Governing Council's interest rate decisions. However, these rather involved measures could have had additional effects for the Eonia and the interest rates in the interbank money market. For example, the shorter maturity of the main refinancing operations could have made banks' refinancing more difficult, more risky and, thus, more expensive. Thus, the 'new framework' may have contributed to the recently observed, puzzling, unintended and persistent increase of the spread between the Eonia and the ECB's key policy rate (see e.g. European Central Bank, 2006b, p. 34). It has also been argued that the new framework helped lowering the volatility of the Eonia, see European Central Bank (2006a) and Durré

[1] The Eonia (**E**uropean **O**ver**N**ight **I**ndex **A**verage) is published by the European Banking Federation (FBE) as a weighted average of the overnight rates reported by a panel of approx. 50 banks that have the highest business volume in the Euro area money market. For more information about the Eonia and further short-term interest rates, see the Euribor website of the FBE at `http://www.euribor.org`.

[2] Further examples include the Fed's redefinition of the discount rate as an upper bound of the Federal funds rate (Furfine, 2003) and the Bank of England's introduction of voluntary reserve requirements as a liquidity buffer for banks (Clews, 2005).

and Nardelli (2007). In order to shed more light on these issues, we will investigate how the new framework affected the dynamics and the volatility of the Eonia as well as the transmission of Eonia volatility along the yield curve.

Our study builds on earlier work on Eonia dynamics, where the effects of the new framework could not be considered simply due to data availability. Following Würtz (2003) or Pérez Quirós and Rodríguez Mendizábal (2006) the time-varying pattern of Eonia volatility is estimated in an EGARCH framework. In contrast to these contributions, however, we follow Benito et al. (2006) and Nautz and Offermanns (2007) and specify the corresponding mean equation as an error-correction equation where the Eonia adjusts to deviations from the ECB's key policy rate (i.e. the minimum bid rate in the main refinancing operations) and a forward spread reflecting the influence of rate expectations. Based on this extended model of Eonia dynamics, we include the resulting estimate of the conditional Eonia volatility as explanatory variable for the conditional volatility of longer term interest rates. Following e.g. Ayuso et al. (1997) and Moschitz (2004), this seems a natural way of testing for volatility transmission along the yield curve.

According to Ayuso et al. (1997), volatility transmission need not be independent of the *level* of overnight rate volatility. Yet, even more important, volatility transmission may depend on the *nature* of Eonia fluctuations. While seasonal effects in Eonia volatility are usually well understood by the market and need not increase the volatility of longer term rates, non-seasonal Eonia volatility should be closer related to uncertainty about the monetary policy stance. Our empirical results confirm that only non-seasonal Eonia volatility is transmitted along the yield curve. In particular, we find that volatility of longer term rates significantly increased during the so-called underbidding episodes when markets were partly confused about the ECB's interest rate decisions.

The remainder of the paper is organized as follows. Section 2 briefly reviews the ECB's operational framework before and after the reform in 2004 and discusses how certain institutional details have affected the dynamics and the volatility of the Eonia. Section 3 presents the empirical model for the Eonia and examines the impact of the new framework on the adjustment dynamics and the volatility of the Eonia. Section 4 shows how conditional Eonia volatility estimated in Section 3 is transmitted to longer term interest rates. Section 5 summarizes our main results and concludes.

2 The Eonia and the operational framework of the ECB

2.1 How the ECB steers the overnight rate

The ECB's main refinancing operations and the key policy rate Like many other central banks in industrial countries, the European Central Bank implements monetary policy by steering the very short-term interest rates in the interbank money market. In particular, the overnight rate Eonia plays a central role in signalling the stance of monetary policy. It is therefore of crucial importance that the Eonia closely follows the ECB's key policy rate set by the Governing council and that its volatility remains "well contained", compare European Central Bank (2006a).

The ECB's key interest rate has been always implemented via its weekly main refinancing operations (MROs) that determine the liquidity of the European banking sector. From 1999 to June 2000, MROs had been conducted as fixed rate tenders where banks simply bid the amount of refinancing they wish to receive at a pre-announced rate that determined the interest rate level intended by the central bank. Unfortunately, however, the fixed rate tender procedure led banks to overbid, i.e. they increasingly exaggerated their demand for reserves, see Nautz and Oechssler (2006). In June 2000, the ECB stopped banks' overbidding by switching to a variable rate tender format, a standard multi-unit auction augmented by a minimum bid rate. Since June 2000, the MRO minimum bid rate is the ECB's key interest rate.

Standing facilities The minimum bid rate is not the only official interest rate set by the ECB to steer the Eonia. Interest rates of two standing facilities, the marginal lending and the deposit facility, where banks can lend and deposit overnight liquidity at short notice define an interest rate corridor that bounds the volatility of the Eonia. The ECB's key policy rate has always been the midpoint of the corridor because the opportunity cost of holding positive or negative balances at the central bank should be equal at the central bank's target rate, see Bindseil (2004). In practice, however, it is difficult to ensure the symmetry of opportunity costs, because transactions with private market participants are not perfect substitutes for similar transactions with the central bank, see e.g. Whitesell (2006).

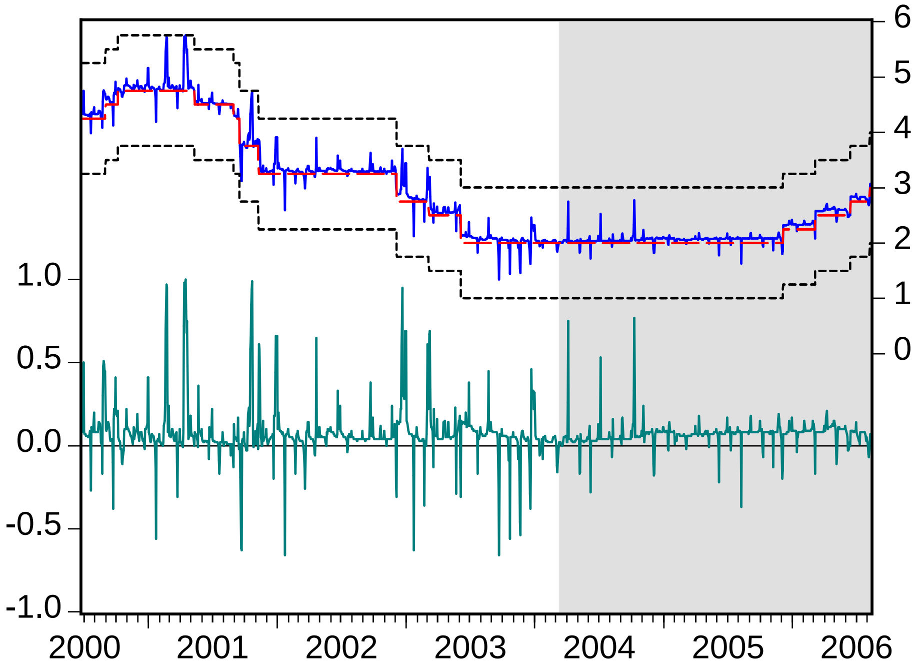
The width of the interest rate corridor has typically been 200 basis points. Of course, setting the marginal lending rate equal to the deposit rate would eliminate Eonia volatility completely. However, a zero width corridor is not a sensible option for the central bank because of the unpredictable effects of drying up trading in the interbank money market. The implications of institutional details in a central bank's operational framework on the behavior of overnight rates are not always obvious. For example, Pérez Quirós and Rodríguez Mendizábal (2006) demonstrated that the ECB's deposit facility does not only lower Eonia volatility but has also significant effects on the predictability of the Eonia at the end of the reserve maintenance period.

Minimum reserves and seasonal Eonia volatility Minimum reserves are an integral part of the ECB's operational framework. They enlarge the structural liquidity shortage and possibly contribute to the control of monetary expansion. More importantly, however, minimum reserves create a liquidity buffer for banks since reserve holdings can be averaged over the maintenance period. The ECB's minimum reserve system is therefore a particular powerful tool to smooth the Eonia within the reserve maintenance period.[3] At the end of the maintenance period, however, liquidity shortages or excess reserves can lead to sharp interest rate peaks and troughs. A similar kind of *seasonal volatility* is also observed at the first day of the reserve period and at the end of each month. The following analysis of volatility transmission takes into account that these dramatic increases of Eonia volatility are temporary, well understood by the market and, therefore, less problematic for the communication of monetary policy. In particular, a certain extent of end of period volatility may even improve banks' incentives to invest in an efficient reserve management.

Fine tuning operations On several occasions, the ECB executed fine-tuning operations to manage the liquidity situation in the market to avoid large interest rate fluctuations. Although the ECB has typically been very reluctant to intervene in the interbank market on such an ad hoc basis, the frequency of fine tuning operations has recently increased, see European Central Bank (2006a) and Footnote 5.

[3] If funds are seen as perfect substitutes within a reserve period, risk neutral banks should arbitrage away any expected interest rate movements within a reserve period. As a consequence, the interest rate should behave like a martingale, i.e. past observations should have no predictive content. However, the empirical evidence on the martingale hypothesis is mixed, see e.g. Hamilton (1996).

Figure 1: The ECB's interest rate corridor and the Eonia spread



Right scale: Eonia (solid line) and ECB key rates (dashed line: minimum bid rate, dotted lines: deposit and marginal lending facilities). Left scale: Difference between Eonia and the minimum bid rate (*Eonia spread*). The shaded area refers to the period after the reform in the ECB's operational framework in March 2004.

The interest rate corridor Figure 1 depicts the time series of the Eonia (i), the ECB's policy rate (i^*), the marginal lending and deposit rate and the Eonia spread defined as $i - i^*$. Apparently, the ECB has been very successful in steering the Eonia. The Eonia never left the interest rate corridor and apart from a few outliers, typically occurring at the end of the reserve maintenance period, the Eonia follows the policy rate of the ECB closely. While unit-root tests show that the Eonia should be treated as a non-stationary $I(1)$ variable, the Eonia spread is clearly stationary, see Table 2 in Section 3. Therefore, the link between the Eonia and the ECB's policy rate is very much in line with the notion of a long-run level relationship. In this sense, the Eonia and the policy rate are cointegrated and any equation explaining the dynamics of the Eonia should entail the lagged Eonia spread as an error-correction term, see Benito et al. (2006) and Nautz and Offermanns (2007).

2.2 The puzzling increase of the Eonia spread

A slightly positive Eonia spread $(i - i^*)$ is often called 'natural' because the collateral cost for refinancing via the interbank money market and the ECB's refinancing operations differ, see e.g. Würtz (2003). Furthermore, it seems plausible that a policy rate implemented as a minimum bid rate tends to be somewhat lower than related market interest rates.[4] Table 1 presents some descriptive statistics on the Eonia spread for the periods before and after the introduction of the new framework in March 2004. Because of the numerous end-of-period outliers, the median and the interquartile range give a more reliable picture on the Eonia's central tendency and variation. At first sight the Eonia spread seems slightly less volatile during the new framework. More interestingly, however, the median of the Eonia spread has increased over time from five to eight basis points.

Table 1: Descriptive statistics on interest rate spreads

	Old framework Jun. 2000 – Mar. 2004				New framework Mar. 2004 – Aug. 2006			
	Mean	Median	Std. dev.	IQR	Mean	Median	Std. dev.	IQR
$i - i^*$	0.079	0.050	0.170	0.060	0.068	0.080	0.069	0.050
$f - i^*$	0.021	0.030	0.174	0.153	0.133	0.090	0.114	0.090

Notes: First and second moments of the Eonia spread $(i-i^*)$ and the one-month/one-month forward spread $(f-i^*)$ during the variable rate tender period. IQR denotes the interquartile range.

This remarkable increase in the Eonia spread was not intended by the central bank and it seems that it is neither clear why it happened nor whether this upward trend will continue. Since October 2005, the ECB has "communicated to market participants its uneasiness about the upward trend in the spread between the Eonia and the minimum bid rate", see European Central Bank (2006a, p. 33). In fact, the ECB has repeatedly allotted up to two billion Euros excess liquidity (i.e. above the benchmark allotment) in all MROs of a maintenance period, but even these strong measures could not bring the Eonia spread back to its former level.[5] Given former estimates of the liquidity effect in the

[4] In fact, the average spread between the U.S. Federal Funds rate and the more symmetric Federal Funds rate target has been much lower in recent years, compare Thornton (2006).

[5] This explains the higher frequency of fine-tuning operations under the new framework. Since November 2005 the ECB has used fine-tuning operations on a regular basis to absorb the resulting liquidity surplus on the last day of the maintenance period.

Euro area, the non-response of the Eonia to the excess liquidity provided by the ECB is surprising. Moschitz (2004) and Würtz and Krylova (2004), for example, estimated that a permanent increase of reserves by one billion Euro will decrease the Eonia by eight and seven basis points, respectively. Explaining the puzzling rise in the Eonia spread is not the aim of the current study. It demonstrates, however, the importance of more research on the determinants, the dynamics and the volatility of overnight rates.

2.3 The ECB's new operational framework

When interest rates began to fall in autumn 2000, the ECB experienced that using the minimum bid rate in its main refinancing operations as key policy rate is not without problems. In particular, when banks expected an interest rate cut, they *underbid*, i.e. banks bid less than their actual liquidity needs in the hope that they would subsequently be able to refinance at a lower interest rate cost once key ECB interest rates had been reduced.[6] On several occasions, underbidding prevented the ECB from injecting the necessary amount of reserves into the money market. As a result, the Eonia increased sharply although everyone expected interest rates to decrease, see Figure A.1 in the Appendix. Therefore, banks' underbidding did not only impede the ECB's liquidity management and increased banks' refinancing cost, it also increased the volatility of the Eonia to undesired levels that obscured monetary policy signals. In contrast to the seasonal Eonia volatility stirred by calendar effects, these underbidding episodes are a typical example for non-seasonal volatility that may well be transmitted to longer term interest rates.

With the introduction of the new operational framework in March 2004, the ECB solved the underbidding problem by mitigating the role of rate expectations on banks' bidding behavior. Under the old framework, underbidding could occur at each of the weekly MROs, i.e. within as well as at the end of the maintenance period. If a rate cut was expected *within* the reserve period, reserve averaging allowed banks to postpone refinancing to the end of the reserve period where interest rates are expected to be lower. Under the new framework, the ECB linked the starting dates of the reserve maintenance periods to the Governing council meetings for which decisions on policy rates are scheduled

[6] Put differently, banks underbid because the minimum bid rate in the current auction prevented them from bidding at lower interest rates. Looking at the Bundesbank's experience with auctions without minimum bid rate, Linzert et al. (2003) suggest that omitting the minimum bid rate in the ECB's MROs would have been an alternative solution to the underbidding problem.

such that policy rate changes always take effect as of the start of the new reserve period. As a consequence, underbidding within the reserve period has stopped making sense, simply because the ECB promised that there will be no policy rate changes within the reserve period anymore. However, under the old framework underbidding even occurred at the end of the reserve period. Since weekly MROs had a maturity of two weeks, the last MRO of a reserve period overlapped in the subsequent period where the ECB's policy rate could change. Therefore, even with the new timing of reserve periods and interest rate changes, banks would have underbid in the last MRO of a reserve period. To avoid this overlap of rate change expectations, the second major change to the operational framework was to shorten the maturity of the MROs from two weeks to one week.

From March 2004 to August 2006, key ECB interest rates have been steadily increased from 2% to 3%. Thus, although there is no obvious reason why the new framework should not have removed the disturbing impact of rate cut expectations, there has been no real stress test so far. In fact, even under the new framework the role of rate expectations on the Eonia rate remains unclear. For example, in contrast to the ECB's intentions, rate hike expectations apparently lead to an increase in the Eonia in November 2005, see European Central Bank (2006b). Moreover, rate hike expectations might also have contributed to the increase of the Eonia spread described above. In view of the interesting role of rate expectations on the Eonia, our empirical equation specified to estimate the dynamics and the volatility of the Eonia before and after the new framework accounts for prevailing rate expectations. Specifically, we follow e.g. Würtz (2003) and include a forward spread in our regressions to check whether the impact of rate expectations on the Eonia has actually declined.

Since underbidding was costly for Euro area banks, they generally approved the new framework. Yet some concerns were related to additional operational risks associated with the move away from the overlapping main refinancing operations. In fact, if a bank does not achieve the necessary amount of refinancing in the last MRO of a reserve period, a far greater proportion of the total refinancing volume is affected than under the old framework with overlapping operations. Banks might therefore be inclined to make price-boosting safety bids in order to avoid an underallotment of reserves, compare Deutsche Bundesbank (2003). In the worst case, this bidding behavior could make refinancing more expensive.

The ECB's overall assessment of the new framework is positive. According to European Central Bank (2006a), these changes significantly improved the efficiency of its operational framework and even reduced the volatility of the Eonia. In the following, we will test whether the new framework has affected Eonia volatility and its transmission along the yield curve.

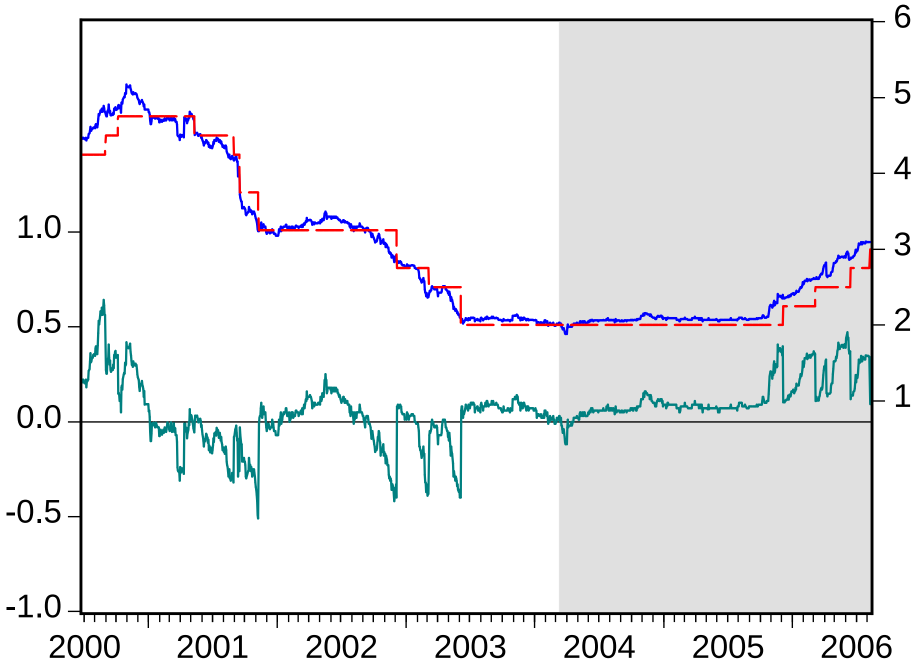
3 An empirical model for the Eonia

3.1 Data and model specification

Our empirical analysis of Eonia dynamics and its volatility uses daily data for the representative Euro overnight rate Eonia (i) and the ECB's key policy rate (i^*) defined as the MRO minimum bid rate. There is evidence that both, the level (Nautz, 1997) and the volatility (Nautz, 1998) of the overnight rate can be affected by the auction rule applied in the central bank refinancing operations. We thus concentrate on the recent variable rate tender period running from June 27, 2000 to August 9, 2006. This sample gives us 966 and 631 observations before and after the introduction of the new operational framework, respectively. Furthermore, we used Eonia swap rates published by Reuters to construct the one-month rate in one-month forward rate (f) for measuring the prevailing interest rate expectations. Specifically, high or low values of the *forward spread* ($f - i^*$) should indicate whether the market expect interest rates to increase or decrease, see e.g. Würtz (2003).

Apart from a few exceptions (compare Figure A.1), the development of the forward rate indicates that the ECB's interest rate decisions have been well anticipated by the market, see Figure 2 and Gaspar et al. (2001). Similar to the results already discussed for the Eonia spread, unit root tests indicate that the forward spread is also a stationary variable, compare Table 2. This implies that the forward spread can be interpreted as a second long-run level relation affecting the Eonia dynamics. Therefore, a natural starting point of the empirical analysis of the Eonia is an error-correction equation that incorporates both, the lagged Eonia spread, $i - i^*$, as well as the lagged forward spread, $f - i^*$, as error-correction terms.

Figure 2: Forward spread



Right scale: One-month/one-month forward rate (solid line) and ECB policy rate (dashed line). Left scale: Difference between both interest rates (*forward spread*). The shaded area refers to the period after the reform in the ECB's operational framework in March 2004.

In order to account for the time-varying pattern of Eonia volatility, the conditional mean and volatility of the Eonia rate are estimated in an EGARCH framework:[7]

$$\begin{aligned}\Delta i_t &= \mu + \sum_m \alpha_m D_t^m (i - i^*)_{t-1} \\ &+ \sum_m \beta_m^{old} D_t^m (1 - D_t^{new})(f - i^*)_{t-1} + \sum_m \beta_m^{new} D_t^m D_t^{new} (f - i^*)_{t-1} \\ &+ \sum_{k=1}^{p} \phi_{1,k} \Delta i_{t-k} + \sum_{k=1}^{q} \phi_{2,k} \Delta f_{t-k} + \theta' X_t + \sigma_t \varepsilon_t \qquad (1)\end{aligned}$$

and

$$\log(\sigma_t^2) = \omega_0 + \omega_1 \log(\sigma_{t-1}^2) + \omega_2 \left| \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \right| + \omega_3 \frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \rho' Z_t + \nu_t \qquad (2)$$

where ε_t is a normally distributed *i.i.d.* error with zero mean and unit variance and σ_t^2 denotes the conditional Eonia variance.

[7] The key feature of the EGARCH model is that it allows for different impacts of positive and negative innovations on conditional variances. While this asymmetry plays a significant role for measuring Eonia volatility, the variance equations of longer-term rates are well-specified using symmetric ARCH models. Durré and Nardelli (2007) suggest realised volatility based on intraday data as an alternative measure of Eonia volatility.

Table 2: Stationarity of interest rate spreads

	Old framework Jun. 2000 – Mar. 2004	New framework Mar. 2004 – Aug. 2006
$i - i^*$	-13.09^{**}	-16.56^{**}
$f - i^*$	-3.86^{**}	-3.059^{**}

Notes: ADF unit-root tests of the Eonia spread ($i - i^*$) and the one-month/one-month forward spread ($f - i^*$) over the variable rate tender period. * (**) denotes significance at the 5% (1%) level.

Equations (1) and (2) include three groups of dummy variables to capture several features of the ECB's operational framework that may affect Eonia dynamics and its volatility. First, the strength of adjustment of the Eonia to the ECB key policy rate (α) may change over the reserve period. In particular, the response of the Eonia to the policy rate should be weaker at the end of the reserve period, i.e. during the days after the last MRO, when reserve averaging gets less effective. Recall that deviations from the policy rate are typically strongest at the last day of the reserve period. Accordingly, the adjustment should be particulary strong at the very first day of the reserve period when the Eonia comes back to the former interest rate level. Similar effects may occur with respect to the influence of rate expectations (β), compare Figure 2. In order to account for the different regimes of Eonia adjustment to both, the Eonia spread as well as the forward spread, we included the dummy variables D_t^m with $m = begin, within, end$, where $D_t^{begin} = 1$ if t is the first day in the reserve period and $D_t^{begin} = 0$ otherwise, $D_t^{end} = 1$ after the last allotment day until the end of the reserve period and $D_t^{end} = 0$ otherwise, and $D_t^{within} = 1 - D_t^{begin} - D_t^{end}$.

The second set of dummy variables solely consists of D^{new} and refers to the introduction of the ECB's new framework in March 2004. Specifically, we defined $D_t^{new} = 0$ and $D_t^{new} = 1$ for t before and after March 2004, respectively. Since the new framework was introduced in order to mitigate the influence of rate expectations on the current Eonia, Equation (1) allows for a different role of forward rates before and after the new framework.[8]

The third set of dummies controls for several calendar effects as well as special events like the cash change-over in January 2002, the terrorist attacks at September 11, 2001 or

[8]We also checked whether the adjustment to the Eonia spread has changed but found no significant impact of the new framework.

the underbidding episodes discussed in Section 2.3. A detailed description of all dummy variables comprised in the vector X (for the mean equation) and Z (for the variance equation) is provided with the tables. Finally, note that we included D^{new} into the conditional variance equation to investigate whether the new framework has affected the conditional variance of the Eonia.

3.2 Eonia dynamics and volatility: empirical results

Table 3 summarizes the empirical results for the conditional mean and the volatility of the Eonia. In line with the notion of an equilibrium relation between the Eonia and the ECB policy rate, we find a significant within-period adjustment ($\hat{\alpha}_{within} = -0.198$) of the Eonia to deviations from the Eonia spread. Moreover, as expected, the response is particularly strong at the first day while it becomes insignificant at the end of the reserve period.

A similar pattern is found for the adjustment of the Eonia to the forward spread. Independent of the introduction of the new framework (indicated by the dummies D^{new} and $1 - D^{new}$, respectively), there is evidence for a significant impact of rate expectations on the Eonia within and, particularly, at the beginning of the reserve period. In contrast, forward rates cannot explain the fluctuations of the Eonia at end-of-period days. Interestingly, the significance of the forward spread within period even slightly increased, not decreased, with the introduction of the new framework. Introducing D^{new} in the mean equation, we allowed for a possible mean shift in the Eonia spread or any other explanatory variable due to the new framework. However, the estimate obtained for the corresponding coefficient ($\theta^{new} = 0.002$) proved to be insignificant.

Let us now turn to the results obtained for the Eonia variance equation. All calendar effects and special events dummies show the expected sign. In particular, there has been a remarkable increase in Eonia volatility at the various underbidding days ($\rho^{ubidday} = 5.484$). Moreover, the introduction of the new framework has indeed decreased the conditional variance of the Eonia both, within and at the end of the reserve period. The significant coefficients ($\rho^{new}_{within} = -0.996$, $\rho^{new}_{end} = -0.498$) reveal that the relative decline in Eonia volatility has been even more pronounced within period. Therefore, the reduction of Eonia volatility since March 2004 is not only due to the ECB's fine-tuning operations which have been increasingly applied to stabilize interest rate end-of-period since November 2004.

Table 3: Eonia dynamics and volatility

Dependent variable: Δi_t		Dependent variable: $\log(\sigma_t^2)$	
Eonia spread		EGARCH	
α_{begin}	-1.010^{**} (93.1)	ω_1	0.585^{**} (12.10)
α_{within}	-0.198^{**} (6.06)	ω_2	0.805^{**} (11.98)
α_{end}	-0.077 (1.07)	ω_3	0.277^{**} (4.77)
Forward spread: old framework		New framework	
β^{old}_{begin}	0.211^{**} (5.73)	ρ^{new}_{within}	-0.996^{**} (6.83)
β^{old}_{within}	0.017^{*} (2.04)	ρ^{new}_{end}	-0.498^{**} (2.60)
β^{old}_{end}	-0.033 (0.68)	Seasonal effects	
Forward spread: new framework		ρ^{begin}	-2.326^{**} (5.77)
β^{new}_{begin}	0.159^{**} (9.56)	ρ^{end}	1.562^{**} (8.82)
β^{new}_{within}	0.028^{**} (4.43)	ρ^{last}	1.151^{**} (4.62)
β^{new}_{end}	0.000 (0.00)	Other effects	
Calendar and other effects		$\rho^{Jan\,2002}$	1.003^{*} (2.37)
θ^{eos}	0.097^{**} (4.44)	$\rho^{Sep11,\,2001}$	1.463^{*} (2.42)
$\theta^{eoy\,2001}$	0.185^{*} (2.32)	$\rho^{ubidday}$	5.484^{**} (7.98)
θ^{new}	0.002 (1.14)	ω_0	-3.264^{**} (9.58)
μ	-0.002 (1.37)		

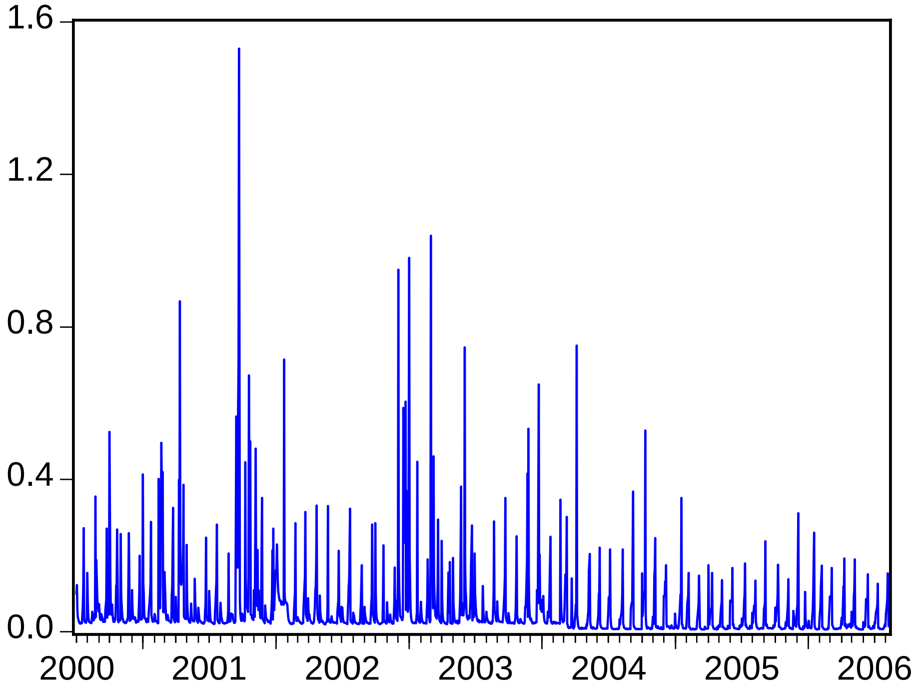
Notes: Estimated parameters from Equations (1)–(2),

$$
\begin{aligned}
\Delta i_t &= \mu + \sum_m \alpha_m D_t^j (i - i^*)_{t-1} + \sum_m \beta_m^{old} D_t^j (1 - D_t^{new})(f - i^*)_{t-1} + \sum_m \beta_m^{new} D_t^j D_t^{new} (f - i^*)_{t-1} \\
&+ \sum_{k=1}^{5} \phi_{1,k} \Delta i_{t-k} + \sum_{k=1}^{5} \phi_{2,k} \Delta f_{t-k} + \theta^{eos} D_t^{eos} + \theta^{eoy\,2001} D_t^{eoy\,2001} + \theta^{new} D_t^{new} + \sigma_t \varepsilon_t \\
\log(\sigma_t^2) &= \omega_0 + \omega_1 \log(\sigma_{t-1}^2) + \omega_2 \left| \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \right| + \omega_3 \frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \rho^{new}_{within} (1 - D_t^{end}) D_t^{new} + \rho^{new}_{end} D_t^{end} D_t^{new} \\
&+ \rho^{begin} D_t^{begin} + \rho^{end} D_t^{end} + \rho^{last} D_t^{last} + \rho^{Jan\,2002} D_t^{Jan\,2002} + \rho^{Sep11,\,2001} D_t^{Sep11,\,2001} \\
&+ \rho^{ubidday} D_t^{ubidday} + \nu_t
\end{aligned}
$$

where D_t^{eos} refers to the last day of the semester, and $D_t^{eoy\,2001}$ and $D_t^{Jan\,2002}$ capture the turbulences due to the cash changeover in the Euro area at the end of the year 2001 and during January 2002, respectively. $D_t^{Sep11,\,2001}$ equals 1 at the day after September 11, 2001, and $D_t^{ubidday}$ equals 1 at the allotment day of an underbidding episode. Absolute t-values in parentheses are computed using heteroskedasticity-consistent standard errors, * (**) denotes significance at the 5% (1%) level.

Figure 3 depicts the time series of the estimated conditional standard deviation of the Eonia. The regular peaks are end-of-period effects, the largest peak, however, is on September 11, 2001. The time series plot also shows the reduction in Eonia volatility since March 2004. In the following, the corresponding conditional Eonia variance shall be employed to examine how Eonia volatility is transmitted along the yield curve.

Figure 3: Eonia volatility



Notes: The figure shows the estimated conditional standard deviation of daily Eonia rates resulting from Equations (1) and (2).

4 Volatility transmission

The previous section showed that institutional details of the ECB's operational framework explain a considerable part of the dynamics and the volatility of the Eonia. This section investigates how the volatility of the Eonia affects interest rates with longer maturities, i.e. how Eonia volatility is transmitted along the yield curve. To that aim, we follow e.g. Ayuso et al. (1997) and Moschitz (2004) and include the previously estimated conditional Eonia volatility as explanatory variable in an equation explaining the conditional volatility of longer-term interest rates.

In the following, we consider the transmission of Eonia volatility for daily Euribor interest rates (r^j) with a maturity of one week, as well as one, three, six, nine, and twelve months ($j = 1w, 1m, 3m, 6m, 9m, 12m$). Standard unit-root tests show that these interest rates are integrated of order one, while their deviations from the ECB's policy rate ($r^j - i^*$) can be seen as stationary. Accordingly, all interest rates are mutually cointegrated and the mean equations of the longer term interest rates r^j are specified as error-correction equations:

$$\begin{aligned} \Delta r_t^j &= \mu_j + \alpha_j (r^j - i^*)_{t-1} + \beta_j (r^j - r^{j'})_{t-1} \\ &+ \sum_{k=1}^{p} \varphi_{j,k} \Delta r_{t-k}^j + \sum_{k=1}^{p} \varphi_{j',k} \Delta r_{t-k}^{j'} + \vartheta_j' X_t + u_{j,t} \end{aligned} \quad (3)$$

where $u_{j,t} \sim N(0, \sigma_{j,t}^2)$ and X_t refers to a vector of calendar dummies. For all Euribor rates r^j, the mean equations include the deviation from the minimum bid rate ($r^j - i^*$) and the spread between r^j and the rate with subsequent maturity ($r^{j'}$) as error-correction term. Additional interest rate spreads proved to be insignificant. In accordance with the expectations theory of the term structure, the spread between r^j and the longer term rate $r^{j'}$ proxies prevailing rate expectations.[9]

The main results for the mean equations are summarized in Table A.1 in the Appendix. As expected, the immediate impact of the policy rate on r^j ($\hat{\alpha}_j$) decreases with the maturity of the money market rate. Furthermore, according with the expectations theory of interest rates, the adjustment to the longer term spread ($\hat{\beta}_j$) is significantly positive for all j.

For all maturities, the autocorrelogram of the squared residuals of (3) strongly suggests to model the conditional variance as an ARCH(6) process:

$$\begin{aligned} \sigma_{j,t}^2 &= \psi_{j,0} + \sum_{k=1}^{6} \psi_{j,k} u_{j,t-k}^2 + \gamma_j^{ubid} D_t^{ubid} + \gamma_j^{new} D^{new} \\ &+ \delta_j^{seas} D_t^{seas} \hat{\sigma}_t^2 + \delta_j^{nonseas} (1 - D_t^{seas}) \hat{\sigma}_t^2 + \delta_j^{new} D^{new} \hat{\sigma}_t^2 + \eta_{j,t} \end{aligned} \quad (4)$$

Moreover, the ARCH(6) model is also suggested by standard model selection criteria. For sake of robustness, the variance equations of longer term rates were estimated by the consistent two-step approach which yielded by far the most reliable results.

[9]Note that these longer-term rate expectations were not included in the volatility equations employed by Ayuso et al. (1997) and Moschitz (2004).

Table 4: Eonia volatility transmission along the yield curve

	Dependent variable: conditional variance of r_t^j					
	1 Week	1 Months	3 Months	6 Months	9 Months	12 Months
Seasonal volatility						
δ_j^{seas}	4.091 (1.95)	−0.123 (0.27)	−0.094 (0.30)	−0.277 (0.71)	−0.702 (1.30)	−0.998 (1.43)
Non-seasonal volatility						
$\delta_j^{nonseas}$	7.206* (2.27)	5.087** (7.34)	5.297** (10.93)	6.561** (11.13)	7.285** (8.93)	8.051* (7.61)
New framework						
δ_j^{new}	−4.012 (0.45)	0.066 (0.03)	0.454 (0.33)	1.677 (1.01)	2.316 (1.00)	2.599 (0.87)
γ_j^{new}	−0.611 (1.95)	−0.168* (2.43)	−0.061 (1.26)	−0.123* (2.06)	−0.259** (3.06)	−0.398** (3.61)
Underbidding						
γ_j^{ubid}	9.866** (10.36)	2.011** (9.68)	0.859** (6.06)	0.628** (3.69)	0.504* (2.15)	0.429 (1.42)
ARCH						
$\psi_{j,0}$	−0.736** (3.53)	0.192** (4.16)	0.0892** (2.75)	0.182** (4.26)	0.395** (6.05)	0.644** (7.26)
$\sum_{k=1}^{6} \psi_{j,k}$	0.188	0.105	0.330	0.435	0.425	0.368

Notes: Estimated parameters for Equation (4)

$$\begin{aligned}\sigma_{j,t}^2 &= \psi_{j,0} + \sum_{k=1}^{6} \psi_{j,k} \hat{u}_{j,t-k}^2 + \gamma_j^{ubid} D_t^{ubid} + \gamma_j^{new} D_t^{new} \\ &+ \delta_j^{seas} D_t^{seas} \hat{\sigma}_t^2 + \delta_j^{nonseas} (1 - D_t^{seas}) \hat{\sigma}_t^2 + \delta_j^{new} D_t^{new} \hat{\sigma}_t^2 + \eta_{j,t}\end{aligned}$$

All coefficients, except the AR parameters, have been scaled up by 10^3. Absolute t-values in parentheses, * (**) denotes significance at the 5% (1%) level.

The estimation results for the various variance equations (4) are summarized in Table 4. We accounted for the introduction of the new operational framework in two ways. First, we multiplied Eonia volatility with the dummy variable D^{new} to test whether the transmission of Eonia volatility has been influenced by the new framework. However, we did not find this type of influence of the new framework, i.e. for all maturities the corresponding coefficients δ_j^{new} were clearly insignificant. Second, we included D^{new} as a separate variable to check whether the volatility of an interest rate has changed since March 2004. In fact, since the introduction of the new framework the average conditional variance has declined for nearly all maturities under consideration, i.e. $\gamma^{new} < 0$.

Seasonal Eonia volatility should not have a major impact on the communication of monetary policy and, thus, on the volatility of longer term interest rates. To account for the specific role of seasonal volatility, we defined the dummy variable

$$D_t^{seas} = \min(1, D_t^{end} + D_t^{eom} + D_t^{first}),$$

comprising all seasonal calendar effects relevant for Eonia volatility, and multiplied D^{seas} with Eonia volatility $\hat{\sigma}_t^2$. Accordingly, $\delta_j^{nonseas}$, i.e. the coefficients of $(1 - D_t^{seas})\hat{\sigma}_t^2$ measure the response of the longer term rate r^j to non-seasonal Eonia volatility. We expect that only non-seasonal Eonia volatility can reflect uncertainty about the monetary policy stance.

Table 4 confirms that the transmission of seasonal Eonia volatility (δ^{seas}) is small and insignificant at all maturities. In contrast, the response to non-seasonal Eonia volatility ($\delta^{nonseas}$) is significantly positive for all longer-term money market rates, even for the twelve-month rate. Eonia volatility is particularly relevant if it is stirred by uncertainty about monetary policy signals. Consider, for example, the underbidding episodes captured by the dummy variable D^{ubid} when Eonia volatility sharply increased due to unclear monetary policy signals, see Figure A.1. For all interest rates, the corresponding coefficients γ^{ubid} are positive and highly significant, indicating that the volatility of longer term rates is particularly high when monetary policy communication is not effective. Therefore, the ECB's new operational framework has lowered the volatility of money market rates both, directly (solving the underbidding problem) and indirectly because it lowered the average Eonia volatility which is transmitted along the yield curve.

5 Conclusions

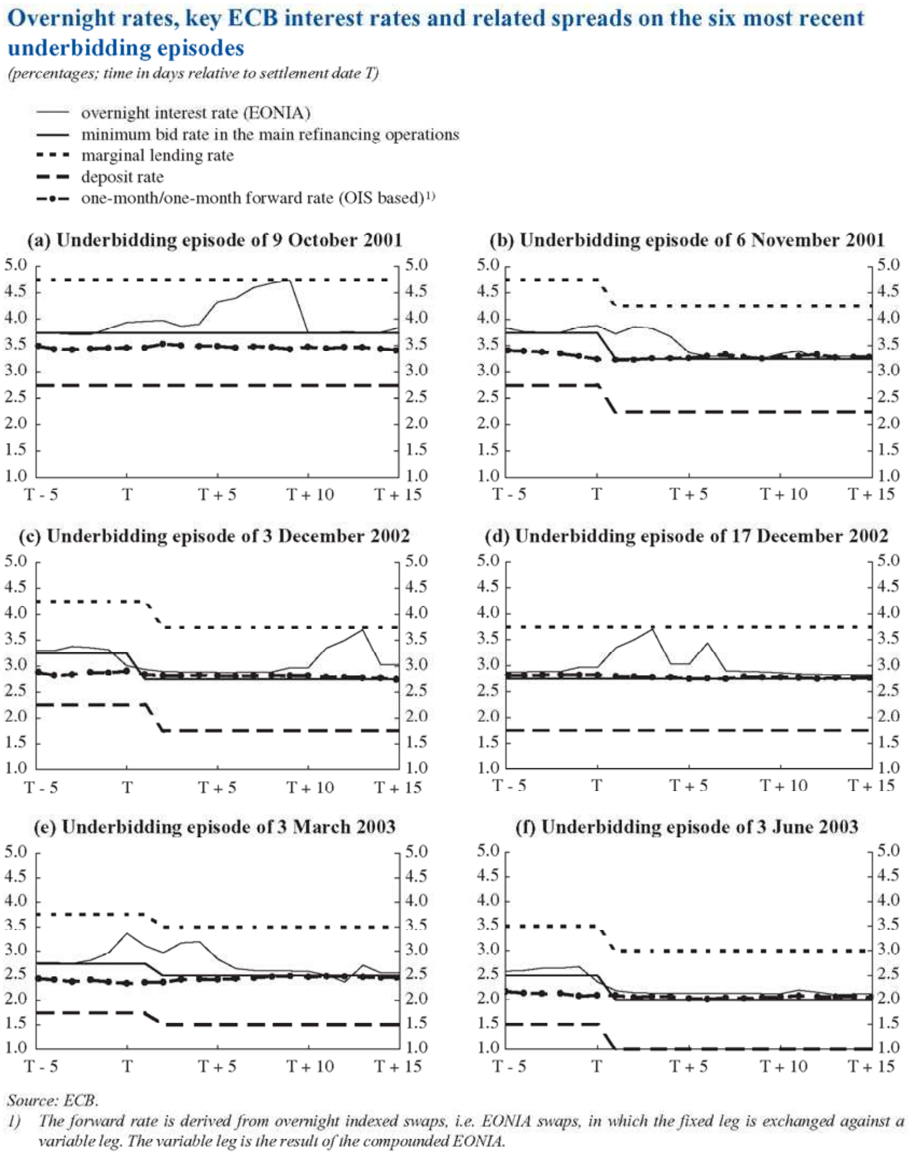
This paper presented new evidence on the dynamics of the European money market rates, the determinants of their volatility and, in particular, the transmission of overnight rate (Eonia) volatility along the yield curve. One focus of our analysis has been on the effects of the ECB's new operational framework introduced in March 2004. Shortening the maturity of its main refinancing operations and synchronizing the timing of its interest rate decisions with the reserve maintenance periods, the ECB stopped banks underbidding by mitigating the disturbing impact of rate change expectations on the Eonia.

Our results suggest that the new framework reduced the volatility of all money market rates under consideration: directly, because volatility was particulary high during the former episodes of underbidding, and indirectly, because the new framework also decreased Eonia volatility which we found to be partly transmitted to longer term rates. Yet, the role of rate expectations for the Eonia remains puzzling. In particular, even under the new framework, the Eonia adjusts significantly to a forward spread reflecting the prevailing rate expectations. Thus, rate hike expectations may have contributed to the recent increase of the spread between the Eonia and the ECB's policy rate.

According to Ayuso et al. (1997), volatility transmission may depend on the level of overnight rate volatility. In this paper, we argue that it may be even more critical to take into account that volatility transmission may depend on the source and nature of Eonia fluctuations. Although Eonia volatility is particularly high at the end of the reserve maintenance period or at the end of month, this seasonal volatility should not impede the communication of monetary policy and the signalling role of the Eonia. In fact, we found that seasonal Eonia volatility is not transmitted to longer term interest rates. However, non-seasonal volatility, defined as conditional Eonia variance estimated at days unrelated to seasonal effects, is significantly transmitted along the yield curve. Our results show that even the conditional variance of the twelve-month rate is affected by an increase of non-seasonal Eonia volatility. This indicates that transmission of Eonia volatility along the yield curve is a relevant issue if Eonia fluctuations are stirred by uncertainty about monetary policy signals.

A Appendix

Figure A.1: Non-seasonal Eonia volatility



Notes: The figure is taken from the ECB's monthly bulletin, August 2003.

Table A.1: Euribor mean dynamics

	Dependent variable: Δr_t^j					
	1 Week	1 Month	3 Months	6 Months	9 Months	12 Months
Adjustment to Eonia spread						
α_j	-0.085^{**}	-0.003	0.004	0.002	0.001	0.005^{*}
	(3.14)	(0.25)	(0.72)	(0.39)	(0.26)	(1.98)
Adjustment to longer-term rate						
β_j	0.179^{**}	0.047^{**}	0.023^{**}	0.029^{*}	0.034	
	(4.33)	(5.08)	(3.25)	(2.10)	(1.61)	

Notes: Estimated parameters from Equation (3),

$$\begin{aligned}\Delta r_t^j &= \mu_j + \alpha_j (r^j - i^*)_{t-1} + \beta_j (r^j - r^{j'})_{t-1} + \sum_{k=1}^{5} \varphi_{j,k} \Delta r_{t-k}^j + \sum_{k=1}^{5} \varphi_{j',k} \Delta r_{t-k}^{j'} \\ &+ \vartheta^{May11,\,2001} D_t^{May11,\,2001} + \vartheta^{Sep18,\,2001} D_t^{Sep18,\,2001} + u_{j,t}\end{aligned}$$

where $r_t^{j'}$ refers to the interest rate with maturity subsequent to maturity j, and $D_t^{May11,\,2001}$ and $D_t^{Sep18,\,2001}$ capture strong interest rate cuts at May 11, 2001, and at September 18, 2001. Absolute t-values in parentheses are computed using heteroskedasticity-consistent standard errors, * (**) denotes significance at the 5% (1%) level. For brevity, detailed results are not presented but can be obtained from the authors.

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