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The dynamic relationship between the Euro overnight rate, the ECB´s policy rate and the term spread

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Discussion Paper
Series 1: Economic Studies
No 01/2006

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ISBN 3–86558–108–0 (Printversion)
ISBN 3–86558–109–9 (Internetversion)

Abstract

This paper investigates how the dynamic adjustment of the European overnight rate Eonia to the term spread and the ECB's policy rate has been affected by rate expectations and the operational framework of the ECB. In line with recent evidence found for the US and Japan, the reaction of the Eonia to the term spread is non-symmetric. Moreover, the response of the Eonia to the policy rate depends on both, the repo auction format and the position of the Eonia in the ECB's interest rate corridor.

Keywords: Monetary Policy Implementation, Term Structure of Interest Rates, Nonlinear Cointegration

JEL classification: E43, E52

Nontechnical Summary

For many central banks, including the European Central Bank (ECB) and the US Federal Reserve, the interbank money market for overnight lending is the key channel through which monetary policy is executed. Overnight rates are the operational target of monetary policy that anchors the term structure of interest rates. Understanding the determinants and the dynamics of the overnight rate is therefore of crucial importance for implementing monetary policy in an efficient way. This paper investigates how the dynamic adjustment of the European overnight rate Eonia to the term structure and the ECB's policy rate is affected by rate expectations and the operational framework of the ECB.

Our empirical setup for the analysis of the overnight rate dynamics emphasizes the role of two separate relations driving the long-run behavior of the Eonia. One major determinant of the level of the overnight rate is the central bank's policy rate defined as the repo rate set in the ECB's main refinancing operations. A second long-run relation is suggested by the expectations hypothesis of the term structure which implies that the Eonia adjusts to the difference from a longer-term interest rate. Our empirical model incorporates both effects, taking account of persistent deviations of the Eonia from the policy rate at the end of the monthly reserve maintenance period. These deviations are found to represent a counterintuitive reaction of the Eonia to rate change expectations, which can be explained by the disturbing influence of banks' under- and overbidding on the interbank market in the period before the ECB reformed its operational framework in March 2004.

Similar to the US Federal funds rate target, the ECB's fixed repo rate seems to be a symmetric policy rate. In contrast, one might expect that a minimum bid rate, as applied by the ECB since June 2000, is particularly effective in defining a lower bound for interest rates. Furthermore, the under- and overbidding episodes in the ECB's main refinancing operations suggest that also the direction of expected rate changes affected Eonia dynamics. We therefore extend our base model and allow for non-symmetric adjustment to both long-run relations, taking account of potential influences from monetary policy implementation by the ECB. In particular, we investigate how the dynamic adjustment of the Eonia to its long-run determinants depends on the June 2000 change in the auction format of the ECB's main refinancing operations.

Our results indicate that the dynamics of the Eonia within the monthly reserve maintenance period depend on the auction format. Interestingly, the introduction of variable rate tenders with a minimum bid rate in June 2000 did not lead to a loss of control of the ECB over the Eonia. An asymmetric response to rate expectations is confirmed for the Euro Area, although this may partly mirror the over- and underbidding problems of the auction format episodes.

Nicht-technische Zusammenfassung

Für viele Zentralbanken wie z.B. die Europäische Zentralbank (EZB) und die US-amerikanische Notenbank, ist der Interbankenmarkt für Tagesgeld der Haupttransmissionkanal ihrer geldpolitischen Maßnahmen. Der Zinssatz für Tagesgeld ist das operationelle Ziel der Geldpolitik, das die Zinsstrukturkurve verankert. Das Verständnis von Bestimmungsfaktoren und Dynamik des Tagesgeldsatzes ist daher von entscheidender Bedeutung für die effiziente Implementierung der Geldpolitik. Dieses Papier untersucht, wie die dynamische Anpassung des europäischen Zinssatzes für Tagesgeld, Eonia, an die Zinsstrukturkurve sowie an den Politikzins der EZB durch Zinsänderungserwartungen und den operationellen Rahmen der EZB beeinflußt wird.

In unserem empirischen Ansatz zur Analyse der Dynamik des Eonia-Tagesgeldsatzes wird die Bedeutung von zwei separaten Beziehungen, die das Langfristverhalten des Eonia bestimmen, betont. Zum einen ist der Politikzins der Zentralbank eine wichtige Determinante des Niveaus des Tagesgeldsatzes. Dieser Politikzins ist definiert als der Reposatz aus den Hauptrefinanzierungsgeschäften der EZB. Zum anderen impliziert die Erwartungshypothese der Zinsstrukturkurve die Anpassung des Tagesgeldsatzes an einen längerfristigen Zinssatz. Unser empirisches Modell beinhaltet beide Einflüsse und berücksichtigt dabei persistente Abweichungen zwischen Eonia und Politikzins am Ende der monatlichen Reservehaltungsperiode. Diese Abweichungen beruhen auf der kontraintuitiven Reaktion des Eonia auf Zinsänderungserwartungen, die jedoch durch den verzerrenden Einfluß erklärt werden kann, den das Unter- und Überbieten von Banken bei Offenmarktgeschäften vor der Reform der EZB im März 2004 auf den Interbankenmarkt ausgeübt hatte.

Ähnlich wie das Zinsziel für die US-amerikanische *Federal funds rate* ist der Reposatz der EZB ein symmetrischer Politikzins. Im Gegensatz dazu ist zu erwarten, daß ein Mindestbietungssatz, wie er von der EZB seit Juni 2000 angewendet wird, vorrangig als untere Grenze für den Tagesgeldsatz wirkt. Darüberhinaus legt das Auftreten von Unter- und Überbietungsverhalten in den Hauptrefinanzierungsgeschäften der EZB nahe, daß auch die Richtung von Zinsänderungserwartungen die Entwicklung des Eonia bestimmt hat. Wir erweitern daher unseren Ansatz und modellieren eine nicht-symmetrische Anpassung des Eonia an beide Langfristbeziehungen. Dabei wird der potentielle Einfluß der Implementierung der Geldpolitik durch die EZB berücksichtigt. Insbesondere untersuchen wir, wie sich die Änderung im Auktionsverfahren der EZB im Juni 2000 auf die dynamische Anpassung des Eonia an seine langfristigen Bestimmungsfaktoren ausgewirkt hat.

Unsere Ergebnisse zeigen, daß die Entwicklung des Eonia-Tagesgeldsatz innerhalb der monatlichen Reservehaltungsperiode vom Auktionsformat abhängt. Allerdings hat die Einführung des Zinstenders mit Mindestbietungssatz nicht zu einer geringeren Kontrolle über den Eonia durch die EZB geführt. Eine asymmetrische Reaktion auf Zinsänderungserwartungen kann für die Eurozone unterstützt werden, obwohl diese zum Teil die Probleme des Unter- und Überbietens in den untersuchten Zeiträumen widerspiegeln dürfte.

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The Dynamic Relationship between the Euro Overnight Rate, the ECB's Policy Rate and the Term Spread[1]

1 Introduction

For many central banks, including the ECB and the US Federal Reserve, the interbank money market for overnight lending is the key channel through which monetary policy is executed. Overnight rates are the operational target of monetary policy that anchors the term structure of interest rates. Understanding the determinants and the dynamics of the overnight rate is therefore of crucial importance for implementing monetary policy in an efficient way. This paper investigates how the dynamic adjustment of the European overnight rate Eonia to the term spread and the ECB's policy rate is affected by rate expectations and the operational framework of the ECB.

Our empirical setup for the analysis of the overnight rate dynamics emphasizes the role of two separate long-run level relations. One major determinant of the level of the overnight rate is the central bank's policy rate defined as the repo rate set in the ECB's main refinancing operations (MROs). This direct influence of the ECB on the overnight rate should imply that the *policy spread* between the Eonia and the repo rate is small and, in particular, stationary. A second long-run relation is suggested by the expectations hypothesis of the term structure. According to e.g. Campbell and Shiller (1987), the Eonia should adjust to the *term spread* defined as the difference between the 3-month rate Euribor and the Eonia. Therefore, our analysis of overnight rate dynamics starts with an error-correction model for the Eonia that includes both, the policy spread and the term spread as error-correction terms.

The relation between the Eonia and the policy spread might be affected by the way the policy rate is implemented by the central bank. In June 2000, the ECB switched from fixed rate to variable rate tenders in its main refinancing operations. If the fixed repo rate entails a stronger signal about the policy-intended interest rate level than a minimum bid rate, the introduction of variable rate tenders might have led to a partial loss of control over short-term interest rates. We therefore investigate how the dynamic adjustment of the

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Eonia to the policy rate depends on the MRO auction format. In particular, we compare the period between January 1999 and June 2000 with the period between July 2000 and March 2004.[2]

Similar to the US Federal funds rate target, the ECB's fixed repo rate seems to be a symmetric policy rate. In contrast, one might expect that a minimum bid rate is particularly effective in defining a lower bound for interest rates. Therefore, the Eonia adjustment to the policy spread could be stronger if the Eonia is low relative to the minimum bid rate. According to Ayuso and Repullo (2003), non-symmetric adjustment of the Eonia would also be induced by an asymmetric loss function of the central bank. In a further step of our analysis of the Eonia dynamics we therefore extend our base model and employ non-symmetric error-correction equations.

Following Enders and Granger (1998) and Sarno and Thornton (2003) we also allow for an asymmetric adjustment of the Eonia to the term spread. The under- and overbidding episodes in the ECB's MROs suggest that both, the direction of expected rate changes (i.e., the sign of the term spread) and the MRO auction format affect Eonia dynamics. The impact of rate expectations on the Eonia as well as the persistence of deviations from the policy rate were often particularly strong at the end of the monthly reserve maintenance period. We therefore allow for different Eonia dynamics at the end of the reserve period. Our results indicate that irrespective of the applied auction format, the end-of-period response of the Eonia to the term spread shows the wrong sign. However, this counterintuitive reaction of the Eonia to rate expectations can be explained by the disturbing influence of banks' under- and overbidding on the interbank market in the period under consideration.

The paper is structured as follows. Section 2 introduces the three interest rate series under investigation and determines their integration and cointegration properties. Furthermore, the econometric specification is motivated and compared with the modeling strategies of the empirical literature. Section 3 presents the results of a symmetric error-correction equation of the Eonia and pays particular attention to the Eonia's interesting end-of-reserve-period dynamics. In Section 4, we use non-symmetric error-correction equations to investigate whether rate expectations, the position of the Eonia in the interest rate corridor, and the MRO auction format affect the dynamics of the Eonia within and at the end of the reserve period. Section 5 summarizes our main results.

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[2] As of March 10, 2004, the maturity of the MROs was reduced from two weeks to one, and the reserve period was re-scheduled to match the meetings of the Eurosystem's Governing Council (see European Central Bank, 2004) in order to mitigate the role of rate expectations on banks' bidding behavior. We restrict our analysis to the period before this reform to avoid a structural break.

2 Data and Econometric Specification

2.1 (Co-)Integration Properties of the Data

The following empirical analysis uses daily data for the representative Euro overnight rate Eonia[3] (i), the 3-month money market rate Euribor ($i3$), and a key policy rate (i^*) of the ECB. Depending on the auction format, the policy rate i^* is defined as the fixed repo rate or the minimum bid rate set by the ECB in the fixed or variable rate tenders applied in its weekly main refinancing operations. The sample period runs from January 2, 1999 to March 9, 2004.

Over the whole sample period, the overnight rate is on average about seven basis points above the ECB's policy rate, see Table 1. Note that the average size of the policy spread is merely unaffected by the MRO auction format. A slightly positive policy spread $i - i^*$ is often called "natural" because the collateral cost for refinancing via the interbank money market and the ECB's repo auctions differ, see e.g. Würtz (2003). The time series of the Eonia, the policy rate, and the policy spread ($i - i^*$), are depicted in Figure 1.

Table 1: Descriptive Statistics

	Whole sample		FRT period		VRT period	
	Jan. 1999 – Mar. 2004		Jan. 1999 – Jun. 2000		Jun. 2000 – Mar. 2004	
	Mean	Median	Mean	Median	Mean	Median
i	3.325	3.290	3.020	2.995	3.447	3.300
i^*	3.252	3.250	2.950	3.000	3.373	3.250
$i3$	3.405	3.353	3.266	3.222	3.460	3.368
$i - i^*$	0.073	0.050	0.070	0.060	0.074	0.050
$i3 - i$	0.079	0.063	0.246	0.183	0.013	0.029

Notes: First moments of the Eonia (i), the ECB policy rate (i^*), the 3-month Euribor ($i3$), the policy spread ($i - i^*$), and the term spread ($i3 - i$). Sub-sample periods comprise the fixed rate tender (FRT) and the variable rate tender (VRT) period, respectively.

Apparently, the ECB has been very successful in steering the overall interest rate level of short-term interest rates.[4] Apart from a few outliers, typically occurring at the end of the monthly reserve maintenance period, the Eonia follows the policy rate of the ECB closely. Unit-root tests provide clear evidence that the Eonia should be treated as a non-stationary

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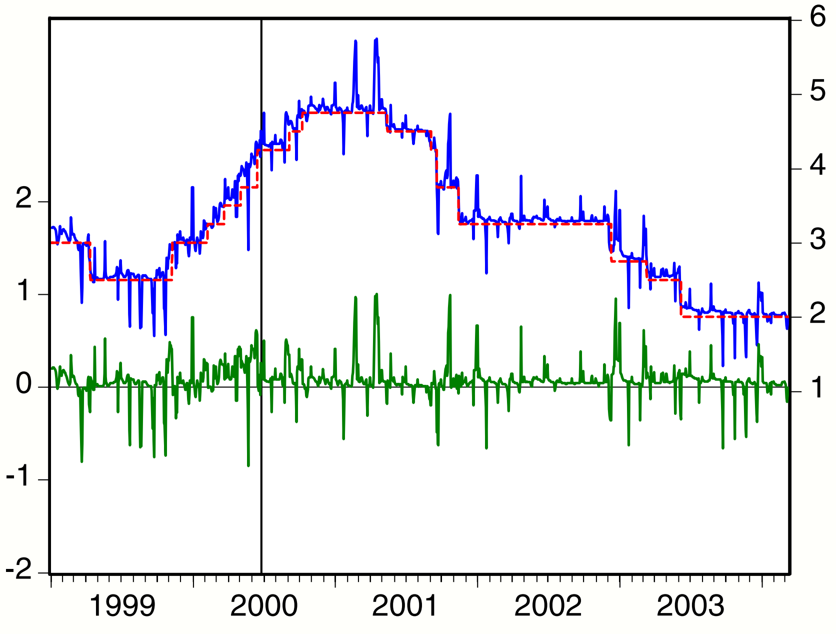
[3] The *E*uro *O*ver*N*ight *I*ndex *A*verage (Eonia) is a weighted average of daily interest rates reported by a panel of approx. 50 banks that have the highest business volume in the Euro Area money market. For more information, see the Euribor website of the European Banking Federation at www.euribor.org.

[4] The close relationship between the US Federal funds rate and the Fed's interest rate target is documented by e.g. Rudebusch (1995).

or $I(1)$ variable, see Table 2. Since the ECB varies its policy rate only infrequently and clearly not on a daily basis, a standard unit-root test would not be appropriate for this discrete-valued time series, see Hamilton and Jorda (2002). Yet Figure 1 shows that the link between the Eonia and the partly deterministic policy rate is very much in line with the notion of a long-run level relationship. In fact, as Table 2 shows, the policy spread $i - i^*$ is clearly stationary. In this sense, the Eonia and the policy rate are cointegrated and any equation explaining the dynamics of the Eonia should entail the lagged policy spread as an error-correction term.

However, the link to the ECB's policy rate is probably not the only relevant long-run relation for understanding the dynamics of the Eonia. A second long-run or cointegrating relationship relevant for the dynamics of the Eonia might be stirred by prevailing rate expectations pinned down in the level of longer-term interest rates. The close relation between the Eonia and the 3-month Euribor is shown in Figure 2.

Figure 1: Euro Overnight Rate and the ECB's Policy Rate



Right scale: Euro Overnight Index Average (solid line) and ECB policy rate (dashed line, up to June 26, 2000: repo rate, since June 27, 2000: minimum bid rate). Left scale: Difference between both interest rates (*policy spread*). The vertical line denotes the change from fixed rate tender auctions to variable rate tenders. Sample: January 2, 1999 – March 9, 2004.

Table 2: Unit-Root Tests

Variable	ADF Test	Variable	ADF Test	Variable	ADF Test
i	-0.286	Δi	-10.555^{**}	$i - i^*$	-15.713^{**}
$i3$	-0.270	$\Delta i3$	-8.996^{**}	$i3 - i$	-3.482^{**}

Notes: t-statistics of Augmented Dickey-Fuller (ADF) tests with a constant in the test equation and lag length according to the Akaike Information Criterion (AIC). The 5% (1%) critical value is -2.863 (-3.434), significance is denoted by * (**). All test results are robust against variation of the lag length or the deterministics in the test equation.

According to the expectation hypothesis of the term structure, i and $i3$ should be cointegrated with a stationary term spread $i3-i$, see Campbell and Shiller (1987). Figure 2 nicely illustrates the significance of the expectations theory for the short end of the term structure. The term spread $i3-i$ is large and well above its median of 6.3 basis points in times of rate hike expectations and small and sometimes even negative when interest rates are expected to decrease. In line with Gaspar et al. (2001), this indicates that interest rate changes of the ECB typically have been anticipated by the interbank market. Unit-root tests provide further evidence for the stationarity of the term spread $i3-i$, see Table 2. Note that this result can easily be confirmed by cointegration tests where the cointegrating vector is not restricted to be $(1, -1)$ *a priori*.

2.2 Modeling Overnight Rate Dynamics

The above cointegration analysis implies that a natural starting point of the empirical analysis of the dynamics of the Eonia is an error-correction equation that incorporates both, the lagged policy spread, $i - i^*$, as well as the lagged term spread, $i3 - i$, as error-correction terms:

$$\Delta i_t = \alpha(i-i^*)_{t-1} + \beta(i3-i)_{t-1} + \delta\Delta i^*_t + \sum_{k=1}^{p} \phi_{1,k}\Delta i_{t-k} + \sum_{m=1}^{q} \phi_{2,m}\Delta i3_{t-m} + \theta' X_t + \varepsilon_t \quad (1)$$

where Δ is the first-difference operator and X_t is a vector of (0,1)-dummy variables capturing e.g. calendar and end-of-reserve-period effects.[5] In Section 3, this empirical setup will

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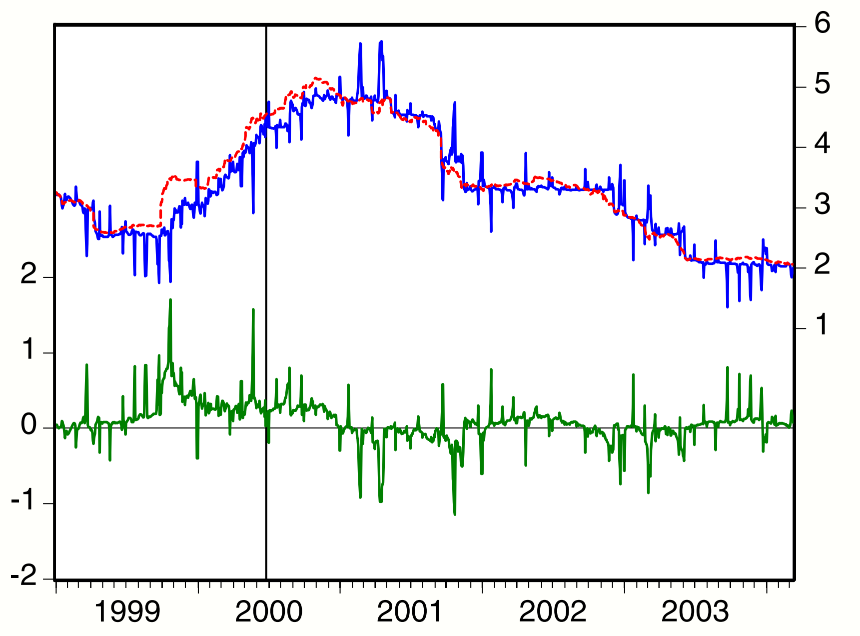
[5] Specifically, X_t comprises dummies for the end of the quarter, of the semester, and of the year, as well as a constant. We employ further dummies to account for irregular influences due to the Year-2000 effect and the terrorist attacks at September 11, 2001, see Appendix.

Figure 2: Euro Overnight Rate and 3-Month Euribor



Right scale: Euro Overnight Index Average (solid line) and 3-Month Euro Interbank Offered Rate (dashed line). Left scale: Difference between both interest rates (*term spread*). The vertical line denotes the change from fixed rate tender auctions to variable rate tenders. Sample: January 2, 1999 – March 9, 2004.

serve as the base model to investigate how the dynamics of the Eonia depend on prevailing rate expectations and the way monetary policy is implemented by the central bank.

Typically, related studies dealing with daily overnight rates often have a different focus and thus, also different modeling strategies and econometric specifications. The recent empirical literature on the overnight rate was initiated by the seminal article by Hamilton (1996). This paper had a strong focus on testing the martingale hypothesis.[6] Therefore, in order to test for predictable regularities of the Federal funds rate during the reserve period, he specified the dynamics of the Federal funds rate by a simple autoregressive process augmented, however, by dummy variables for each specific day of the reserve maintenance period. To capture the increased volatility of the interest rate at the end of the reserve period, the equation for the Federal funds rate is estimated in an EGARCH framework. Since Hamilton (1996), the EGARCH model has been widely used for analyzing the martingale

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[6] The intuition of the martingale hypothesis is as follows: Since central banks typically allow reserve averaging, funds should be perfect substitutes within a reserve period. Therefore, 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.

hypothesis and the volatility of daily interest rates.

Pérez Quirós and Rodríguez Mendizábal (2005) use the EGARCH model to test the martingale hypothesis for German and European overnight rates. Following Hamilton (1996), the change of the overnight rate is explained by a set of dummy variables X_t capturing calendar and end-of-reserve-period effects:

$$\Delta i_t = \theta' X_t + \varepsilon_t \tag{2}$$

Gaspar et al. (2004) use a similar model to analyze the individual interest rates reported by the banks contained in the Eonia panel. Equation (2) does not account for adjustments of the Eonia to the ECB's policy rate or to the term spread.

Bartolini and Prati (2005) analyze the volatility pattern in daily overnight rates for a whole set of countries, including the Euro Area. The focus of that paper is on how interest rate volatility is affected by cross country differences in monetary policy execution. Therefore, they put much emphasis on the specification of the variance equation of the EGARCH model. For example, they allow the variance of overnight rates to depend on the (squared) position of the interest rate in the central bank's interest rate corridor. In contrast, the specification of the mean equation for the overnight rate contains less economic structure and is very similar to Equation (2). Bartolini and Prati (2005) account for a short-run impact of monetary policy on the overnight rate by including the change of the policy rate Δi^* in the mean equation. However, for most countries, including the Euro Area, they do not consider a long-run level effect of the policy rate. In particular, the policy spread $i - i^*$ is generally not incorporated in the mean equation.[7]

In a related paper, Würtz (2003) focuses on the determinants of the policy spread $i-i^*$. To that aim, he proposes a very comprehensive model that considers many institutional details of the ECB's operational framework. In particular, the equation for the policy spread is non-linear in order to take into account that the Eonia is bounded by the corridor set by the ECB's standing facilities. With regard to the effect of the MRO auction format, it is found that fixed rate tenders effectively limit the downward potential of the spread. However, in line with the impression given by the average size of the policy spread in Table 1, there is no evidence that fixed rate tenders are more effective than variable rate tenders in keeping overall the overnight rate close to the policy rate. According to Würtz (2003), a crucial variable for the policy spread are expectations about changes in the ECB's policy rate.

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[7] The only exceptions are the equations for the US and pre-EMU France where banks are allowed to carry reserve imbalances over to the next reserve period. Therefore, banks are able to arbitrage over cross-period interest rate gaps. For that reason, Bartolini and Prati (2005) consider the influence of the policy spread only at the first day of the reserve period.

The importance of interest rate expectations for the dynamics of the overnight rate has been emphasized recently by e.g. Sarno and Thornton (2003). They estimate error-correction equations for the US Federal funds rate and the 3-month Treasury bill rate including a stationary linear combination of the interest rates as error-correction term.[8] Using non-linear error-correction equations, they find that the adjustment of the overnight rate to the Treasury bill rate is asymmetric. Specifically, the reaction of the Federal funds rate is stronger whenever it is below its equilibrium value. According to Kuo and Enders (2004) and Clarida et al. (2006), non-symmetric error-correction is also present in the Japanese and the German term structure of interest rates. Note that these three papers do not account for an influence of the policy rate (e.g., the Federal funds rate target) on the dynamics of the overnight rate.

3 The Adjustment of the Euro Overnight Rate to the Policy Rate and the Term Spread

3.1 The Base Model

Table 3 presents the estimates of the long run adjustment coefficients, α and β, corresponding to the error-correction equation of the Euro overnight rate as proposed in Equation (1).[9] Both adjustment coefficients have the expected sign. On the one hand, the negatively-signed adjustment to the lagged policy spread shows that the Eonia tends to return to the interest rate level intended by the central bank. On the other hand, the Eonia tends to increase when a positive term spread indicates rate hike expectations.

Table 3: Eonia Adjustment to Policy Spread and Term Spread

$i - i^*$	-0.261^{**} (5.61)
$i3 - i$	0.037 (1.55)
$\bar{R}^2$	0.227

Notes: Estimated adjustment coefficients of lagged policy and term spreads in Equation (1). Absolute t-values in parentheses are computed using heteroskedasticity-consistent standard errors, * (**) denotes significance at the 5% (1%) level.

The adjustment to the policy spread is both, economically and statistically significant, implying that approximately one quarter of the deviation of the Eonia from the policy rate

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[8] Note that Sarno and Thornton (2003) find the linear combination $i - 1.15\ i3$ to be stationary, not the term spread.

[9] The complete set of estimated coefficients is shown in the Appendix.

is eliminated in one day.[10] In contrast, the influence from the term spread is considerably weaker and even insignificant. However, this weak adjustment could be due to some irregular behavior of the Eonia at the end of the reserve period. In the following section, we will therefore consider an extension of the base model (1), where the adjustment of the Eonia to both spreads may differ at the end of the reserve period.

3.2 Eonia Adjustment Within and at the End of the Reserve Period

The dynamics of the Eonia depend on the central bank's operational framework for its liquidity management and banks' reserve management strategies. In particular, since the ECB allows averaging of reserve holdings within the monthly reserve maintenance period (RMP), the volatility of the Eonia within the reserve period is typically low. At the end of the period, however, liquidity shortages or excess reserves can lead to sharp interest rate peaks and troughs, see Figure 1. The interest rate fluctuations are usually most pronounced at the very last day of the reserve period.[11] Yet, due to the ECB's reluctance to fine-tune the supply of reserves, the end-of-period effects often already start immediately after the last MRO of the reserve period.

End-of-period effects in the Eonia are often related to rate expectations and banks' bidding behavior in the ECB's main refinancing operations. Banks have a clear incentive to underbid, i.e. to postpone refinancing, whenever they expect an interest rate cut within the current reserve period. Moreover, since bi-weekly repos overlapped in the next reserve period until April 2004, banks may even have underbidden at the end of the reserve period. This underbidding resulted in a lack of bids such that the ECB could not allot the intended volume of reserves. In fact, on several occasions, the resulting lack of reserves forced many banks to use the ECB's marginal lending facility on a large scale and the Eonia sharply increased until the end of the reserve period. Note that the interest rate *increased* although underbidding occurred because banks expected interest rates to *decrease*. As a consequence, at end-of-period days (i.e. after the last MRO) the reaction of the Eonia to the term spread may even have a reversed sign. This disturbing influence of banks' bidding behavior may also be relevant in times of rate hike expectations. During the fixed rate tender period, rate hike expectations led banks to overbid, i.e. to exaggerate their demand for reserves. In order to stop overbidding, the ECB repeatedly allotted too much reserves in their MROs. As a result, in contrast to banks' expectations, the Eonia fell dramatically at the end of the reserve period.

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[10] Note that the short-run effect of a change in the policy rate is significantly positive but does not entail a one-for-one change in the Eonia ($\hat{\delta} = 0.324$), see Appendix. This result is found to be very robust over all specifications.

[11] Similar end-of-period effects are found by Furfine (2000) and Bartolini et al. (2001) for the US.

Typically, end-of-period effects in the overnight rate are modeled by the use of simple dummy variables, thus treating at least the average size of the peak as a periodic deterministic phenomenon, see Section 2.2. However, this approach to end-of-period effects may be misleading whenever the peaks in the interest rate are not predominantly positive or negative, but can have both signs, as shown in Figure 1. In order to shed more light on the Eonia dynamics, we therefore extend the base model (1) (that includes the usual dummy variables) by allowing for different adjustment dynamics of the EONIA during the end of the reserve period. Specifically, we define the indicator variable I_t^{eop} to be one at days after the last allotment in the reserve period until the end of the RMP and zero otherwise, and estimate the following extended error-correction equation of the Eonia:

$$\begin{aligned}\Delta i_t = {} & \alpha_1(1 - I_t^{eop})(i - i^*)_{t-1} + \alpha_2 I_t^{eop}(i - i^*)_{t-1} \\ & + \beta_1(1 - I_t^{eop})(i3 - i)_{t-1} + \beta_2 I_t^{eop}(i3 - i)_{t-1} + \ldots + \theta' X_t + \varepsilon_t\end{aligned} \tag{3}$$

Note that the Eonia adjustment to the policy spread (α) or to the term spread (β) within ($I^{eop} = 0$) and at the end of the reserve period ($I^{eop} = 1$) is the same if $\alpha_1 = \alpha_2$ or $\beta_1 = \beta_2$, respectively.

The estimation results shown in Table 4 clearly indicate that the adjustment coefficients within and end of period are different. For both spreads, Wald tests (see lower panel) reject the equality of the adjustment coefficients at the 5% significance level. The extended adjustment equation reveals that the link of the Eonia to both, the policy spread and the term spread is in fact much closer within the reserve period. Although the adjustment to the term spread is now also significant and plausibly signed, the policy rate is still the major determinant of the Eonia within the reserve period ($|\hat{\alpha}_1| = 0.367 > 0.108 = \hat{\beta}_1$).

During the end of the period, however, the dynamics of the Eonia are very different. First, the estimated adjustment coefficient of the policy rate is smaller in magnitude ($|\hat{\alpha}_2| = 0.164$) and remains only weakly significant. This shows that the influence of the policy rate on the Eonia becomes weaker after the last MRO of the reserve period when reserves have to be ultimately met without any further access to central bank refinancing at that rate. For the term spread, the difference in adjustment for within-period and end-of-period days is even more pronounced. In contrast to the plausibly signed adjustment coefficient estimated within period ($\hat{\beta}_1 = 0.108$), the end-of-reserve-period effect is significantly negative ($\hat{\beta}_2 = -0.154$) implying that e.g. the Eonia decreases in times of rate hike expectations.

The end-of-period adjustment coefficients for the policy and the term spread are very similar. In fact, testing the equality of the coefficients ($\alpha_2 = \beta_2$) yields a p-value of 0.878. Accordingly, during the end of the period the two different spreads can be combined to a modified term spread where the Eonia is replaced by the policy rate: $(i_t - i_t^*) + (i3_t - i_t) = i3_t - i_t^*$. This modified term spread has an interesting economic interpretation: at the end

Table 4: End-of-Period Effects in Eonia Adjustment

	Unrestricted estimation		Restricted estimation	
	within period	end of period	within period	end of period
$i - i^*$	-0.367^{**}	-0.164	-0.364^{**}	-0.151^{*}
	(7.92)	(1.49)	(7.65)	(2.25)
$i3 - i$	0.108^{**}	-0.154^{*}	0.108^{**}	-0.151^{*}
	(4.21)	(2.21)	(4.25)	(2.25)
$\bar{R}^2$	0.323		0.324	

Wald Tests of Parameter Equality

$\mathcal{H}_0$:	Same adjustment of the Eonia within and end of period	
$i - i^*$	0.041	0.004
$i3 - i$	0.000	0.001

Notes: Estimated adjustment coefficients of lagged policy and term spreads. Absolute t-values in parentheses are computed using heteroskedasticity-consistent standard errors, * (**) denotes significance at the 5% (1%) level. Wald tests of parameter equality are presented as p-values.

of the reserve period, the actual level of the Eonia loses its significance for rate change expectations. It is rather the policy rate that anchors the term structure in this particular situation. The right panel of Table 4 shows the results for the restricted estimation. Note that the coefficient estimated for the modified term spread is highly significant and still has a counterintuitive sign.

The counterintuitive adjustment of the Eonia to the term spread at the end of the reserve period can be reconciled with the under- and overbidding episodes outlined above. For example, recall that expectations of declining interest rates caused banks to underbid which eventually drove the overnight rate up, not down. Therefore, the implausible adjustment of the Eonia to the term spread might be due to the turbulences in the interbank money market stirred by e.g. under- and overbidding of banks in the ECB's main refinancing operations. This suggests to use the end-of-period coefficient estimated for the modified term spread as a measure for the disturbing influence of rate change expectations on the Eonia dynamics and the ECB's liquidity management.

In the following section, we investigate whether the dynamics of the Eonia within and at the end of the period depend on rate expectations and the way monetary policy has been implemented. In particular, we estimate the influence of the MRO auction format on the Eonia dynamics. Moreover, following Nautz (1997) and Sarno and Thornton (2003), we employ non-symmetric error-correction models to investigate whether the Eonia dynamics depend on the sign of the (mean-adjusted) term spread and the position of the overnight rate in the ECB's interest rate corridor.

4 Asymmetries in Eonia Adjustment and the Impact of the Auction Format

The impact of the auction format: Fixed and variable rate tenders

During the first 18 months of the Euro, the ECB used fixed rate tenders in its main refinancing operations to allocate liquidity to the banking sector. In a fixed rate tender, the repo rate is pre-determined by the central bank, and banks can only indicate how much refinancing they would like to receive at that rate. Therefore, a fixed repo rate contains a very strong signal of the ECB about the intended level of short-term interest rates.

In June 2000, the ECB switched to variable rate tenders to stop the MRO's escalating overbidding problem, see Nautz and Oechssler (2003, 2005). In variable rate tenders, the resulting repo rates partially depend on the bids of the banks and thus, are not under the ECB's full control. Since then, the ECB's policy rate has been the MRO's preannounced minimum bid rate. With respect to the average policy spread, it is not clear whether the fixed repo rate had been more effective than the minimum bid rate in keeping overall the overnight rate close to the policy rate, compare Table 1. In the following, we will investigate how the dynamic adjustment of the Eonia to the policy rate depends on the MRO auction format. Specifically, we will interact the adjustment coefficients with a dummy variable (I^f, see Appendix) indicating the applied auction procedure.

Non-symmetric Eonia adjustment with respect to the policy spread

The fixed repo rate is a symmetric policy rate in the sense that it is both, upper and lower bound for the repo rate. Comparable to the working of the US Federal funds rate target, it is in general not obvious whether the central bank is more concerned about overnight rates below or above that policy rate. In contrast, a variable rate tender with a minimum bid rate should be more effective in defining a lower bound for the bids and the resulting repo rates. Therefore, using a minimum bid rate as the key policy rate might induce an asymmetry in the Eonia dynamics. In particular, the adjustment of the Eonia should be stronger when it is low relative to the policy rate, i.e. if the (mean-adjusted) policy spread is negative. According to Ayuso and Repullo (2003), this asymmetry in the Eonia dynamics would also prevail under the fixed rate tender format if the central bank has an asymmetric loss function in the sense that it is more averse to let interest rates fall below the target than to let them exceed it.

In order to investigate the empirical relevance of these effects, one has to extend the standard symmetric error-correction equations estimated in the preceding section. In the following, we consider non-symmetric error-correction equations for the Eonia, where the adjustment coefficients may depend on the sign of the (mean-adjusted) policy spread, i.e. on the position of the Eonia in the ECB's interest rate corridor.[12] Moreover, to control for a possible impact of the tender procedure on this asymmetry, we will interact the non-symmetric error-correction terms with the tender dummy I^f introduced above.

Non-symmetric Eonia adjustment with respect to the term spread

There is clear evidence that the Euro overnight rate is crucially influenced by interest rate expectations, see e.g. Würtz (2003). However, the impact of rate expectations on the Eonia may depend on the direction of expected rate changes, i.e. on the sign of the (mean-adjusted) term spread. For example, Sarno and Thornton (2003) and Kuo and Enders (2004) showed that rate hike expectations have a particularly strong effect on US and Japanese overnight rates. In the Euro Area, the impact of rate expectations on the interbank market was strongly affected by the tender procedure applied in the ECB's MROs (until April 2004). Therefore, we will also allow for an asymmetric adjustment of the Eonia to the term spread that depends on the applied auction format.

Summarizing, the extended adjustment equation of the Eonia is characterized as follows: first, the Eonia adjustment is specified as a non-symmetric error-correction equation where the asymmetry is implemented for both, the policy spread and the term spread. To implement asymmetric adjustment, both spreads were mean-adjusted using their long-term averages given by the respective median, see Table 1.[13] Second, all adjustment coefficients may depend on the MRO auction format. Third, as in the preceding section, the adjustment coefficients may differ within and at the end of the reserve period. Confirming the findings of the symmetric adjustment equation of the preceding section, the restriction that the term spread and the policy spread have the same coefficients for end-of-period observations ($\alpha_2 = \beta_2$) still holds for the extended specification. In the following we present the results for this more parsimonious restricted specification, but our results do not depend on this choice.

Evidence on the Eonia adjustment within the reserve period

Table 5 shows the estimates of the adjustment parameters of the extended non-symmetric error-correction equation of the Eonia.[14] Let us first look at the Eonia adjustment within

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[12] Non-symmetric error-correction models were introduced by Granger and Lee (1989). Nautz (1997) used non-symmetric error-correction equations to show that the response of the German overnight rate depends on the pricing rule applied in the variable rate tenders of the Bundesbank.

[13] Note that the following results are robust with respect to alternative mean adjustments (e.g. using the arithmetic mean).

[14] For a presentation of the complete set of parameters, see Appendix.

the reserve period. The p-values of the corresponding Wald tests shown in the lower left part of the table are all below 0.05 indicating that - within period - the adjustment of the Eonia depends for both spreads on its sign as well as on the auction format.[15] For the policy spread, the adjustment of the Eonia is significantly stronger when the policy spread is below average (i.e. for $(i - i^*)^-$). Therefore, the ECB's policy rate has been more effective in limiting the downward potential of the overnight rate. This finding is plausible for the variable tender procedure where the minimum bid rate sets a floor on the bids. However, supporting Ayuso and Repullo (2003), asymmetry is found irrespective of the MRO tender procedure. In line with Würtz (2003), we find that the asymmetric adjustment to the policy spread is even more pronounced during the fixed rate period. During that period, the adjustment coefficient in case of a large policy spread ($(i - i^*)^+$) is very small (-0.048) and even insignificant. From this perspective, the introduction of variable rate tenders improved the ECB's control over the Eonia.

For the term spread, the kind of asymmetry also depends on the tender procedure. Under the fixed rate procedure, the adjustment coefficient (0.516) is only significant in case of a negative term spread $(i3 - i)^-$ indicating rate cut expectations. In contrast, under the variable rate procedure, there is only a significant adjustment for $(i3 - i)^+$, i.e. in times of rate hike expectations.[16] Note, however, that both situations, i.e. rate cut expectations during the fixed rate tender period and rate hikes under the variable rate procedure, were more the exception than the rule, see Figure 2.

Evidence on the Eonia adjustment at the end of the reserve period

For both spreads and irrespective of the tender procedure, there is no evidence of asymmetric adjustment of the Eonia at the end of the reserve period. This is confirmed by the p-values of the corresponding Wald tests reported in the lower right part of Table 5. The large standard errors of the estimated adjustment coefficients may partly be due to the relatively small number of end-of-period observations for each of the different episodes. However, confirming the results of the symmetric specification in Section 3, the estimated adjustment coefficients of the Eonia to the (modified) term spread show the counterintuitive negative sign in each case. In fact, restricting all end-of-period coefficients to be equal (such that asymmetry is only allowed within period) yields an adjustment coefficient of -0.15 which is significant at the 5%-level and very close to the estimate obtained in Section

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[15] Table 5 reads as follows: the p-value corresponding to the null hypothesis that e.g. during the variable rate period (VRT) the within period adjustment of the Eonia is symmetric with respect to the policy spread $(i - i^*)$ is 0.017.

[16] Sarno and Thornton (2003) report a similar asymmetry in the adjustment of the US Federal funds rate to the Treasury bill rate.

Table 5: Non-symmetric Adjustment and the Impact of the Tender Procedure

	within period		end of period	
	FRT	VRT	FRT	VRT
$(i - i^*)^+$	-0.048 (0.92)	-0.321^{**} (4.27)		
$(i - i^*)^-$	-1.004^{**} (10.50)	-0.619^{**} (6.69)		
$(i3 - i)^+$	0.012 (0.32)	0.286^{**} (5.36)		
$(i3 - i)^-$	0.516^{**} (3.14)	-0.022 (0.46)		
$(i3 - i^*)^+$			-0.156 (1.71)	-0.201 (1.07)
$(i3 - i^*)^-$			-0.269 (0.26)	-0.095 (0.58)
$\bar{R}^2$	0.395			

Wald Tests of Parameter Equality

$\mathcal{H}_0$: Symmetric adjustment for positive and negative spreads

	within period		end of period	
	FRT	VRT	FRT	VRT
$i - i^*$	0.000	0.017		
$i3 - i$	0.004	0.000		
$i3 - i^*$			0.915	0.716

$\mathcal{H}_0$: No impact of MRO auction format on Eonia adjustment

	within period		end of period	
	+	−	+	−
$i - i^*$	0.002	0.001		
$i3 - i$	0.000	0.001		
$i3 - i^*$			0.811	0.863

Notes: Estimated adjustment coefficients of lagged policy and term spreads. Asymmetric error-correction terms are corrected for "natural" spreads by subtracting the median. FRT and VRT differentiate between the fixed and variable rate tender period, $^+$ and $^-$ differentiate between positive and negative observations for the respective expression. Absolute t-values in parentheses are computed using heteroskedasticity-consistent standard errors, * (**) denotes significance at the 5% (1%) level. Wald tests of parameter equality are presented as p-values.

3. Thus, the switch to the variable rate tender procedure had no significant impact on the end-of-period dynamics of the Eonia. Moreover, the behavior of the Eonia during the last days of the reserve period appears to be counterintuitive irrespective of the prevailing rate expectations and the position of the Eonia in the ECB's interest rate corridor.

5 Conclusion

This paper investigated the dynamic relationship between the Euro overnight rate (i), the 3-month Euribor ($i3$) and the ECB's key policy rate (i^*). In a first step, we established that both, the policy spread ($i - i^*$) and the term spread ($i3 - i$) are stationary implying that the dynamic relation between these interest rates should be modeled in an error-correction framework. In particular, the Eonia may adjust to the lagged policy spread as well as to the lagged term spread.

Our results indicate that the within-period dynamics of the Eonia depend on the auction format. Interestingly, the introduction of variable rate tenders with a minimum bid rate in June 2000 did not lead to a loss of control of the ECB over the Eonia. Since June 2000, the link between the Eonia and the ECB's policy rate is even strengthened when the policy spread tends to increase. For both auction formats, the Eonia adjustment is significantly stronger when the policy spread is relatively low. Following Ayuso and Repullo (2003), this pattern of the Eonia dynamics could be due to asymmetric preferences of the central bank with regard to the sign of the policy spread.

Particular attention was paid to the dynamics of the Eonia during the last days of the reserve period. We found that end-of-period, the influence of the policy rate on the Eonia remains only weak and that its response to the term spread even shows the wrong sign. We argued that these seemingly implausible end-of-period dynamics of the Eonia partly reflect the market's reaction to banks' over- and underbidding behavior in the ECB's main refinancing operations. For example, due to banks' underbidding the ECB could not allot the intended volume of reserves. As a consequence, the Eonia often sharply increased at the end of the reserve period even though banks underbid because they expected interest rates to decrease.

In March 2004, the ECB redesigned its operational framework of monetary policy in order to mitigate the distorting impact of rate expectations on banks' bidding in MROs and the dynamics of the Eonia. The empirical framework proposed in this paper might be useful for evaluating the success of these measures. Considering the lack of strong interest rate change expectations up to the most recent past, future will have to show whether the observed counterintuitive end-of-period behavior of the Eonia still maintains or not.

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A Appendix

Table A.1: Complete Specification: Base Model

Variable		Coefficient	t-statistic
$i - i^*$		-0.2613	-5.6121
$i3 - i$		0.0365	1.5527
Δi^*		0.3242	5.0436
Δi_{-1}		0.0282	0.6377
Δi_{-2}		-0.0373	-1.1958
Δi_{-3}		-0.0065	-0.2425
Δi_{-4}		-0.0217	-0.9151
Δi_{-5}		-0.0053	-0.2420
$\Delta i3_{-1}$		0.2839	2.1960
$\Delta i3_{-2}$		0.1341	0.5469
$\Delta i3_{-3}$		0.4256	2.5347
$\Delta i3_{-4}$		-0.3871	-2.0751
$\Delta i3_{-5}$		0.1318	1.0241
d_{Y2K}	(*Dummy for Year-2000 effect*)	0.4061	6.5863
d_{Sep11}	(*Dummy for Sep.-11 effect*)	0.1349	20.3581
I^{eop}	(*Dummy for end-of-period day*)	-0.0433	-2.5897
d_{first}	(*Dummy for first day of RMP*)	0.0869	2.3688
d_{eoq}	(*Dummy for end of quarter*)	0.0673	3.3401
d_{eos}	(*Dummy for end of semester*)	0.1594	3.0523
d_{eoy}	(*Dummy for end of year*)	0.0964	1.2494
constant		0.0045	1.6980

Notes: Estimates of the base specification (Eq. (1)). Δi_{-k} and $\Delta i3_{-k}$ denote the k-th lag of the first difference of i and $i3$, respectively. t-statistics are computed using heteroskedasticity-consistent standard errors (HCSE).

Table A.2: Complete Specification: End-of-Period Effects in Eonia Adjustment

	Unrestricted estimation		Restricted estimation	
Variable	Coefficient	t-statistic	Coefficient	t-statistic
$(1 - I^{eop}) \cdot (i - i^{*})$	-0.3667	-7.9225	-0.3640	-7.6507
$(1 - I^{eop}) \cdot (i3 - i)$	0.1079	4.2053	0.1082	4.2460
$I^{eop} \cdot (i - i^{*})$	-0.1642	-1.4900	-0.1509	-2.2475
$I^{eop} \cdot (i3 - i)$	-0.1535	-2.2126	-0.1509	-2.2475
Δi^{*}	0.3604	6.1186	0.3585	6.2019
Δi_{-1}	0.0275	0.6875	0.0241	0.6163
Δi_{-2}	-0.0321	-1.1935	-0.0349	-1.1866
Δi_{-3}	-0.0093	-0.3844	-0.0117	-0.4572
Δi_{-4}	-0.0159	-0.6848	-0.0176	-0.6578
Δi_{-5}	0.0074	0.3564	0.0062	0.2784
$\Delta i3_{-1}$	0.3156	1.9727	0.3124	1.9694
$\Delta i3_{-2}$	0.1749	0.7097	0.1749	0.7107
$\Delta i3_{-3}$	0.3236	1.8469	0.3205	1.8403
$\Delta i3_{-4}$	-0.3269	-2.0874	-0.3268	-2.0898
$\Delta i3_{-5}$	0.0032	0.0290	0.0004	0.0032
d_{Y2K}	0.3459	5.0418	0.3463	5.0379
d_{Sep11}	0.1398	21.0670	0.1400	21.0682
I^{eop}	0.0647	2.3422	-0.0337	-2.2204
d_{first}	-0.0337	-2.2193	0.0647	2.3429
d_{eoq}	0.0627	2.7929	0.0633	2.7937
d_{eos}	0.1680	3.3683	0.1673	3.3511
d_{eoy}	0.1307	1.6474	0.1302	1.6410
$constant$	0.0083	3.2004	0.0082	3.1636

Notes: Estimates of the extended specification differentiating between within-period ($I^{eop} = 0$) and end-of-period days ($I^{eop} = 1$) in the adjustment to the policy spread and the term spread (Eq. (3)). The restricted estimation is performed under the condition that the end-of-period adjustment to both spreads is the same. For the definition of variables see Table A.1. t-statistics are computed using HCSE.

Table A.3: Complete Specification: Asymmetric Eonia Adjustment

Variable	Coefficient	t-statistic
$(1-I^{eop})\cdot I^{f}\cdot(i-i^{*})^{+}$	-0.0478	-0.9155
$(1-I^{eop})\cdot I^{f}\cdot(i-i^{*})^{-}$	-1.0035	-10.495
$(1-I^{eop})\cdot I^{f}\cdot(i3-i)^{+}$	0.0122	0.3249
$(1-I^{eop})\cdot I^{f}\cdot(i3-i)^{-}$	0.5155	3.1357
$(1-I^{eop})\cdot(1-I^{f})\cdot(i-i^{*})^{+}$	-0.3210	-4.2690
$(1-I^{eop})\cdot(1-I^{f})\cdot(i-i^{*})^{-}$	-0.6192	-6.6926
$(1-I^{eop})\cdot(1-I^{f})\cdot(i3-i)^{+}$	0.2857	5.3623
$(1-I^{eop})\cdot(1-I^{f})\cdot(i3-i)^{-}$	-0.0218	-0.4591
$I^{eop}\cdot I^{f}\cdot(i3-i^{*})^{+}$	-0.1560	-1.7146
$I^{eop}\cdot I^{f}\cdot(i3-i^{*})^{-}$	-0.2686	-0.2592
$I^{eop}\cdot(1-I^{f})\cdot(i3-i^{*})^{+}$	-0.2008	-1.0712
$I^{eop}\cdot(1-I^{f})\cdot(i3-i^{*})^{-}$	-0.0948	-0.5796
Δi^{*}	0.3780	4.4580
Δi_{-1}	0.0692	1.9058
Δi_{-2}	-0.0022	-0.0783
Δi_{-3}	0.0048	0.2048
Δi_{-4}	0.0020	0.0798
Δi_{-5}	0.0030	0.1470
$\Delta i3_{-1}$	0.2620	1.9430
$\Delta i3_{-2}$	0.1872	0.8561
$\Delta i3_{-3}$	0.3704	2.3847
$\Delta i3_{-4}$	-0.2996	-2.3267
$\Delta i3_{-5}$	0.0037	0.0420
d_{Y2K}	0.4012	6.3152
d_{Sep11}	0.1447	23.5150
I^{eop}	-0.0067	-0.2849
d_{first}	-0.0259	-1.1122
d_{eoq}	0.0628	3.3104
d_{eos}	0.1732	3.6354
d_{eoy}	0.1011	1.3406
$constant$	-0.0135	-3.2131

Notes: Estimates of the extended specification allowing for asymmetric adjustment to the policy spread and the term spread as well as for different adjustment coefficients under the fixed rate tender ($I^{f}=1$) and the variable rate tender ($I^{f}=0$). Asymmetric error-correction terms are corrected for “natural” spreads by subtracting the median. For the definition of variables see Table A.1. t-statistics are computed using HCSE.

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