Monetary Transmission Right from the Start: On the Information Content of the Eurosystem's Main Refinancing Operations*

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Abstract

The Eurosystem's main refinancing operations (MRO) are key for the interbank money market and the monetary transmission process in the euro area. This paper investigates how money market rates respond to the information revealed by various aspects of an MRO auction outcome. Our results confirm that the level of MRO rates governed short-term money market rates before the financial crisis. Since the start of the financial crisis, however, the information content of MRO rates has changed. While the levels of MRO rates have lost much of their pre-crisis significance, the spread between the weighted average and the marginal MRO rate has become an important barometer for the actual situation in the money market during the crisis.

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1 Introduction

Weekly main refinancing operations (MROs) are of overwhelming importance for the monetary policy implementation of the European Central Bank (ECB). The liquidity supply in MROs should ensure that short-term money market rates closely follow the MRO rates and that their volatility remains well contained, see e. g. Cassola and Morana (2008) and Ejerskov et al. (2008). This central aim of monetary policy implementation has never been an easy task. Even before the financial crisis, a puzzling and unintended upward trend in the spread between the European overnight rate (Eonia) and the MRO rates indicated that the monetary transmission mechanism is not sufficiently understood, see Linzert and Schmidt (2011).[1] Since the start of the financial crisis, spreads between the Eurosystem's main refinancing rates and the money market rates have been huge and persistent. In order to shed more light on the very beginning of the monetary transmission process in the euro area, this paper investigates how the European money market responds to MRO auction outcomes.

On the allotment day, the Eurosystem publishes the number of bidders, total allotment and total bids together with the marginal and the weighted average allotment rate of the MRO. All these variables may contain new information about the expected course of monetary policy and the situation in the money market. This paper assesses the role of MROs for the monetary transmission mechanism by estimating the response of money market rates to the various aspects of an MRO auction outcome.

Our study can be related to two groups of papers. First, there is a growing empirical literature on the dynamics and the volatility of overnight rates. Recent examples include Bartolini and Prati (2006), Pérez Quirós and Rodríguez Mendizábal (2006), Colarossi and Zaghini (2009), and Nautz and Scheithauer (2011). All these contributions investigate how distinguishing features of the central bank's operational framework influence the behavior of overnight rates. They do not focus on the response of the overnight rate to auction outcomes. The second group of papers explores banks' bidding behavior in central bank auctions, see e. g. Linzert et al. (2007), Bindseil et al. (2009), and Cassola et al. (2009). Using individual bidding data, it can be shown that money market conditions significantly affect banks' bidding behavior. These papers try to explain the

[1] In contrast to earlier estimates of the liquidity effect, the Eurosystem's pre-crisis provision of excess liquidity in MROs could not bring the Eonia back to its intended level, see European Central Bank (2006). In the U. S. the empirical relevance of the liquidity effect has been analyzed by e. g. Carpenter and Demiralp (2008) and Thornton (2008).

auction outcome but do not consider its repercussions on the money market.

The current paper fills this gap and explores the impact of the Eurosystem's MRO auctions on short-term money market rates in the euro area using both daily and intra-day data of overnight rates. Longer-term Eonia swap rates are employed to examine how the auctions affect market's expectations about future Eonia movements. Our results show that the recent crisis significantly impeded the first step of the monetary transmission mechanism. Before the financial crisis, MRO auction outcomes helped to stabilize the money market. If e. g. the spread between the Eonia and the new marginal MRO rate was above average, the Eonia would adjust accordingly. Since the outbreak of the crisis, however, the stabilizing effect of MRO auctions on the Eonia level has disappeared. The most relevant information is now contained in the MRO spread, i.e. the spread between the weighted average and the marginal MRO rate. While MRO spreads were virtually negligible before the crisis, they widened substantially in the period after August 2007, when banks increasingly submitted safety bids at high interest rates. Our empirical results show that the resulting MRO spread revealed new information about the actual situation in the money market.

The remainder of the paper is structured as follows. In Section 2, we briefly review the role of MRO auctions in the operational framework of the Eurosystem and consider the timing of the auctions. Section 3 introduces the auction variables, discusses their expected influence on the money market on the auction day, and presents the econometric model. Section 4 presents the empirical results on the impact of MRO auction outcomes on money market rates before and during the crisis. Section 5 summarizes our main results and offers some concluding remarks.

2 The Role of MRO Auctions in the Eurosystem's Operational Framework

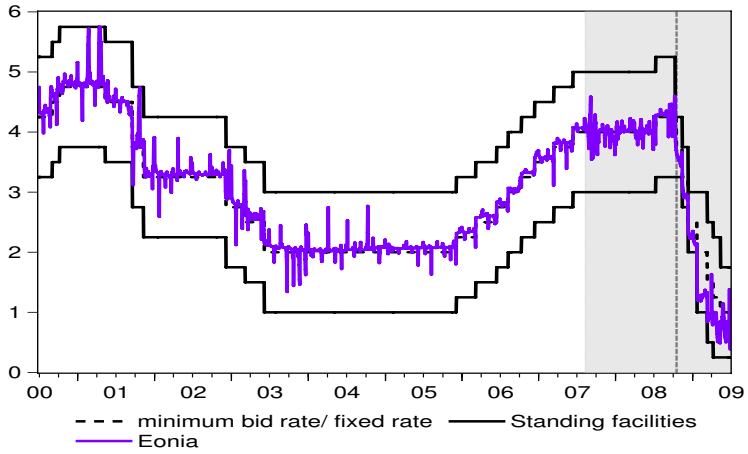
2.1 Monetary Policy Implementation

The Eurosystem implements its monetary policy through a framework in which the banking sector operates in a liquidity deficit vis-á-vis the Eurosystem. The weekly main refinancing operations (MROs) cover the bulk of banks' liquidity demand and play the pivotal role in signalling the monetary policy stance. From June 2000 until October 2008, MROs were conducted as variable rate tenders, i. e. as price-discriminatory multi-unit auctions where banks are allowed to submit multiple price-quantity bids. In variable rate tenders the resulting repo rates partially depend on the bids of the banks and, thus, are not under the Eurosystem's full control. Therefore, the Eurosystem pre-announces a minimum bid rate. The interest rates actually applied in the MROs

can be viewed as the first step in the transmission of monetary policy and should determine the level of short-term interest rates in the euro area's money market.

Unlike the U.S. Federal Reserve Bank, the Eurosystem has never announced an explicit operational target for its monetary policy implementation, see e. g. Ho (2008). However, there is no doubt that the Eurosystem's liquidity policy aims at stabilizing the shortest money market rate, Eonia, to a level close to its main refinancing rates, see e. g. Cassola and Morana (2008) and Ejerskov et al. (2008). Figure 1 shows the corridor in which the Eonia fluctuates between the rates of the two standing facilities and the minimum bid rate.

Figure 1: The interest rate corridor of the Eurosystem



Notes: The light shaded area refers to the crisis period as of August 9, 2007. The dashed vertical line represents the Eurosystem's adoption of the fixed rate tender procedure with full allotment as of October 15, 2008.

On August 9, 2007 tensions surrounding assets backed by US sub-prime mortgages started to spill over into money markets around the world, leading to liquidity shortages in the money market. In the euro area, the Eonia rate rose substantially following an increased liquidity demand in the overnight market. More precisely, banks developed a preference to (over-)satisfy their liquidity needs at the earliest stage possible.[2] The Eurosystem adjusted its liquidity provision in its weekly MROs to this change of liquidity demand pattern. In order to account for the changes in the demand and supply of liquidity in the Eurosystem's MROs, we allow money markets to respond differently to auction results after August 2007. Therefore, we explore the link between the Eonia and MROs for the crisis and pre-crisis sample separately. In fact, splitting our sample on August 9, 2007 is also implied by structural breakpoint tests, see Section B in the Appendix.

[2]See Fecht et al. (2008) for a detailed analysis of banks liquidity demand pattern before the crisis.

After Lehman Brothers filed for bankruptcy on September 15, 2008, the crisis intensified. Banks became even more reluctant to engage in interbank money market trading and relied to an increasing extent upon the Eurosystem's refinancing operations, see e. g. Hauck and Neyer (2010). On October 15, 2008 the Eurosystem responded to the exacerbated crisis and switched from the variable rate tender format to a fixed rate full allotment policy, hence satisfying the full liquidity demand of the banking sector.[3] The information content of an auction outcome is very limited under this format: in a fixed rate tender, the repo rate is pre-announced and all MRO rates are equal by construction. Moreover, due to full allotment, the cover-to-bid ratio is always one. Therefore, in the following empirical analysis on the information content of MROs, we shall focus on the variable rate tender period.

2.2 Overnight Rate Dynamics, MRO Results, and the Martingale Hypothesis

The euro area financial institutions are obliged to hold a minimum amount of reserves with the Eurosystem. For the fulfilment of these required reserves, banks are granted an averaging scheme where compliance is judged over a reserve maintenance period. As a result, the reserve holdings on any day of a given maintenance period may be considered as perfect substitutes for purposes of satisfying reserve requirements on any other day within the same maintenance period. Hence, the overnight rate on a given Monday should be equal to the interest rate that banks' funds traders expect to hold on Tuesday on the basis of information available on Monday as to the value of Tuesday. The reason for this property is that any misalignment between the current overnight rate and its expected future value within the maintenance period would trigger attempts on the part of the banks to reschedule their fulfilment of reserve requirements for the remainder of the maintenance period. This in turn would ultimately lead to an equalization of interest rates, see Hamilton (1996) and Bindseil (2004a).

From an *ex ante* view, interest rates should therefore be constant within a maintenance period, i.e. the expected future overnight rates within a maintenance period should never diverge from one day to the next. The logical implication of this argument is that interest rates should follow a martingale within the maintenance period. For the euro area, Würtz (2003), for instance, provides

[3] On August 4, 2011 the Eurosystem decided to continue conducting its MROs as fixed rate tender procedures with full allotment for as long as necessary, and at least until the end of the last maintenance period of 2011 on 17 January 2012, see Eurosystem's press release webpage. For further explanations, refer to European Central Bank (2010).

empirical evidence supporting the martingale hypothesis.

The martingale hypothesis, however, does not predict that actual overnight rates are constant from an *ex post* perspective. In fact, within a reserve maintenance period, money market rates should adjust to new and only new information and, in particular, to the unexpected components of an auction outcome. Following the martingale hypothesis, an MRO auction outcome, which contains new information for the money market during the respective reserve maintenance period, should affect the corresponding interest rates observed immediately after the auction results have been published. Therefore, our following empirical analysis on the information content of MRO auctions applies an event study approach and focuses on the response of money market rates on the auction day.

2.3 Measuring the Money Market Response to an MRO Auction Outcome

In the MROs of the Eurosystem, banks are invited to submit their bids from Monday 3:30 p. m. CET to Tuesday 9:30 a. m. CET. At Tuesday 11:20 a. m. CET, the Eurosystem communicates the auction outcome via its wire service. The response of the money market to an auction outcome should be reflected in overnight rates observed immediately after the auction results are available. Let i_b and i_a be the market rates valid *b*efore and *a*fter banks are informed about the auction outcomes. The money market response to the auction is then revealed in $\Delta i = i_a - i_b$. We measure Δi in three ways and thereby cover three main trading segments of the money market. First, in line with the empirical literature, we use daily data of the Eonia, the European Over-Night Index Average published by the Eurosystem.[4] Eonia rates refer to transactions carried out before the closing of real-time gross settlement (RTGS) system at 6.00 p. m. CET and are published on the same evening. Since the bulk of money market transactions are carried out after the auction result is announced, the timing of MROs suggests to use Eonia rates of Monday (i_b) and Tuesday (i_a) to measure the money market reaction to an auction outcome.

If money markets react quickly to new information about the liquidity situation, the *average* overnight rate on the auction day might be only a poor approximation for i_a and similar problems may apply to i_b. Therefore, in a second specification of Δi, we use intra-day broker quotes col-

[4]The Eonia is based on a panel of approx. 50 banks with the highest business volume in the euro area money market, see http://www.euribor.org. Following European Central Bank (2007), the unsecured market remains mainly an overnight market segment, with roughly 70% of the volumes both in the lending and borrowing activities in the shortest maturity bucket.

lected from Reuters at 9:30 a. m. CET and 11:25 a. m. CET for i_b and i_a, respectively. These rates are very close to the end of bid submission and the announcement of the auction outcome. Yet the available intra-day data bears two shortcomings. Firstly, intra-day data cover only that part of the 'over the counter' (OTC) market trading that is processed through voice brokers. [5] Thus, transactions between banks directly are missing. And secondly, in contrast to the daily Eonia data, intra-day data only refer to unbinding quotes rather than actual transactions.

A third approximation of Δi uses daily data of Eonia swap rates with one-week maturity obtained from Reuters. The Eonia swap market, in general, serves as the main instrument to manage short-term interest risk exposures and covers roughly 40% of the overall OTC derivatives market, see e. g. European Central Bank (2007). The one-week swap rate corresponds to the maturity of the MROs and measures the expected average Eonia over the next week. Thus, it is less affected by outliers than the daily Eonia. Because MROs are conducted only once a week, the one-week Eonia swap rate cannot be affected by expectations about future auction outcomes at an auction day. Since March 2008, the announcement of Eonia swap rates has changed from 4:30 p. m. CET to 11 a. m. CET. In line with the timing of MROs, the definition of Δi is adjusted accordingly.

Starting with the first price-discriminatory multi-unit auction on June 27, 2000 we have collected 434 auctions until October 14, 2008. The intra-day data is only available for December 4, 2000 to June 17, 2008. For the sake of comparability, we will run all our regressions from December 4, 2000 to June 17, 2008. At the end of the reserve maintenance period, when no further MRO will be conducted, liquidity shortages or excess reserves can lead to dramatic increases of overnight rate volatility. It is well understood by the market that these seasonal interest rate fluctuations are temporary and unrelated to monetary policy signals, see e. g. Nautz and Offermanns (2008). To ensure that our results will not depend on the large Eonia movements at the very last day of the reserve period, we excluded the auctions performed at those particular days from our regressions.[6] After these sample adjustments, we are left with 282 and 33 auctions before and during the crisis, respectively.

[5] According to European Central Bank (2007), more than 90% of all interbank transactions in the OTC derivatives market (other than foreign exchange swaps) are traded directly or through voice brokers. Since data on bilateral trading is notoriously hard to obtain, we use transactions through voice brokers that account for 27% of the total turnover in OTC derivatives.

[6] For the sake of robustness, the following observations were identified as outliers: the MRO with anomalous allotment one week after the terrorist attack on September 11, 2001 and on December 17, 2007, and the MRO distorted by the announcement of the six-month supplementary operation in April 2008.

3 The Response of Money Market Rates to MRO Auction Outcomes

3.1 The MRO Auction Outcomes: Variables and Predictions

On the allotment day, the Eurosystem publishes (i) the marginal rate (r_m) of the MRO, (ii) the quantity weighted average rate (r_w) of all successful bids, (iii) total bids and total allotments, and (iv) the number of bidders. Section A in the Appendix provides a graphical illustration of these MRO auction results. All these variables may contain new information about the situation in the money market and the policy-intended interest rate level.

The ***marginal rate*** or stop-out rate of an MRO, r_m, depends on both the banks' bidding behavior and the Eurosystem's allotment decision. The martingale hypothesis suggests that the overnight rate valid immediately before the auction corresponds to the value of the marginal rate that banks' expect to prevail in the upcoming auction. Any deviation of the marginal rate from the overnight rate valid immediately before the auction, $r_m - i_b$, may then be considered to carry unexpected news. This, in turn, should affect the same day's interest rates, i. e. the overnight rate i_a should adjust accordingly. In an error-correction type adjustment equation of Δi, the coefficient of $r_m - i_b$ is expected to be positive.

Before the crisis, the ***weighted average rate*** of an MRO, r_w, used to be only a few basis points above the marginal rate. By contrast, after August 2007, the MRO spread, $r_w - r_m$, increased up to 30 basis points, see Figure A.1. Large MRO spreads reveal that the bulk of bids had been submitted at relatively high rates. The related literature provides several explanations for this phenomenon. According to Nyborg and Strebulaev (2004) and Fecht et al. (2011), large MRO spreads might be the result of banks' precautionary liquidity acquisition in times of uncertainty about the future liquidity situation. Higher individual bids might also be a consequence of an adverse selection problem prevailing in the secondary money market, for reasons put forward by Heider et al. (2010). An increased MRO spread could also indicate that certain financial institutions face difficulties in seeking funding from alternative refinancing sources. In that case, banks would use the MROs as safe haven and submit more aggressive bids in order to make sure that they receive at least a minimum level of liquidity, see e.g. Cassola et al. (2009). Finally, according to Välimäki (2008), banks may also bid at higher rates because they are uncertain about the auction's marginal rate. For all these reasons, the MRO spread should provide information about the degree of tensions in the money market. Therefore, we expect that a large MRO spread leads to an upward pressure on money market rates.

The ***cover-to-bid ratio***, CBR, of an MRO is defined as the ratio between the Eurosystem's total allotment and the banks' total bid volume, compare Figure A.2. Large cover-to-bid ratios indicate that banks received a lot of refinancing relative to their bids. Note that this measure also captures the change in the liquidity-supply-demand pattern as of mid 2007. One might expect that overnight rates should always decrease with increasing cover-to-bid ratios. However, as Linzert et al. (2007) already emphasized, a low cover-to-bid ratio only leads to money market tensions if it resulted from banks' misperceptions of the marginal rate and the situation in the money market. If banks bid seriously and the marginal rate of the MRO simply exceeded banks' willingness to pay, a low cover-to-bid ratio will not necessarily lead to increasing overnight rates.

Until March 2004, banks anticipated future rate cuts of the Eurosystem on several occasions and, therefore, simply refrained from bidding. As a result, banks' total bid volume was so low that the Eurosystem could not allot the intended volume of reserves. Due to banks' underbidding, the cover-to-bid ratio peaked to one but due to the lack of reserves overnight rates increased sharply on the auction day. In order to stop the disturbing strategic bidding behavior of banks, the Eurosystem adjusted its operational framework in March 2004. Reducing the MRO maturity from two to one week and synchronizing its interest rate decisions with the reserve requirement periods ensured that auction results are not affected by banks' expectations about future policy rates, see e. g. European Central Bank (2003). To avoid that our results are driven by underbidding episodes, we exclude these observations from the following regressions and allow for a different information content of cover-to-bid ratios before and after March 2004.

The ***number of bidders*** in MROs has significantly declined since June 2000, see Figure A.3. Following e. g. Bindseil et al. (2009), we estimated the new information contained in the number of bidders, i. e. the unexpected part in this variable, employing a univariate forecast equation, see Section C in the Appendix. Note that alternative forecast and de-trending methods would not affect our results in a significant way. In case of a surprisingly large number of bidders which should reveal an unexpectedly high demand for refinancing, the overnight rate should increase.

Daily autonomous liquidity factors such as net foreign assets, banknotes, and government deposits are closely related to central bank activities, yet neither determined by the central bank's liquidity management nor by counterparties. However, as these transactions involve the same means of payment and central bank money, changes of these items have exactly the same liquidity-providing or liquidity-absorbing effect as monetary policy related transactions, see Bindseil et al. (2003). Since June 2000, the Eurosystem uses weekly autonomous factors forecasts to rationalize

its current allotment decision and to determine its benchmark allotment. If actual autonomous factors are higher than the Eurosystem's benchmark allotment calculation would suggest, the liquidity situation should be tight leading to tensions in the overnight rate, see Linzert and Schmidt (2011). Therefore, the difference between ***updated forecasts and forecasted autonomous factors***, ΔAF, should be included as a control variable in the empirical analysis of the link between MROs and the money market. The Eurosystem's forecast of autonomous factors is published around 3 p.m. CET on the day before the MRO auction is conducted, whereas the updated values are provided on the allotment day together with the MRO auction results, between 11:15 a.m. CET and 11:20 a.m. CET. Therefore, we would expect ΔAF to increase daily overnight rates.

Table 1: Expected Response of the Money Market Rates to MRO Auction Outcomes

Auction Outcome		Expected Response
Tender Spread	$(r_m - i_b)$	+
MRO Spread	$(r_w - r_m)$	+
Cover-to-Bid Ratio	(CBR)	–
# of Bidders	(B)	+
Δ Autonomous Factors	(AF)	+

Notes: This table summarizes the predicted response of money market interest rates to the unexpected part of an MRO auction outcome. + and − denote a positive and negative reaction, respectively.

3.2 The Econometric Specification

In accordance with the predictions of the martingale hypothesis, the empirical analysis of the information content of the Eurosystem's MRO auctions is based on the following error-correction type adjustment equation for the money market rate observed on the auction day:

$$\begin{aligned} \Delta i_t &= c + \alpha(r_m - i_b)_t + \beta(r_w - r_m)_t \\ &+ \gamma_C CBR_t + \gamma_B B_t + \gamma_A \Delta AF_t + \varepsilon_t, \end{aligned} \tag{1}$$

where for each auction t, $\Delta i_t = i_{a,t} - i_{b,t}$ denotes the change of the money market rate immediately after the MRO auction results have been published. Thus, all right-hand-side variables are predetermined as an outcome of the MRO auction. CBR and B denote the auction's cover to bid ratio and the unexpected part in the number of bidders, ΔAF controls for news concerning autonomous factors. According to Table 1, the expected signs of the coefficients are $\gamma_C < 0, \gamma_B > 0, \gamma_A > 0$.

The coefficients α and β determine the impact of the marginal (r_m) and the weighted average MRO rate (r_w) on the respective money market rate. In case of $\alpha \neq 0$ and $\beta = 0$, only the marginal rate bears new information for the money market while the weighted average rate plays no additional role. $\alpha = \beta \neq 0$ implies that $\alpha(r_m - i_b) + \alpha(r_w - r_m) = \alpha(r_w - i_b)$. In this case, the money market rate responds predominantly to the weighted average MRO rate. Since $r_w - r_m = (r_w - i_b) - (r_m - i_b)$, equation (1) could be re-parameterized in terms of $(r_m - i_b)$ and $(r_w - i_b)$. Therefore, $\alpha = 0$ implies that money market rates do neither respond to the level of the marginal nor to the level of the weighted average MRO rate. In the particular case of $\alpha = 0$ and $\beta \neq 0$, money market rates would only respond to the information contained in the MRO spread.

4 The Information Content of MRO Auctions: Empirical Results

4.1 The Response of Money Market Rates to MRO Auctions before the Financial Crisis

Table 2 shows the results estimated for the response of the Eonia to an MRO auction outcome. In the pre-crisis sample, the estimates indicate a significant and plausibly signed reaction of the Eonia to the newly announced main refinancing rates. Irrespective of the interest rate measure, $\widehat{\alpha} > 0$ implies an error-correction type level-relationship between the Eonia and MRO rates. Specifically, for the daily Eonia and intra-day overnight data, Wald tests cannot reject the null-hypothesis that $\alpha = \beta$. This suggests that the level of the Eonia and the overnight rate respond to the weighted average MRO rate, not to the marginal rate. For the one-week Eonia swap rates, the relevant information is contained in the marginal rate. In fact, the corresponding adjustment coefficient $\widehat{\alpha} = 0.8587$ is very close to one. Thus, in accordance with the martingale hypothesis, news about the marginal MRO rate strongly influence market's expectations about the Eonia of the following week. In line with the central role of MROs in the transmission process of monetary policy, the evidence in favor of an error-correction type adjustment of the Eonia confirms that MRO auctions governs the Eonia before the crisis.

The results obtained for the impact of the cover-to-bid ratio CBR are also in line with expectations. Before the introduction of the new operational framework in 2004, results concerning the significance and sign of the estimated CBR coefficients are mixed which reflects the distortions in the CBR implied by banks' strategic bidding behavior. After March 2004, the Eurosystem's reform apparently re-established the information content of CBRs about banks' liquidity situa-

tion. According to our estimates, an increase of the cover-to-bid ratio by ten percentage points decreases the Eonia by about 0.5 basis points.

Further plausible, yet less significant results are obtained for the number of bidders. For daily data, we estimate that an unexpected increase of the number of bidders by 100 would decrease the Eonia by about 3 basis points. The results obtained for ΔAF, the variable reflecting news about autonomous factors, are more puzzling. Although the Eurosystem has always been eager to estimate and publish its forecasts on autonomous factors on a regular basis, the evidence on the information content of this variable for the money market is rather weak.

4.2 The Response of Money Market Rates to the MRO Auctions during the Financial Crisis

In the next step we will investigate whether the information content of MRO auctions has changed during the crisis. The results obtained for the response of money market rates at an auction day during the crisis are shown in the right panel of Table 2. They differ from those obtained for the pre-crisis period in two important aspects. First, the estimates imply that there is no significant error-correction type adjustment of the Eonia to the level of the MRO rates in the crisis period, i. e. $\alpha = 0$ cannot be rejected. As a consequence, the level of MRO rates lost much of its former information content that we found for the pre-crisis period. Second, according to the large and significant estimates for β, the main information revealed by MRO auctions is now contained in the spread between the MRO rates $(r_w - r_m)$. Apparently, during the crisis, MRO spreads inflated by safety bids revealed new information about the prevailing tensions in the money market. This indicates that the MRO spread acted as a stress barometer which unfolded these liquidity frictions within the euro area's banking sector. In line with the martingale hypothesis, the strong response of the Eonia to the MRO spread suggests that banks knowledge about the situation in the money market was only imperfect. In other words, the observed MRO spread revealed information that allowed banks to adjust their expectations about market conditions accordingly.

The estimated adjustment equation of the Eonia further indicates a growing importance of the number of bidders and the refinancing volumes allotted in the MRO auctions. For example, an increase in the cover-to-bid ratio CBR by 10 percentage points would lower the Eonia by roughly 2.5 basis points. This suggests that the change of the Eurosystem's liquidity provision pattern within the maintenance period might have contributed to reduce Eonia rates during the crisis.

Table 2: The Money Market Response to an MRO Outcome

Money Market Response (Δi_t)

$$\Delta i_t = c + \alpha(r_m - i_b)_t + \beta(r_w - r_m)_t + \gamma_C CBR_t + \gamma_B B_t + \gamma_A \Delta AF_t + \epsilon_t$$

	Pre–Crisis: Dec 2000 - Aug 2007			Crisis: Aug 2007 - Jun 2008		
Auction Variables	Daily Eonia	Intra Day Data	1–Week Eonia Swap Rates	Daily Eonia	Intra Day Data	1–Week Eonia Swap Rates
$(r_m - i_b)$	0.5190^{***} [0.1301]	0.2655^{***} [0.0921]	0.8587^{***} [0.1209]	-0.0725 [0.0687]	0.0583 [0.0674]	-0.0050 [0.0795]
$(r_w - r_m)$	0.5166^{**} [0.2354]	0.2953^{*} [0.1539]	0.1467 [0.2295]	1.4565^{*} [0.8733]	1.9740^{***} [0.7260]	0.7891^{*} [0.4014]
Cover-to-Bid Ratio (CBR)						
before March 2004	0.0922^{***} [0.0318]	-0.0287^{**} [0.0119]	-0.0036 [0.0221]			
after March 2004	-0.0649^{**} [0.0295]	-0.0541^{**} [0.0223]	-0.0287 [0.0285]	-0.2359^{*} [0.1227]	-0.2523^{*} [0.1379]	-0.2395^{***} [0.0600]
Number of Bidders (B)	0.0003^{*} [0.0002]	0.0001 [0.0001]	0.0000 [0.0010]	0.0012^{***} [0.0003]	0.0005 [0.0003]	0.0034^{*} [0.0017]
Autonomous Factors (ΔAF)	0.0009^{**} [0.0004]	0.0002 [0.0003]	-0.0006^{***} [0.0002]	0.0015^{*} [0.0009]	0.0001 [0.0012]	-0.0002 [0.0007]
Obs.	282	282	282	33	33	33
R^2	0.58	0.45	0.65	0.72	0.41	0.40

Wald tests of parameter equality: $H_0 : \alpha = \beta$ vs $H_1 : \alpha \neq \beta$

p-value	0.98	0.82	0.00	0.08	0.01	0.05

Notes: ***,** ,* indicate significance at the 1%, 5%, 10% level. Newey-West HAC standard errors in parentheses. The index t denotes the number of the MROs covering the period December 2000 to June 2008.

4.3 MRO Auctions and Longer-Term Interest Rates during the Crisis

From the auction literature, it is well known that interest rate expectations affect the bidding behavior and, thereby, the results of MRO auctions. Yet, it is less clear whether the results of MRO auctions have an impact on the current interest rate expectations. In this section, we therefore investigate the response of longer-term money market rates to the results of MRO auctions. The focus of the following analysis relies on the crisis period since the Eurosystem was very reluctant to give strong signals about the policy-intended level of longer-term money market rates before the outbreak of the financial crisis.[7]

Table 3: The Longer-Term Money Market Response to an MRO Outcome during the Crisis

Response of longer-term money market rates (Δi_t)

$$\Delta i_t = c + \alpha(r_m - i_b)_t + \beta(r_w - r_m)_t + \gamma_C CBR_t + \gamma_B B_t + \gamma_A \Delta AF_t + \epsilon_t$$

	Crisis: Aug 2007 - Jun 2008			
Auction Variables	Eonia Swap Rates			
	1–Month	3–Month	6–Month	12–Month
$(r_m - i_b)$	-0.0050 [0.0400]	0.0582 [0.0460]	0.0570 [0.0528]	0.0425 [0.0426]
$(r_w - r_m)$	0.5848^{***} [0.1829]	0.6537^{**} [0.2589]	0.7844^{**} [0.3213]	1.3251^{**} [0.5366]
Cover-to-Bid Ratio (CBR)	-0.1341^{***} [0.0304]	-0.0868^{***} [0.00313]	-0.0669 [0.0570]	-0.1458^{*} [0.0866]
Number of Bidders (B)	0.0002^{**} [0.0001]	0.0003^{***} [0.0001]	0.0002^{*} [0.0001]	0.0005^{**} [0.0002]
Autonomous Factors (ΔAF)	0.0001 [0.0003]	0.0003 [0.0004]	0.0001 [0.0005]	-0.0002 [0.0008]
Obs.	33	33	33	33
R^2	0.53	0.35	0.21	0.25

Notes: For further explanations, see Table 2.

[7] For example, in contrast to its shorter-term MROs, the Eurosystem's longer-term refinancing operations (LTROs) have always been conducted as variable rate tenders without a pre-announced minimum bid rate that could have signalled a policy-intended level of longer-term interest rates, see Linzert et al. (2007). During the crisis, the expectations' management of the ECB via its longer-term refinancing operations has become much more explicit. In particular, from October 2008 onwards, both MROs and LTROs have been conducted as fixed rate tenders with full allotment. While the maturity of LTROs has been three month before the crisis, the Eurosystem additionally introduced LTROs with maturities of one, six and even twelve months during the crisis.

To that aim, we adopt the empirical approach of the previous sections and estimate the response of longer-term Eonia swap rates at an auction day to the variables characterizing the MRO auction outcome. The Eonia swap market is the most important derivative market segment in the euro area, see Durré (2006). Changes of the Eonia swap rate on the auction day should reflect the information content of the MRO outcome for market's expectations about future Eonia rates, see Taylor and Williams (2009).

For all maturities under consideration, the results obtained for the longer-term swap rates are very similar to those obtained for the Eonia, compare Table 2 and Table 3. As expected, $\alpha = 0$ suggests that longer-term money market rates react stronger to news about the future path of MRO rates and less to their current levels. More interestingly, however, and in line with our findings for the response of the Eonia rate, the coefficients of the MRO spreads $(r_w - r_m)$ are large, plausibly signed and highly significant. This may suggests that the market regarded the prevailing liquidity frictions revealed by the MRO spread as a longer-term issue rather than a transitory phenomenon.

4.4 MRO Auctions and the Volatility of Euribor Futures Rates during the Crisis

The significant response of longer-term Eonia swap rates to the increased MRO spreads of the crisis period showed that results of MRO auctions have an impact on market expectations about future short-term interest rates. In order to shed more light on this issue, this section investigates how the results of MRO auctions affect the degree of the prevailing interest rate uncertainty during the crisis period.

In order to measure interest rate uncertainty, we collected daily data of the implied volatility of option prices on Euribor futures from the NYSE Euronext database.[8] Option prices rely on the volatility of the underlying asset, i.e. on Euribor futures in our case. In the futures market, even tiny moves are tradable, which implies a very sensitive measure of interest rate expectations. Note that the volatility of Euribor futures is closely linked to the volatility of Euribor rates given the linear relationship between these two series at final settlement, i.e. $f = 100 - i$ where f denotes

[8] For more details, see www.euronext.com.

the Euribor futures contract.[9]

Following the empirical approach of the previous sections, we estimate how the options' implied volatility of the three month Euribor futures rate responds at an auction day to the new information revealed by the MRO auction. The results presented in Table 4 confirm the information content of the MRO spread during the crisis. Apparently, the increased MRO spreads during the crisis revealed the importance of safety bids and, thereby, affected the perceived uncertainty about the behavior of future interest rates.

Table 4: The Response of Implied Volatility to an MRO Outcome during the Crisis

Response of Options' Implied Volatility (ΔIV_t)

$$\Delta IV_t = c + \alpha(r_m - i_b) + \beta(r_w - r_m)_t + \gamma_C CBR_t + \gamma_B B_t + \gamma_A \Delta AF_t + \epsilon_t$$

	Crisis: Aug 2007 - Jun 2008
Auction Variables	Underlying Contract: 3–Month Euribor Futures
$(r_m - i_b)$	0.0239 [0.0404]
$(r_w - r_m)$	0.4830*** [0.1094]
Cover-to-Bid Ratio (CBR)	0.0226 [0.0169]
Number of Bidders (B)	0.0006 [0.0005]
Autonomous Factors (ΔAF)	0.0001 [0.0002]
Obs.	28
R^2	0.25

Notes: The three-month Euribor future is a commitment to engage in a three month loan or deposit. The delivery dates are settled at the third Wednesday of March, June, September, and December of each year. The last trading day of each futures contract, however, is two trading days prior to the respective settlement day. We have excluded these last trading days from our analysis which is why our observations are reduced to 28 from 33 MRO auctions. For further explanations, see Table 2.

[9]These contracts are traded at the London International Financial Futures Exchange (LIFFE) and account for over 90% of euro-denominated short-term interest rate trades with an average daily volume of roughly 1,000,000 contracts. The euro interbank offered rate (Euribor) is the standard reference rate for the unsecured longer-term money market and serves as the benchmark for the pricing of fixed-income securities throughout the economy. Moreover, short-term retail bank interest rates are priced in relation to the Euribor, and mortgage rates are often even indexed to it, see De Bondt et al. (2005). Therefore, the prevailing Euribor rate and the uncertainty about its future value play a key role for the monetary transmission process in the euro area.

5 Concluding Remarks

The main refinancing operations (MROs) of the Eurosystem constitute the very beginning of the monetary transmission process in the euro area. For the implementation of monetary policy, the impact of the MRO auctions on money market conditions is of particular importance. The current paper investigated how money market rates respond to new information revealed by an MRO auction outcome before and during the financial crisis.

Our results show that the financial crisis changed the information content of MRO auctions in two important ways. First, we find that the information contained in the levels of the MRO rates has significantly declined since the outbreak of the crisis in August 2007. The second change in the information content of MRO auctions concerns the role of the MRO spread, i. e. the difference between the weighted average and the marginal MRO rate. While MRO spreads have been virtually negligible before the crisis, they have been increasing sharply since the outbreak of the crisis. Our results indicate that the MRO spreads stirred by banks' safety bids acted as a stress barometer unfolding the actual tensions in the money market. This additional information about the actual situation in the money market did not only affect the behavior of current short-term money market rates. The significant response of longer-term Eonia swap rates and of the implied volatility of Euribor futures suggest that the market regarded the prevailing liquidity frictions revealed by the MRO spread as a longer-term problem rather than a transitory phenomenon.

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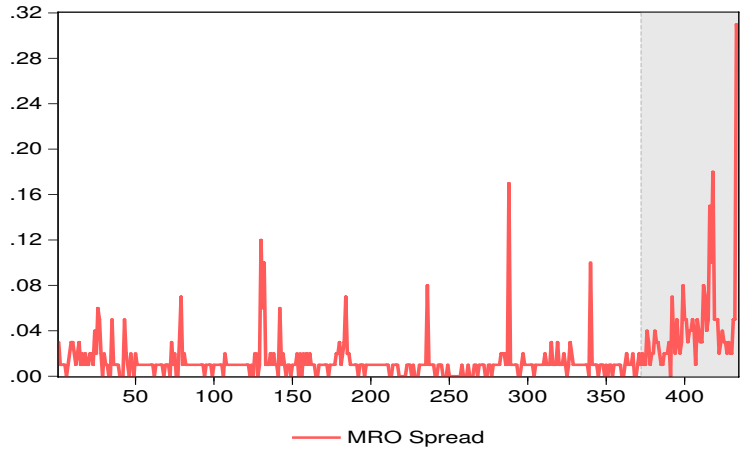
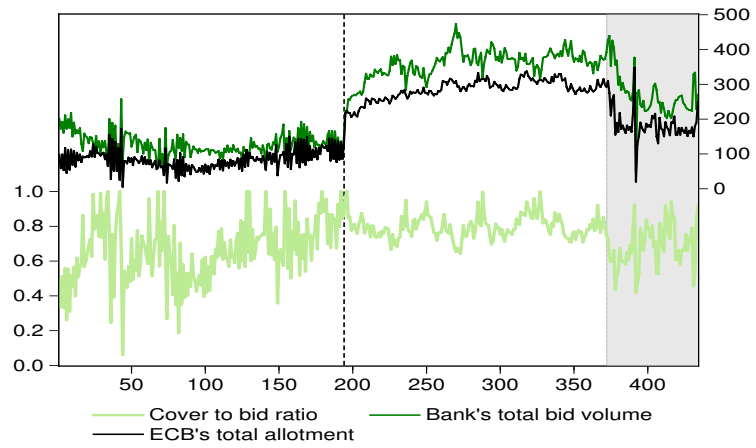
A Figures

Figure A.1: The spread between the MRO rates (in percent)



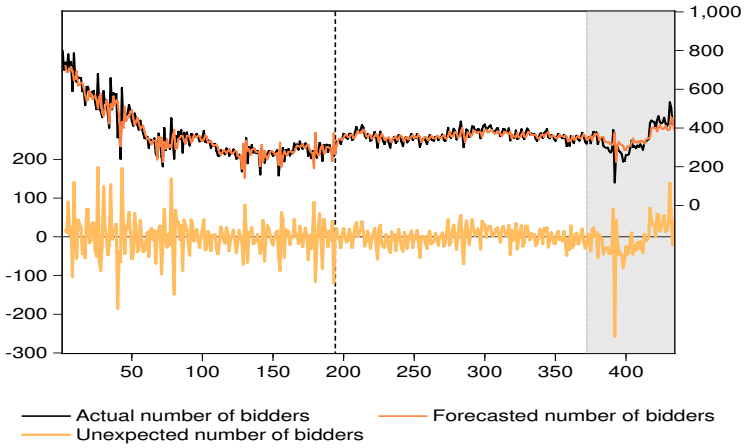
Notes: The MRO spread is defined as the difference between the weighted average and marginal MRO rate. Since the daily dataset has been pared down to the auction relevant days, the drawn data has *not* a daily frequency. The x-axis, therefore, refers to respective auction t. The light shaded area refers to the crisis period as of August 9, 2007.

Figure A.2: The MRO's cover-to-bid ratio



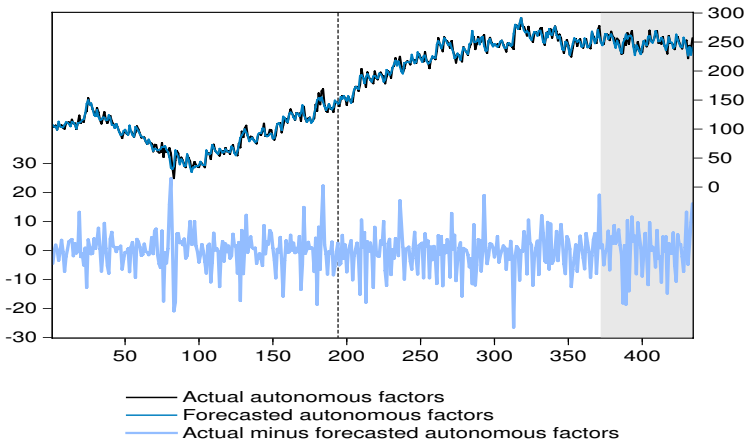
Notes: The aggregate bid volume and total allotment are in EUR billions. The black dashed line represents the introduction of the new operational framework as of March 2004. For further explanations, see Figure A.1.

Figure A.3: The number of bidders in MROs



Notes: For further explanations, see Figure A.1 and Figure A.2.

Figure A.4: Updated forecasts minus forecasted autonomous factors around MROs (in EUR billions)



Notes: For further explanations, see Figure A.1 and Figure A.2

B Structural Break Test

This section uses structural break tests to investigate whether the financial crisis had a significant impact on the relationship between the Eurosystem's MRO auctions and the money market. To that aim, the Quandt-Andrews test for unknown breakpoints is applied to the error-correction type adjustment equation of the Eonia, compare equation (1):

$$\begin{aligned}\Delta i_t &= c + \alpha(r_m - i_b)_t + \beta(r_w - r_m)_t \\ &+ \gamma_C CBR_t + \gamma_B B_t + \gamma_A \Delta AF_t + \varepsilon_t,\end{aligned}$$

We test whether there has been a break in the equation parameters c, α, β, γ_B, and γ_A for the full sample from June 27, 2000 to October 14, 2008.[10] The Quandt-Andrews test is based on standard F-statistics, see Andrews (1993). $Max\ F$ denotes the maximum of the individual *F*-statistics while the *Ave* statistic refers to their average. Since the break point is unknown, the asymptotic distribution of both test statistics are non standard and depend on the number of coefficients that are allowed to break and on the fraction of the sample that is examined.[11] Approximate asymptotic *p*-values are calculated following Hansen (1997).

Table B.1: Quandt-Andrews unknown breakpoint test

Statistic	Daily Eonia	Intra Day Data
Max F (08/09/2007)	19.06 [0.0556]	17.77 [0.0878]
Ave F	11.54 [0.0047]	13.22 [0.0012]

Notes: Estimated break date and approximate asymptotic *p*-values in line with Hansen (1997) in parenthesis. Test sample: June 27, 2000 to October 14, 2008 for daily Eonia and December 4, 2000 to June 17, 2008 for intra day data. Number of breaks compared: 318 and 284, respectively.

The results confirm that the role of MRO auctions for the money market has significantly changed since the start of the financial crisis. For both, daily and intra-day data, the $Max\ F$ statistics chooses the first MRO auction after the outbreak of the crisis as the main candidate for a significant break point.

[10] Note that we already accounted a structural change in the role of CBR stirred by the reform of the Eurosystem's operational framework as of March 2004. Therefore, we have excluded γ_C from the test.

[11] Note that the distributions become degenerate as the first period tested approaches the beginning of the equation sample, or the end period approaches the end of the equation sample. To compensate for this behavior it is generally suggested to exclude the end of the equation sample from the testing procedure. Following Andrews (1993), we apply a symmetric "trimming" of 5%.

C Forecast Equation of Number of Bidders

Following e.g. Bindseil et al. (2009) and Linzert et al. (2007), we estimate the unexpected part in the number of bidders by regressing the number of bidders (B_t) in the current auction *t* on the number of bidders in previous auctions. With respect to the changes in seasonality and maturity in the Eurosystem's operational framework as of March 2004, we estimate the forecast equations for each subperiod separately:

$$\begin{aligned} B_t^{OldFramework} &= \underset{(7.7)}{19.83} + \underset{(0.05)}{0.39}\, B_{t-1} + \underset{(0.05)}{0.52}\, B_{t-2} \\ &- \underset{(15.90)}{73.98}\, D_t^{Underbid} + \underset{(93.08)}{92.45}\, D_{t-1}^{Underbid} + \underset{(16.17)}{21.07}\, D_{t-2}^{Underbid}, \end{aligned} \tag{2}$$

with $R^2 = 0.86$ for the sample prior to March 2004 and

$$B_t^{NewFramework} = \underset{(27.54)}{101.61} + \underset{(0.08)}{0.72}\, B_{t-1}, \tag{3}$$

with $R^2 = 0.52$ after March 2004 until October 2008. Newey-West HAC standard errors are reported in parentheses. $D_t^{Underbid}$ is a dummy variable where $D_t^{Underbid} = 1$ captures the underbidding episodes that occurred in auction *t*.[12] The bi-weekly and weekly maturity of the MROs before and after March 2004, respectively, suggests the choice of the lag structure.

[12] The underbidding events refer to the MROs on 13 Feb, 10 Apr, 9 Oct and 6 Nov 2001, 3 Dec and 17 Dec 2002, 3 Mar, 3 Jun and 25 Nov 2003 and 20 Feb , see Bindseil (2004b).