EUROPEAN CENTRAL BANK

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NO 1052 / MAY 2009

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In 2009 all ECB publications feature a motif taken from the €200 banknote.

1 We thank Claus Brand, Philippe Moutot, Flemming Würtz and an anonymous referee for helpful comments and suggestions. The views expressed in this paper are those of the authors and do not necessarily reflect those of the ECB.

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ISSN 1725-2806 (online)

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Abstract

Liquidity provision through its repo auctions has been one of the main instruments of the European Central Bank (ECB) to address the recent tensions in financial markets since summer 2007. In this paper, we analyse banks' bidding behaviour in the ECB's main refinancing operations (MROs) during the ongoing turmoil in money and financial markets. We employ a unique data set comprising repo auctions from March 2004 to October 2008 with bidding data from 877 counterparties. We find that increased bid rates during the turmoil can be explained by, inter alia, the increased individual refinancing motive, the increased attractiveness of the ECB's tender operations due to its collateral framework and banks' bidding more aggressively, i.e. at higher rates to avoid being rationed at the marginal rate in times of increased liquidity uncertainty.

Keywords: Central Bank Auctions, Financial Market Turmoil, Panel Sample Selection Model, Bidding Behavior, Monetary Policy Instruments

JEL classification: E52, D44, C33, C34

Non-technical Summary

In August 2007, financial tension arising from investor's concerns about the quality of US subprime mortgages spilled over into financial and money markets around the world. As banks became concerned about their own liquidity position as well as the solvency of their trading partners, money markets experienced an enormous drain of liquidity. Subsequently, interbank market rates became more volatile and the spreads between secured and unsecured interbank rates at term maturities rose to historical highs posing a challenge to the smooth implementation and transmission of monetary policy. An important instrument of the European Central Bank (ECB) to tackle these tensions has been the liquidity provision through its refinancing operations. However, despite the significant changes to the overall liquidity provision, banks' bidding has become more aggressive and volatile during the turmoil, driving up substantially aggregate marginal tender rates in the ECB's refinancing operations.

In this paper, we analyse banks' bidding behaviour during the crisis period in the ECB's main refinancing operations (MROs). We are comparing banks' bidding with respect to their bid rates, i.e. the price banks are willing to pay for their liquidity, before and during the money market turmoil observed from August 2007 onward. We analyse the impact of collateral use, liquidity conditions related to the liquidity supply of the ECB and liquidity needs of the banking sector as well as the conditions in money market, such as the volatility in interest rates on banks' bid rates. Moreover, we investigate whether banks' bidding differs with respect to bank characteristics like its size or its access to certain type of ECB operations. For this, we employ a unique data set of individual bidding data of ECB's main refinancing operations (MROs) from March 2004 to October 2008, allowing us to compare banks' bidding behaviour prior and during the current financial market turmoil.

Our main results can be summarized as follows. We observe - on the one hand - that banks' motive to reduce their allotment uncertainty increases, i.e. banks want to avoid being rationed at the marginal rate placing bids well above the marginal rate. On the other hand, we observe that the number of bids below the marginal rate increases markedly. This may imply both, banks becoming more uncertain about the marginal rate, i.e. bidding less precise and banks bidding more opportunistically, i.e. bidding at rates that are ex-ante unlikely to be successful. Despite this, aggregate bid rates and

marginal tender rates increased during the turmoil, which we can attribute to a number of factors. First, with greater interest rate uncertainty banks wish to secure their funds, i.e. bid at higher rates to satisfy their individual refinancing needs. Second,we find strong evidence that the increased relative attractiveness of the Eurosystem's collateral framework has contributed to higher marginal tender rates. Third, banks bid at higher rates when uncertainty over the marginal rate and their liquidity needs increase.

1 Introduction

In August 2007, financial tension arising from investor's concerns about the quality of US subprime mortgages spilled over into financial and money markets around the world. In particular, interbank market rates became more volatile and the spreads between secured and unsecured interbank rates at term maturities became elevated by historical standards, posing a challenge to the smooth implementation and transmission of monetary policy. An important instrument of the European Central Bank (ECB) to tackle these tensions has been the liquidity provision through its refinancing operations. However, despite the significant changes to the overall liquidity provision, banks' bidding has become more aggressive and volatile during the turmoil, driving up substantially aggregate marginal tender rates in the ECB's refinancing operations.[1]

The main goal of this paper is to understand increasing banks' bid rates in the ECB's refinancing operations during the recent turmoil, which have introduced a considerable upward pressure on marginal tender rates. We, therefore, study banks' bidding behaviour during in the ECB's main refinancing operations (MROs), comparing banks' bidding with respect to their bid rates, i.e. the price banks are willing to pay for their liquidity, before and during the money market turmoil observed from August 2007 onward.[2] We analyse the impact of collateral use, liquidity conditions related to the liquidity supply of the ECB and liquidity needs of the banking sector as well as the conditions in money market, such as the volatility in interest rates on banks' bid rates. Moreover, we investigate whether banks' bidding differs with respect to bank characteristics like its size or its access to certain type of ECB operations.[3]

There are a few strands in the theoretical literature on auctions that may help to better understand the factors behind banks' increased aggressive bidding. First, according to the seminal contribution of Milgrom and Weber (1982), the valuation of the auction

[1] The term 'marginal tender rate' refers to the marginal stop out rate of the auction for central bank liquidity conducted by the ECB. 'Aggressiveness' in bidding refers to banks' bidding at increased bid rates to secure their funding.

[2] In this paper, the term bid rate is used for the individual bank specific bid volume weighted average bid rate. Hence, while a bank can bid at more than one bid rate, we only refer to a bank's weighted average bid rate. As the marginal rate in the ECB's MROs is an outcome of all individual bid rates, studying the driving forces and determinants of banks' bidding with respect to their bid rates will help to understand the sources behind the recently observed upward pressure on marginal tender rates.

[3] This in line with previous literature on banks' bidding behaviour, such as Bindseil, Nyborg, and Strebulaev (2004), Linzert, Nautz, and Breitung (2006), Linzert, Nautz, and Bindseil (2007), Craig and Fecht (2007), and Fecht, Nyborg, and Rocholl (2008).

good may play a crucial role for the bidder's willingness to pay. In the case of a common valuation, bidders try to hedge against the "winner's curse", i.e. the risk of paying a too high price, and therefore, shade their bids in reaction to increased uncertainty over the exact value of the auction good, see e.g. Gordy (1999) for evidence. If, however, bidders attach a strong private value to the auction good, bidders would bid more aggressively if the private value increases, see e.g. Hortacsu (2002). In fact Bindseil, Nyborg, and Strebulaev (2004) and Bruno, Ordine, and Scalia (2005) found only weak evidence in favor of the winner's curse effect in the ECB's MROs. It might appear that the demand for reserves in MROs is more closely related to the *known* liquidity needs of individual banks and thus influenced less by *uncertain* market conditions. In the current financial market turmoil both interest rate uncertainty and the liquidity needs of banks increased substantially. Therefore, banks' reaction to this heightened uncertainty will be informative for the specific valuation that banks attach to the auction good, namely central bank liquidity prior and during the financial market turmoil.

Second, more aggressive bidding may arise from bidders anticipating the possibility of a liquidity squeeze in the secondary market stemming, for example, from a lower than expected supply in the auction, see Nyborg and Strebulaev (2004) for details and Fecht, Nyborg, and Rocholl (2008) for evidence. We capture the possibility of banks being squeezed by looking at banks' response to changing money market conditions, the supply of liquidity in the secondary market and a measure for banks' liquidity uncertainty.

Third, Välimäki (2006) relates banks' allotment uncertainty to more aggressive bidding. Banks wish to secure their funds by bidding at higher rates to avoid rationing. According to Välimäki (2006), banks' aggressiveness in bidding increases the higher the degree of uncertainty regarding their allotment and the higher the overall liquidity needs of the banking sector. We can test these hypothesis by looking at banks' bidding in response to higher volatility in the allotment ratio and the overall volume of the MROs.

Fourth, the occurrence of financial tensions, according to Caballero and Krishnamurthy (2007) may lead to decreasing risk exposures, hoarding of liquidity, and locking-up capital reflecting a general flight to quality. For the behaviour of banks in

central bank auctions these effects should be particularly relevant for the specific use of collateral.

Our analysis is based on a unique data set of 236 main refinancing operation (MRO) auctions conducted between March 2004 and October 2008.[4] Bidder codes allow us to follow bidding behavior of each of the 877 banks over time and to apply panel econometric techniques. Following Bindseil, Nyborg, and Strebulaev (2004), Linzert, Nautz, and Breitung (2006) and Linzert, Nautz, and Bindseil (2007) we look at banks' bidding behaviour in terms of a bank's weighted average bid rate. Since a bank's average bid rate can only be observed if the bank actually participated in the MRO, estimation may be subject to a selection bias, see Heckman (1979). Therefore, we account for a bank's participation decision employing panel sample selection estimation techniques, which extent the cross sectional Heckman (1979) approach to the panel case.

Our main results can be summarized as follows. We observe - on the one hand - that banks' motive to reduce their allotment uncertainty increases, i.e. banks want to avoid being rationed at the marginal rate placing bids well above the marginal rate. On the other hand, we observe that the number of bids below the marginal rate increases markedly. This may imply both, banks becoming more uncertain about the marginal rate, i.e. bidding less precise and banks bidding more opportunistically, i.e. bidding at rates that are ex-ante unlikely to be successful. Despite this, aggregate bid and marginal tender rates increased during the turmoil, which we can explain by a number of factors. First, with greater interest rate uncertainty banks wish to secure their funds, i.e. bid at higher rates to satisfy their individual refinancing needs. Second, we find strong evidence that the increased relative attractiveness of the Eurosystem's collateral framework has contributed to higher marginal tender rates. Third, banks bid at higher rates when uncertainty over the marginal rate and their liquidity needs increase.

The paper is structured as follows. The next section gives a short introduction in the

[4] In March 2004 the ECB introduced changes to its operational framework: (i) a reduction in the MRO maturity from two weeks to one week; and (ii) changes of ECB key interest rates become only effective with the first MRO of a maintenance period. These changes ensured that expectations about future policy rates should not affect the determination of MRO rates, see ECB (2003) or Bindseil, Nyborg, and Strebulaev (2004) for details. In October 2008 the ECB changed its auction design to a fixed rate tender full allotment procedure which marks the natural endpoint of our sample.

practice of the ECB's conduct of monetary policy operations, particularly during the ongoing turmoil. Section 3 presents and discusses descriptive statics of the data, including statistics related to bidding strategies and bidding success. Section 4 presents the empirical evidence based on a panel econometric estimation. Section 5 concludes.

2 The ECB's Implementation of Monetary Policy and the Turmoil Period

Tender operations in the form of repurchase agreements are the predominant instrument for the implementation of monetary policy of the European Central Bank (ECB). Marginal tender rates govern short-term interest rates and the allotment of central bank liquidity determines the liquidity of the European banking sector. The ECB conducts its tender operations as weekly main refinancing operations (MRO) and as longer term refinancing operations (LTRO) maturing after three months. Occasionally, the ECB resorts to fine tuning operations (FTO) with a maturity of one day, mainly employed to steer the liquidity situation on the last day of a maintenance period.

Since June 2000, the ECB has conducted its MROs as a variable rate tender.[5] Banks submit bids in terms of a volume and a price (the bid rate), subject to a minimum bid rate set by the ECB. The auction is price discriminating, i.e. every successful bidder pays his bid. At the marginal rate, depending on the overall bid amount, bids may be rationed, allotting a pro rata amount to the marginal bidders of the remaining liquidity.

To calibrate the allotment volume in the weekly MROs, the ECB takes the sum of the expected outstanding autonomous factors (such as banknotes, government deposits and net foreign assets) and banks' reserve requirements. The allotment volume that satisfies exactly these liquidity needs of the banking sector is called the "benchmark allotment". An ECB forecast of the autonomous factors on which basis the benchmark allotment is calculated is published prior to the bidding of banks in the MRO and on the allotment day.

[5] From 1999 to June 2000, the MROs were conducted as fixed rate tenders in which banks simply bid the amount they wish to receive at a pre-determined rate set by the ECB. However, the fixed rate tender procedure has led to massive overbidding as banks increasingly exaggerated their demand for reserves, see Nautz and Oechssler (2003).

The outcome of the MRO, i.e. the liquidity supplied and the marginal rate of the operation play a crucial role for determining short term interest rates in the interbank market. In contrast, LTROs are always conducted as pure variable rate tenders, i.e. without a minimum bid rate. The ECB simply accepts the allotment rates resulting from its pre-announced supply of liquidity and the demand for LTROs submitted by the banks. Acting as a price-taker, the ECB does not use LTROs for signaling intended interest rate levels.

Liquidity policy in the recent turmoil

Since August 2007, the operational framework for the implementation of monetary policy has been subject to unprecedented challenges. With rising concerns about the quality of US subprime mortgages, investors became reluctant to hold or to further invest in subprime mortgage related products. Banks providing liquidity lines to these investors became concerned about their own liquidity position as well as the solvency of their trading partners. This led to an enormous liquidity drain in the money market accompanied by a high degree of uncertainty and distrust among counterparties in the interbank market, culminating in a drastic widening of the Euribor-OIS spreads after August 2007.

Central banks reacted immediately to the emerging tensions. On 9 August and the following days, the ECB provided overnight liquidity via a series of fine-tuning operations (FTOs). As the tensions persisted, the ECB provided further liquidity using FTOs, MROs and LTROs, hence making full use of the instruments given by the ECB's operational framework.

Up to October 2008, the main change in the ECB's liquidity policy had been a shift in the supply schedule of the MROs within the maintenance period. While in the pre-turmoil period liquidity provision in the MROs was governed by the calculated benchmark amount, in turmoil period more liquidity than formally needed was supplied early in the maintenance period (i.e. allotments substantially exceeded the benchmark amount) and then gradually reabsorbed throughout the maintenance period by deviating less from the benchmark when approaching the end of the maintenance period. This implied that the overall supply of liquidity throughout the maintenance period remained unchanged (compared to pre-turmoil times), but given banks' prefer-

ences to be less exposed to liquidity uncertainty towards the end of the maintenance period, this liquidity policy allowed banks to 'frontload' their liquidity needs at the beginning of the period.

In addition, relatively frequently absorbing (and occasionally) providing fine-tuning operations were conducted if the overnight rate deviated too far from the policy rate. Furthermore, the maturity structure of the outstanding open market operations was shifted in favour of longer term operations (so-called supplementary LTROs) at the expense of MROs. In July 2007, just before the turmoil, 30% of all outstanding operations were LTROs. This figure increased to 63% in September 2008, which is also evident in the declining allotment volumes in the MROs as shown in Figure 2.

In the wake of the intensified market tensions and volatility following the bankruptcy of Lehman Brothers, the ECB decided to change its auction procedure to fixed rate tender with full allotment for both, MROs and LTROs. The introduction of the new tender procedure was announced on 8 October 2008. Therefore, our sample ends with the MRO on 7 October.

3 Stylized Facts of Bidding Behaviour during the Turmoil Period

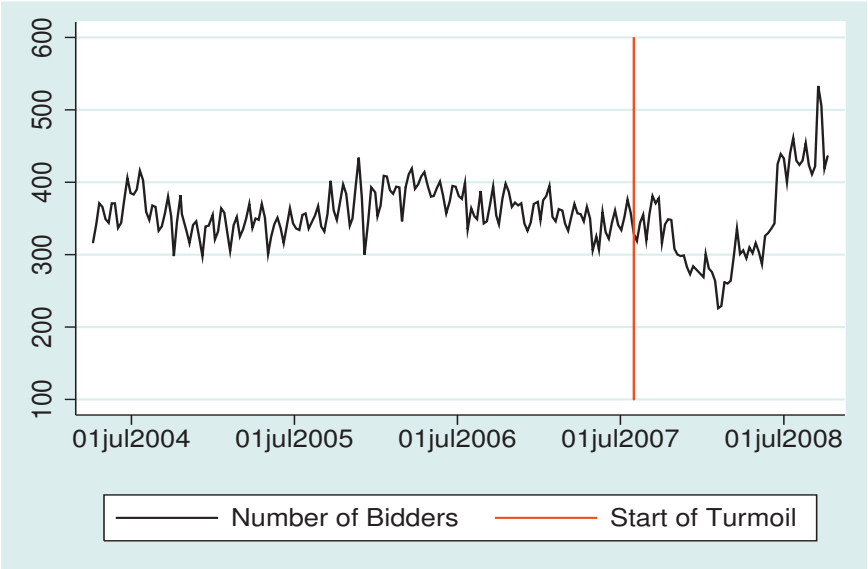
Our data set consists of individual bidding data of 236 main refinancing operations conducted between March 2004 and October 2008.[6] The turmoil period refers to the time period from August 2007 to October 2008. While over 6000 counterparties fulfil the general conditions to participate in ECB's refinancing operations, we restrict ourselves to 877 banks, which were participating in at least one MRO during 2006 and 2007.

3.1 Number of Bidders

With the beginning of the turmoil period the general downward trend in the number of bidders in the MROs observed since January 2006 accelerated further. However, starting from June 2008 a pronounced increase in the number of bidders participating

[6] Note that our data set originally consisted of 238 MROs. However, we omitted the exceptional two week fixed rate tender with full allotment conducted in the penultimate week of 2008 and the last MRO of the year overlapping with the previous MRO (and that accordingly had a negative benchmark and was very small in volume) from our data set.

Figure 1: Number of bidders in the MROs from March 2004 to October 2008



in MROs was observed. While the average number of bidders per MRO in the first half of 2007 has been around 350, this number has fallen slightly to an average of around 346 bidders during the turmoil period (see Figure 1) - however, with an average of 441 bidders per MRO auction for the period from June to October 2008.

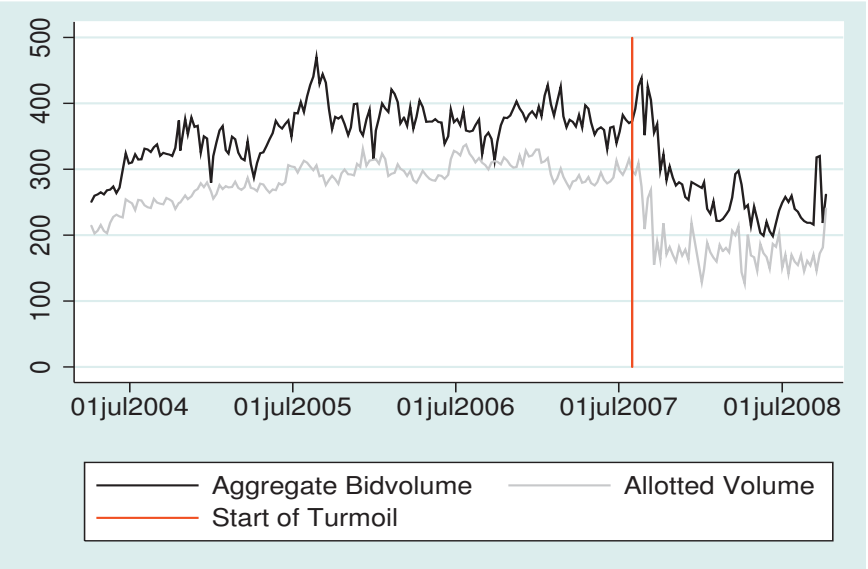
3.2 Allotment and Bid Volumes

Aggregate bid volumes and allotment volumes in the MROs declined during the financial market turmoil as a mechanic effect of the increased size of other liquidity providing operations, mainly supplementary LTROs, see Figure 2. At the same time, the aggregate bid volume relative to the allotment volume increased somewhat, which is evidenced in a slight drop in the aggregate cover-to-bid ratio over the turmoil period, see Figure 3.

3.3 Aggregate Bid Rate and EONIA

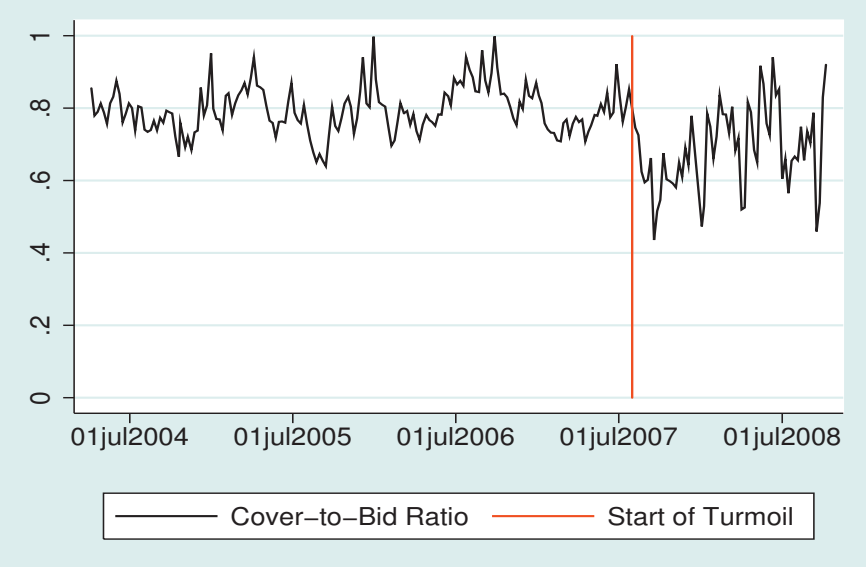
The spread between the average of the individual (volume weighted) average bid rates and the minimum bid rate has increased significantly, see Figure 4. While this spread had been 5.8 basis points in the pre-turmoil period, it increased to 17.6 basis points in the turmoil. Accordingly, the spread between the marginal rate and the minimum bid

Figure 2: Aggregate allotment volume and bid volume per tender



Notes: The aggregate allotment volume refers to the total allotment provided by the ECB in its weekly MROs, while the bid volume refers to the total bid volume received by the participating banks.

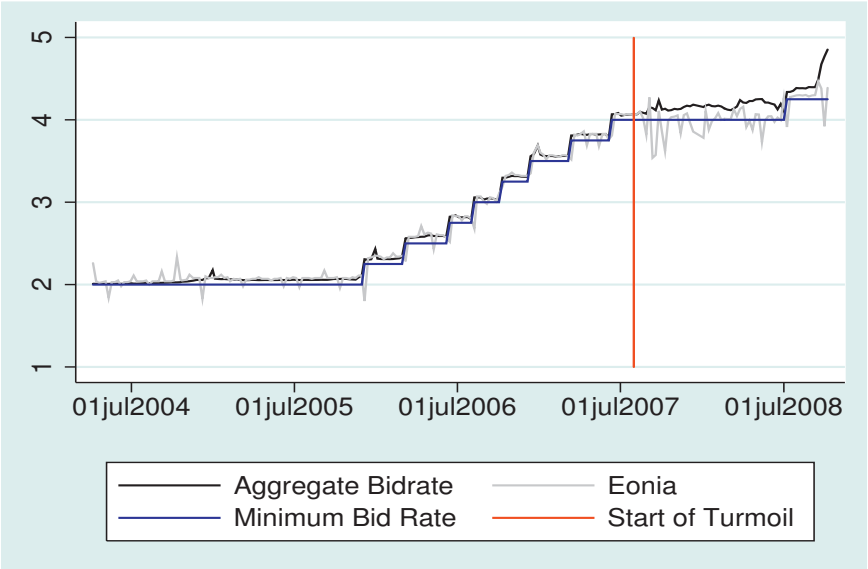
Figure 3: The aggregate cover-to-bid ratio



Notes: The aggregate cover-to-bid ratio is constructed as the ratio of the aggregate allotment volume and the respective total bid volume

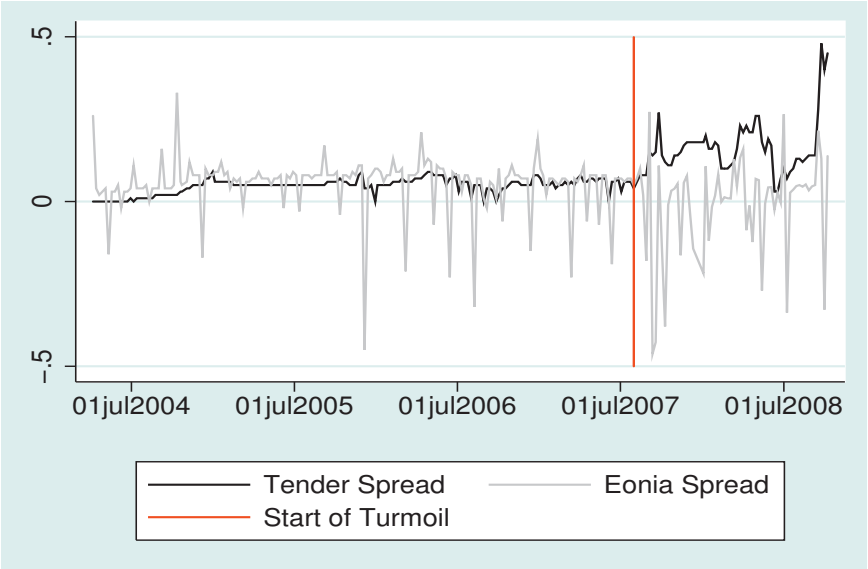
rate - the tender spread - increased substantially to 16 basis points from 5 basis points before the turmoil period, see Figure 5. Under "normal", i.e. pre-turmoil times, the marginal tender rate settles usually below the daily overnight rate, EONIA, except for end of maintenance period days. In the turmoil this relationship seems to have fundamentally changed as the marginal tender rate increased and remained well above

Figure 4: Aggregate bid rate, EONIA and minimum bid rate



Notes: The average bid rate is defined as the average of all bank bid volume weighted average bid rates.

Figure 5: Tender spread and EONIA spread

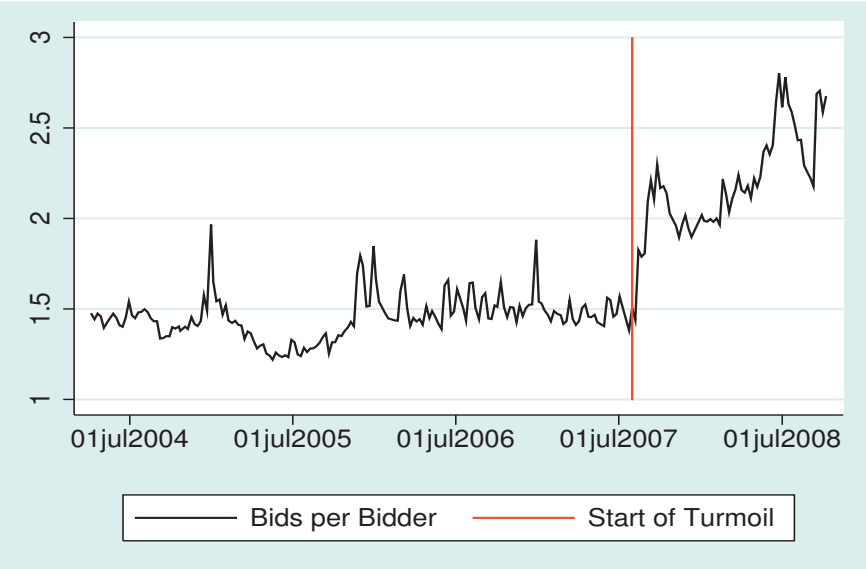


Notes: The tender spread refers to the spread of the marginal rate over the minimum bid rate. The EONIA spread is similarly defined as the spread of the EONIA (overnight rate) over the minimum bid rate

the EONIA. The EONIA spread declined from around 5 basis points (before the turmoil) to -1 basis point in the turmoil period, see Figure 5.[7]

[7] Note that the ECB aims to steer the overnight rate close to the minimum bid rate through its liquidity operations. This explains why the overnight rate spread - steered by the ECB's operations - may show different dynamics than the marginal rate of the MRO which reflects the prevailing willingness to pay of the banking sector for central bank liquidity.

Figure 6: Number of bids per bank



3.4 Bid Rate Dispersion and Number of Bids per Bank

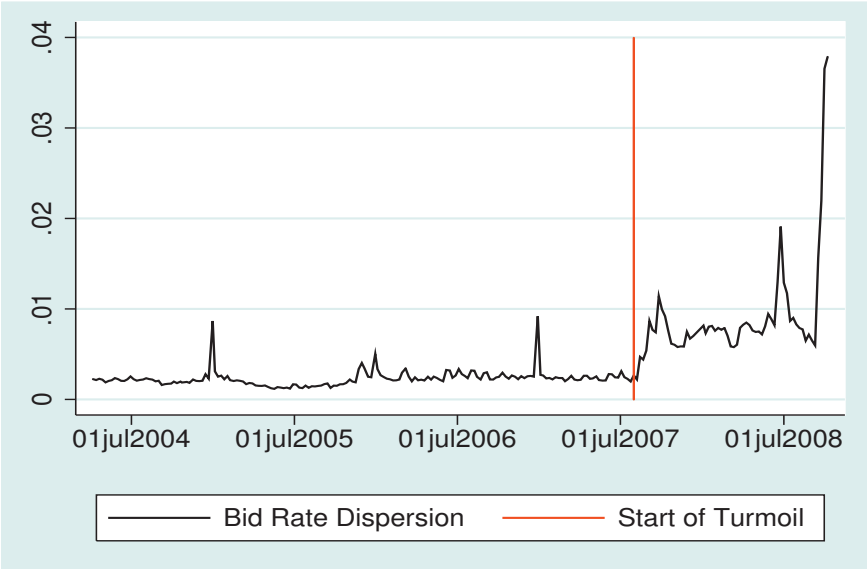
The average number of bids per bank increased considerably from 1.47 in the first half of 2007 to more than 2 in the turmoil period with an increasing trend, see Figure 6. Additionally, banks bid more disperse, i.e. place their bids on a wider range during the turmoil, see Figure 7.

3.5 Aggressive and Opportunistic Bidding

Figure 8 shows that the spread between the individual (volume weighted) average bid rates and the marginal rate increases significantly in the turmoil period. Bidders appear to bid more aggressively, i.e. ex post are willing to pay a considerable premium over the marginal rate. Conversersly, it is also true that an increasing share of bids lies consistently below the marginal rate, particularly compared to pre-turmoil times.

The fact of bids being significantly above *and* below the marginal rate is confirmed by the statistics presented in Table 1 and 2, showing the share of bidders grouped by their bid rate and their respective cover-to-bid ratio. Table 1 shows that - before the turmoil - the bulk of banks bid above the marginal rate (70.3%) accompanied by a high cover-to-bid ratio (average: 0.83) or full allotment. 19.6% of bidders have placed their bid directly at the marginal rate with an average cover-to-bid ratio of 0.71. Only a few

Figure 7: Aggregate bid rate dispersion

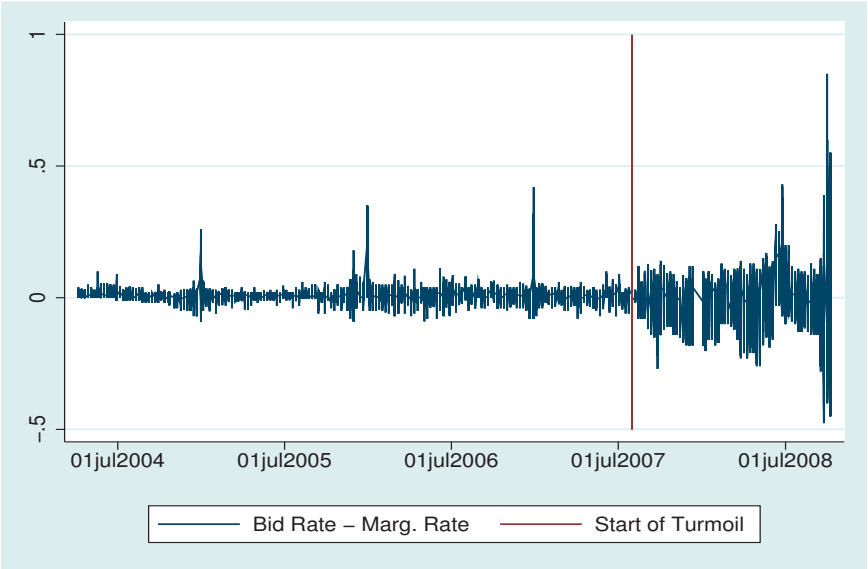


Notes: The aggregate bid rate dispersion refers to the average of all banks' volume weighted variances of their individual bids.

bidders that participated in the ECB's MROs bid below the marginal rate (10.1%). In contrast, as shown in Table 2, the share of bidders that bid below the marginal rate increases substantially in the turmoil (33.1%). Accordingly, bidding directly at the marginal rate (only 5.3%) and above the marginal rate (61.6% compared to 70.3% before the turmoil) declines.

Looking more closely at the bidders that were successful in the ECB's MROs a similar picture emerges. For this we look at banks' allotment rate, which is defined as the individual specific volume weighted bid rate of only the successful bids, i.e. bid rates at or above the marginal rate. The tables confirm that the share of bidders that bid (from an ex-post perspective) at the marginal rate declines significantly in the turmoil. More interestingly, before the turmoil most of the bidders place their bids up to one standard deviation (2.2 basis points) above the marginal rate, which in about two thirds of the cases yields the full allotment of their bid volume, see Table 3, Row 4. Only a small share of bidders bid aggressively, i.e. bidding more than one standard deviation higher than the marginal rate - in part related to the end of year effect on banks' bidding in 2004, 2005 and 2006 (around 2 basis points). During the turmoil the share of bidders that bid aggressively, i.e. more than one standard deviation (equivalent to almost 5 basis points) above the marginal rate increased significantly, see Table 4, Row 5. At the same time, there is an increase of the share of bidders that submit relatively high

Figure 8: Spread between banks' individual bid rates and the marginal rate



Notes: The chart shows the spread between banks' individual bid rates and the marginal rate. For illustration, observations above the zero line point to an average bid rate of a bank that was greater than the marginal rate, while observations below show an average bid rate below the marginal rate. The individual bid rate of a bank refers to the bid volume weighted average of all its individual bid rates.

Table 1: Bidder shares (in percentages) by bid rate and cover-to-bid ratio in the pre-turmoil period from March 2004 to August 2007

Pre-Turmoil	Cover/Bid=0	Cover/Bid $\in$ (0,1)	Cover/Bid=1
bid rate<marginal rate	3.3%	6.8%	0
bid rate=marginal rate	0	19.6%	0
bid rate>marginal rate	0	18.7%	51.6%

Notes: The table displays shares of bidders according to bidders' bid rates (i.e. the average volume weighted bid rate) in relation to the marginal rate. The table further distinguishes between a bank receiving zero allotment (cover/bid=0), some allotment (cover/bid $\in$ (0,1)) and full allotment (cover/bid=1).

Table 2: Bidder shares (in percentages) by bid rate and cover-to-bid ratio in the turmoil period from August 2007 to October 2008

Turmoil	Cover/Bid=0	Cover/Bid $\in$ (0,1)	Cover/Bid=1
bid rate<marginal rate	23.7%	9.4%	0
bid rate=marginal rate	0	5.3%	0
bid rate>marginal rate	0	13.3%	48.3%

Notes: The table displays shares of bidders according to bidders' bid rates (i.e. the average volume weighted bid rate) in relation to the marginal rate. The table further distinguishes between a bank receiving zero allotment (cover/bid=0), some allotment (cover/bid $\in$ (0,1)) and full allotment (cover/bid=1).

Table 3: Bidder shares by allotment rate (i.e. only successful bids) and cover-to-bid ratio in the pre-turmoil period from March 2004 to August 2007

Pre-Turmoil	Cover/Bid $\in$ (0,1)	Cover/Bid=1
allotment rate=marginal rate	26.2%	0
allotment rate>marginal rate	21.2%	52,6%
allotment rate>marginal rate (up to one stdev)	21.0%	45.4%
allotment rate>marginal rate (more than one stdev)	0.2%	7.2%

Notes: The table displays shares of bidders according to bidders' allotment rate, i.e. the average rate a bank is charges for their successful bids. The table further distinguishes between a bank receiving some allotment (cover/bid $\in$ (0,1)) or full allotment (cover/bid=1).

Table 4: Bidder shares by allotment rate (i.e. only successful bids) and cover-to-bid ratio in the turmoil period from August 2007 to October 2008

Turmoil	Cover/Bid $\in$ (0,1)	Cover/Bid=1
allotment rate=marginal rate	11.6%	0
allotment rate>marginal rate	25.1%	63,3%
allotment rate>marginal rate (up to one stdev)	23.6%	42.1%
allotment rate>marginal rate (more than one stdev)	5.0%	21.1%

Notes: The table displays shares of bidders according to bidders' allotment rate, i.e. the average rate a bank is charges for their successful bids. The table further distinguishes between a bank receiving some allotment (cover/bid $\in$ (0,1)) or full allotment (cover/bid=1).

bids, but nevertheless do not receive full allotment (up from 0.2% to 5% during the turmoil).

In general, these statistics point to bidders being affected differently by the turmoil. On the one hand, there seem to be bidders that are willing to pay a premium (in some cases a substantial premium) over the marginal rate to secure their liquidity. On the other hand, an increasing share leaves the auction empty handed bidding significantly below the marginal rate. This may be due to greater uncertainty about the marginal rate, through which some bidders miss the marginal rate when bidding and, as a consequence, falling in the close neighborhood below the marginal rate.[8] However, it may also be due to banks deliberately bidding at very low rates. These bidders place a bid at very low rates, which would give them liquidity only in the case of a very generous allotment by the ECB or a sudden "normalisation" of bid rates. A possible reason for such behaviour may be that these bidders have good access to interbank market liquidity, which - given the that the overnight rate has been during much of

[8] Note that during the turmoil the variability of the marginal rate (as measured by its standard deviation) doubled.

Table 5: Bidder performance by a bank's size

	Before the turmoil			Turmoil period		
Size group	Allotment rate spread	Cover/Bid	Cover/Bid (if successful)	Allotment rate spread	Cover/Bid	Cover/Bid (if successful)
Large	0.008	0.74	0.78	0.013	0.46	0.76
Medium	0.011	0.83	0.86	0.016	0.56	0.81
Small	0.014	0.88	0.91	0.023	0.69	0.86

Notes: The allotment rate spread refers to the spread between the allotment rate, i.e. the weighted average bid rate of the successful bids, over the minimum bid rate. The cover-to-bid ratios are calculated based on the total bid volume (Column 3 and 6) and the bid volume of only the successful bids (Column 4 and 7).

the turmoil period being rather close to the minimum bid rate - they receive at a much better price than in the ECB operations. Another reason may be that these bidders seek liquidity in the ECB auctions mainly to redistribute it to the market, i.e. are using economies of scale and act as a money market intermediary.[9] In any event, these bidders are to a much lesser degree reliant on receiving their funding from the ECB.

3.6 Bidder Performance by a Bank's Size

Table 5 provides information on the bidding performance and bidding strategies of banks grouped by their size (small, medium and large).[10] [11] In the pre-turmoil period, large banks bid the closest to the marginal rate, while small banks pay the highest premium over the marginal rate, see Table 5, Column 2. At the same time large banks also achieve a lower overall cover-to-bid ratio than small banks, accepting thereby to be rationed at the marginal rate more often than small banks. During the turmoil, banks' allotment rates, i.e. the weighted average rate of the successful bids, of all sizes increased. The biggest increase was observed for small banks (see Column 2 and 5). This may indicate that at least some of the small banks were hit severely by the turmoil

[9] This reasoning is also supported by the fact that big banks show the biggest separation into opportunistic and aggressive bidder, while at the same time big banks are more likely to be in an intermediation role.

[10] We group banks into three size groups according to their respective size of reserve requirements. Small banks are those with reserve requirements below EUR 10 Mio. Banks with reserve requirements ranging from EUR 10 Mio to EUR 100 Mio were grouped as medium banks and banks with reserve requirements greater than EUR 100 Mio. were classified as large banks.

[11] Note that we also looked at the performance indicators for the fine tuning counterparties and EONIA panel banks. We omit the tables for the sake of brevity but can be obtained on request.

as their premium over the marginal rate increased significantly. Alternatively, small banks could have found it more difficult to judge the market situation and, therefore, to predict the marginal rate during the turmoil. The fact that overall cover-to-bid ratios of large banks decreased the most indicates that some large banks were either rationed at the marginal rate or going out empty handed from the operation as a consequence of opportunistic bidding at very low rates that was more prevalent in this group of banks, see also Section 3.5.

4 Empirical Evidence

4.1 Estimation strategy

Since the bidder codes allow to follow the bidding behaviour of each of the 877 banks over time (236 MRO auctions), we are able to provide econometric evidence on the basis of panel econometric techniques. Following Bindseil, Nyborg, and Strebulaev (2004), Linzert, Nautz, and Breitung (2006) and Linzert, Nautz, and Bindseil (2007), we analyse banks' bidding behaviour in terms of the weighted average bid rate. Since a bank's bid rate can only be observed if the bank actually participated in the MRO, estimation may be subject to a selection bias, see Heckman (1979). Therefore, accounting for banks' participation decision, we employ a panel sample selection estimation a la Heckman (1979) to correct for a potential selection bias, see Jofre-Bonet and Pesendorfer (2003), Linzert, Nautz, and Bindseil (2004).

In a first step, a model on a bank's participation decision is estimated using a panel version of the standard probit model. In this model, the dependent variable y_{it} equals one if bank i participates in auction $t \in \{1, \ldots, N = 236\}$ and is zero otherwise:

$$Pr(y_{it} = 1|x_{it}) = \Phi(\beta' x_{it})$$

where x_{it} denotes the vector of explanatory variables introduced in the previous section and β the corresponding coefficients. $\Phi(\cdot)$ is the standard normal distribution function. In a second step, we estimate a random effects panel regression model for the censored dependent variable, in which we include the inverse Mills ratio (obtained from the first step regression) to correct for the selection bias.[12] Note that the inverse Mills ratio has

[12] The choice of a random effects model was generally confirmed by a standard Hausman test. The Hausman test indicated that the hypothesis of the individual effects being uncorrelated with the other regressors could not be rejected.

been highly significant throughout all regressions giving indication for the presence of a selection bias.

4.2 What We Want to Explain and How

In this paper our main focus is on the determinants of banks' bid rates to explain the sources behind elevated marginal tender rates during the turmoil period. Recall that the spread of the average bid rate of all banks over the minimum bid rate increased from 5.7 basis points before the turmoil to 16.4 basis points, on average, during the turmoil. Therefore, in the following, we present results from a panel random effect regression explaining the determinants of banks' bid rates as measured as the spread between average volume weighted individual bid rate and the minimum bid rate (i.e. the policy rate) as dependent variable. In our regression, we explain an individual bank's bid rate (as the spread over the minimum bid rate) using a set of bank and auction specific characteristics as well as variables characterizing money market conditions. In the following, the explanatory variables are introduced in more detail.

Individual bank characteristics and bank specific variables

Bank Size: As documented by earlier studies on bidding behaviour, the size of a bank is associated with its liquidity needs and also with its sophistication in bidding, see e.g. Bindseil, Nyborg, and Strebulaev (2004). We group banks into three size groups according to their respective size of reserve requirements. Small banks are those with reserve requirements below EUR 10 Mio. Banks with reserve requirements ranging from EUR 10 Mio to EUR 100 Mio were grouped as medium banks and banks with reserve requirements greater than EUR 100 Mio. were classified as large banks.

Fine tuning counterparty: We include a dummy variable for a bank belonging to the group of banks that are eligible for the ECB's fine tuning operations. While more than 6000 banks are eligible to participate in the MROs, only around 120 banks are eligible for bidding in the fine tuning operations. These banks are usually very active in the money market and play an important role in their respective home markets.

EONIA panel bank: EONIA panel banks are generally to be considered as very active in the interbank market. We include a dummy variable for a bank belonging to the panel of banks whose data is used for the calculation of the daily EONIA rate.

Size of maturing allotment: The variable *maturing allotment* is defined as the log of a bank's allotment received in previous week's MRO. This variable aims to capture the fact that banks often use the weekly MRO liquidity on a revolving basis and simply simply roll over their outstanding balances with the central bank.

Success in prior LTRO: To investigate the relationship between alternative refinancing opportunities, namely the use of MROs and LTROs, we include a variable indicating a successful allotment in the LTRO prior to an MRO (measured as the the log of the allotment the bank received in the LTRO preceding the MRO). In case banks see refinancing in LTROs as a substitute for MRO refinancing, banks should bid significantly different in the following MRO if successful in an LTRO.

Opt out: We try to differentiate between banks missing an auction unintentionally and those that place their bids consistently below the (expected) marginal rate, a phenomenon that - according to our descriptive statistics - has prevailed during the financial turmoil. To that end we construct a dummy variable which takes the value one if the bank did not obtain any allotment at the last auction although it participated and zero otherwise.

Auction characteristics

MRO size: According to Välimäki (2006), the size of an MRO is related to a banks' allotment uncertainty. In his model, banks' risk aversion related to their allotment uncertainty arises from banks facing convex costs when actual allotment deviates from desired allotment. Therefore the marginal cost of receiving no liquidity in the auction is likely to increase in the size of the banks' refinancing volume which triggers that banks bid at higher rates to avoid being rationed. In order to investigate whether banks bid at higher rates when the MRO volume increases we incorporate the variable *MRO size* that equals the log of the benchmark volume, which is known to the banks prior to the MRO.[13]

Expected size of outstanding LTRO volume during the MRO week: The ECB provides liquidity to the market via its MROs, LTROs and FTOs. If banks view the liquidity provision via the various operations as completely substitutable,

[13] The ECB publishes its autonomous factor forecast for the allotment of the MRO prior to the bidding of banks, see Section 2.

changing the shares of the various instruments in total refinancing should not matter for banks' bidding behaviour. If, however, banks prefer bidding in, say the MRO, increasing the volume of the LTROs at the expense of MRO volume may increase the competition among banks for the weekly MRO liquidity potentially resulting in higher bid rates. We measure this possible effect by the log of the LTRO volume (including supplementary LTROs introduced with the beginning of the financial market crisis) outstanding during the week if the MRO tender. Since the size of the LTRO is normally pre-announced, this measure is equal to the expected size of the outstanding LTRO volume.

Allotment uncertainty: Banks may wish to secure their funds by bidding at higher rates to avoid rationing. According to Välimäki (2006), banks' aggressiveness in bidding increases the higher the degree of uncertainty regarding their allotment and the higher the overall liquidity needs of the banking sector. We measure banks' perceived uncertainty over their allotment at the marginal rate of the forthcoming auction as the volatility of the percentage allotment ratio at the marginal rate (estimated by an GARCH (1,1) model). This variable may also relate to banks' fears of a liquidity squeeze in the secondary market arising, for example, from a lower than expected supply in the auction, see Nyborg and Strebulaev (2004).

End of maintenance period: At the end of the maintenance period reserve requirements become binding, which may induce somewhat higher pressure on banks to receive liquidity in the last auction of the maintenance period. This also entails a higher probability for a liquidity squeeze, see Nyborg and Strebulaev (2004). We include a dummy variable for the end of the maintenance period to account for this effect. Similarly, we include a dummy for the **end of quarter** and **end of the year** which are usually accompanied by higher volatility in interest rates.

Money Market Conditions

Collateral premium: The costs of collateral should be of particular importance for banks' bidding since MRO refinancing blocks collateral and makes it thus unavailable for alternative uses over a three-month horizon. Unfortunately, there is no exact and consistent measure of MRO collateral cost available. We, therefore, define the variable *collateral premium* as the spread between the (US) one week repo rates for treasury

bonds to those for mortgage backed securities as an instrument. This spread measures the opportunity cost of collateral used in the MROs and hence may reflect the relative attractiveness of the ECB tender operations vis-a-vis the interbank market. Therefore, an increase in cost of collateral related, for example, to flight to quality effects as studied in Caballero and Krishnamurthy (2007) might induce banks to increase their willingness to pay in the MROs.

1 week swap spread: Banks' willingness to pay in the MRO should be affected by banks' expectation on future overnight rates. Therefore, we include the spread of the 1 week swap rate over the minimum bid rate as a measure of banks' expectations of the overnight rate over the maturity of the 1 week MRO. If market interest expectations are high, this would naturally lead to a higher willingness to pay in the MROs.

Volatility of the EONIA swap rate: The interest rate uncertainty perceived at the auction day is proxied by the volatility of the EONIA rate which is estimated by a rolling 5-day average of an GARCH (1,1) model for daily observations of the 1 week EONIA swap rate. Regarding the impact of uncertainty on banks' bidding, the implications of auction theory are generally ambiguous. On the one hand, there is the well-known winner's curse effect implying that banks bid more cautious when uncertainty increases, see e.g. Milgrom and Weber (1982). With increasing uncertainty, banks should mitigate the exposure to winner's curse by bidding at lower rates, reducing the quantity demanded and increasing the bid rate dispersion. On the other hand, higher uncertainty may also lead to higher bid rates and bid volumes if banks' concern is rather to go out empty handed, see Bindseil, Nyborg, and Strebulaev (2004) and Bruno, Ordine, and Scalia (2005). In this case, higher uncertainty induces bidders to submit larger bids at higher rates.[14]

EONIA market volume: Higher volumes in the interbank market may be seen as increased liquidity needs of banks which in turn may be associated with increasing demand pressure and hence higher bid rates in the MRO operations. To investigate such possible interaction between refinancing via the interbank market and via the refinancing operations of the ECB, we include the logged turnover of EONIA panel banks the day before the MRO allotment as a proxy for the activity in the interbank market.

[14] This bidding behavior would also be in line with the predictions of multi-period reserve management models, where higher interest rate risk increases banks' demand for reserves, see Nautz (1998).

The estimations are conducted on a sample from March 2004 to October 2008, while the turmoil period refers to the period from August 2007 to October 2008. Therefore, we account for the turmoil period by including a respective dummy variable from August 2007 onwards, but also allowing this dummy to interact with all the explanatory variables in the model.[15] Table 6 shows the results of our regression, which are discussed in the following section.

4.3 Regression Results

4.3.1 The Impact of Individual Bank Characteristics

Medium **sized** and even more so large banks bid at significantly lower rates compared to small banks during the turmoil. E.g. large banks bid on average 3 basis points lower than small banks, compared to 0.4 basis points prior to the turmoil.[16] Similarly, **counterparties eligible for fine-tuning** operations bid at lower rates during the turmoil than banks that are not eligible to fine tuning. In contrast, while **EONIA-panel banks** do not bid significantly different under normal times, during the turmoil EONIA panel banks bid at significantly higher rates than non-panel banks (by 0.8 basis points).[17] This may indicate that at least some of these banks were seeking aggressively liquidity during the turmoil.

Confirming our descriptive statistics, the results show that bidders that participated in the previous auction with zero allotment bid at lower rates in the following auction and thereby (most likely) remaining in the group of the non-successful bidders. Therefore, it appears that a few banks essentially **opt out** from the operations, even though they are still participating.

A **bank's success in the last LTRO operation** has only a negligible impact on

[15] We did not conduct any formal structural break test to justify this modelling strategy. However, given the significant changes in the time series presented in Section 3 since August 2007 and given the significance of the turmoil dummy and all its interactions in our regressions, we believe that this is sufficient evidence for a structural break in the bidding behaviour of banks starting with the turmoil in August 2007.

[16] This is consistent with findings by Fecht, Nyborg, and Rocholl (2008) who show using German data that large banks pay less for liquidity than small banks. Moreover, they show that smaller banks are more vulnerable to liquidity squeezes, hence paying a higher price for their liquidity. The authors conjecture that this relates to small banks having less good access to the interbank market than larger banks.

[17] Since EONIA banks are in their majority big banks, we checked robustness of these findings by running the regressions with and without the EONIA panel variable and with and without bank size, which did preserve the qualitative findings.

Table 6: Estimation results with a bank's bid rate as dependent variable

Variables	Pre-turmoil	Turmoil
Bank specific, time constant characteristics		
Eonia-panel bank	-0.0041*	0.0075**
Fine-tuning counterparty	-0.0052**	-0.0119**
Medium sized bank	-0.0034**	-0.0162**
Large bank	-0.0044**	-0.0259**
Auction specific financial market conditions		
Collateral premium	0.0014	0.0433**
Eoniavolume	0.0030**	-0.0787**
Swap spread	0.6073**	-0.115**
Volatility of 1 week Eonia swap	0.0006	0.0031**
Auction specific characteristics		
Last MRO of MP	0.0077**	-0.0122**
Benchmark amount	0.0325**	-0.0473**
Expected outstanding LTRO	0.0282	0.1508**
Garch percentage allotment rate	0.0027	0.0324**
Auction and bank specifc characteristics		
Maturing allotment	0.0028**	0.0061**
Allotment amount in preceeding LTRO	-0.0004*	-0.0016**
Optout behaviour	-0.0030*	-0.0413**
End of year	0.1092**	0.1092**
End of quarter	-0.0078**	0.1161**

Notes: Results were obtained from a random effects panel regression which includes the inverse Mills ratio (obtained from a panel Probit regression) to correct for selection bias. The turmoil period is accounted for by including a respective dummy variable from August 2007 onwards, but also allowing this dummy variable to interact with all the explanatory variables in the model. The second column is the sum of the two coefficients (pre-turmoil and turmoil) in the case the interaction coefficient turned out significant. * denotes significance on the 10% level, while ** denotes significance on a 5% level or smaller. A bank's bid rate refers to the spread between the average volume weighted bank specific bid rate and minimum bid rate. The estimation is conducted over a sample of 236 MROs.

its bidding in the following MRO in pre-turmoil times. During the turmoil this effect slightly increased with banks bidding at somewhat lower rates in the MRO if they had been successful in the LTRO just prior to that MRO. This may be seen as evidence for a close relationship between LTROs and MROs in times of financial distress in the sense that bidding success in the LTRO may have relaxed some demand pressure of individual banks in the MROs.

The **size of the maturing allotment** has a positive impact on bid rates in both the pre-turmoil and the turmoil period, though a much stronger one in the turmoil period. This suggests that the need to renew the obtained liquidity becomes stronger

in the turmoil period.

4.3.2 Potential Factors Explaining the Upward Pressure on Bid Rates

During the turmoil the **collateral premium**, for which we use the spread of (US) one week repo rates for treasury bonds over those for mortgage backed securities as an instrument, exhibits a significantly positive impact on individual bid rates. According to the regression results, a one percentage point increase in the collateral premium increases banks' bid rates by 0.04 basis points. Since this premium increases substantially during the turmoil, this may explain a large part of the overall increase in bid rates. This shows that with the significant decrease in market prices for ABS collateral, the ECB's operations became relatively more attractive vis-à-vis the refinancing via the interbank market. This seems also in line with results on the behaviour of German banks by Craig and Fecht (2007), who find more aggressive bidding by banks in response to increased risk premia in the interbank market.

The overall **size of the MRO** potentially affects banks' bid rates in two ways: On the one hand, the size of the MRO (as measured by the benchmark) has a positive effect on bid rates before the turmoil. In fact, in pre-turmoil times, higher MRO volumes have been associated with increased operational risks and increased costs of foregone allotment which induces banks to bid at higher rates to secure their funds, see Välimäki (2006). On the other hand, falling MRO volumes in the turmoil period can be associated with upward pressure on banks' bid rates. This may be due to various reasons. First, the increasing volume of the LTROs (via supplementary LTROs) at the expense of MRO volume may have increased the competition among banks for the weekly liquidity resulting in higher bid rates.[18] Second, the higher prices for 3-month liquidity observed in the LTROs may have spilled over into the MROs as banks preferred not to resort to seek 3-month liquidity and instead retaining some flexibility with regard to their liquidity needs.

This effect is confirmed by the variable **expected LTRO** which shows that increasing the amount of 3-month liquidity had a positive impact on bid rates in the turmoil period. It seems to confirm that substitutability between the different types of funds

[18] This is supported by the fact that the number of LTRO participants remained rather constant (even though increasing in relative terms as the number of MRO participants has fallen slightly) can be seen as additional evidence for the reluctance of some banks to increasingly resort to LTROs as a source of refinancing.

(through MROs and LTROs) seems to be limited, especially during times of money market stress, when intermediation is severely hampered and maturity transformation in the interbank market cannot (or only at very high premia) be obtained.

With regard to banks' **liquidity uncertainty**, we can confirm the theoretical predictions of Välimäki (2006), whereby banks bid at higher rates, the more uncertain they are regarding their allotment. In fact, we find that banks bid at significantly higher bids if the uncertainty with regard their allotment volumes at the marginal rate increases. This may also be related to banks' fear of being squeezed in the secondary market, see Nyborg and Strebulaev (2004).

Similarly **interest rate volatility**, as measured by the volatility of the 1 week EONIA swap rate, has a positive impact on bid rates which becomes much stronger during the turmoil. This can be seen as evidence for banks attaching a strong private value to the auction good, i.e. central bank liquidity in form of reserves during the market turmoil.[19] If banks attach a higher private value to the obtained liquidity from the central bank, i.e. banks bid for liquidity for the sake of satisfying a specific liquidity need instead of trading this liquidity in the interbank markets, then bid rates rise with increased interest rate uncertainty as banks wish to secure their funds and avoid going out empty handed from the auction. It appears that this fear increases during the turmoil inducing banks to bid at higher rates.

While before the turmoil the **aggregate volume of EONIA transactions** had only a negligible impact on banks' bid rates, decreasing volumes in the EONIA market as observed during the turmoil are associated with higher bid rates during the turmoil. This may be interpreted as evidence of a hampered intermediation function of the money market during the turmoil period.

5 Conclusion

In this paper, we analysed a unique data set of individual bidding data of ECB's main refinancing operations (MROs) from March 2004 to October 2008, allowing us to compare banks' bidding behaviour prior and during the current financial market turmoil.

[19] See also Bindseil, Nyborg, and Strebulaev (2004), Bruno, Ordine, and Scalia (2005), Linzert, Nautz, and Breitung (2006), and Craig and Fecht (2007) for pre-turmoil evidence.

Overall, we observe that banks place bids well above the marginal rate to avoid being rationed. However, interestingly, we equally observe that the number of banks that places their bids below the marginal rate, hence leaving the auction unsuccessful, increased markedly during the turmoil. We interpret this finding that the turmoil seems to have accentuated differences in bidding strategies. On the one hand, there are bidders that essentially "opt out" from the operation, bidding opportunistically at low rates, and hence leaving the auction empty handed. Such banks could be either seen as cash rich or as still being able to acquire sufficient funds at reasonable prices in the interbank market.[20] On the other hand, there are bidders that bid at significantly higher rates driving up overall marginal tender rates. This general increase in bid rates in the turmoil we can explain by various factors:

First, faced with greater interest rate uncertainty, banks wish to secure their funds, i.e. to avoid going out empty handed from the operation by bidding at higher rates. This suggests that the valuation of the auction good as argued by Milgrom and Weber (1982) plays a crucial role. In the case of banks' bidding during the turmoil, the motive to secure funds due to idiosyncratic liquidity needs becomes stronger, while at the same time the distribution motive and hence the common value becomes weaker.

Second, we find support for the Nyborg and Strebulaev (2004) liquidity squeeze. Banks seem to be afraid of being squeezed in the secondary market (characterized by significantly lower volumes during the turmoil) securing their funds in the ECB's operations bidding at higher bid rates.

Third, we confirm the notion of Välimäki (2006) that banks bid at higher rates once exposed to greater uncertainty about their allotment volume. Indeed the more volatile the marginal allotment, the more banks are willing to pay for securing their allotment.

Fourth, the market tensions in ABS repo markets may explain a significant increase in banks' bid rates. This can be explained by the fact that the significant decrease in market prices for ABS collateral increased the relative attractiveness of the Eurosystem's collateral framework vis-à-vis the alternative of refinancing via the interbank market.

Fifth, while the overall evaluation of liquidity policy seems difficult, the additional

[20] Note, though that some of the bids falling below the marginal rate may also stem from banks that bid less precise when becoming more uncertain about the marginal rate.

LTROs - at the expense of the MRO volumes - may have contributed to higher pressure on MRO tender rates. This may stem from the potential reluctance of banks to substitute a more "common" source refinancing such as the MROs for a less used instrument like the LTROs in times of increased money market tensions. This reluctance becomes particularly relevant if the intermediation function of the money market is hampered.

Finally, we identify significant differences in bidding behaviour by certain bank characteristics. For example, large banks bid at much lower rates than small and medium sized banks during the turmoil. This may be explained by large banks preserving their usual bidding advantage over small and medium sized banks in the turmoil, on the one hand and large banks engaging into more opportunistic bidding, i.e. spreading their bids more widely, on the other hand.

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