Strategic Bidding in ECB Refinancing Operations*

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Abstract

Using individual data from the Eurosystem's liquidity providing tenders for the pre-crisis period we investigate banks' joint bidding behaviour in Main Refinancing Operation (MRO) and Longer Term Refinancing Operations (LTRO) where we specifically focus on the role of timing and position of MROs relative to the LTRO.

We have three main findings. First, banks bid differently in operations immediately before and after an LTRO. More specifically, in MROs before (after) the LTRO banks bid at relatively low (high) rates. The differences in average bid rates of MROs before and after an LTRO are due to banks bidding in only those operations and not to frequent bidders. Second, banks which bid in the LTRO bid in general at lower rates compared to peers. They also bid for larger amounts and bid more frequently in the MROs prior to the LTRO. We provide some evidence that banks bidding in the LTRO bid at lower rates in the MRO immediately preceding the LTRO. Third, banks bidding in the LTRO follow a more persistent bidding strategy and are less likely to drop out from a sequence of operations. Although bank size plays a considerable role for the determination of bidding behaviour, these patterns apply across all groups.

Keywords: repo auctions, open market operations, strategic bidding, central bank operations

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1 Introduction

The Eurosystem's instrument to manage its operational target are collateralized refinancing operations of two different maturities: short term money is auctioned every week in the Main Refinancing Operations (MROs) while term money is auctioned once a month in Longer Term Refinancing Operations (LTROs). Via adjusting the amount of loans given to the banks, the ECB can steer liquidity in the overnight interbank market and can hence control the origin of the yield curve.

By offering operations with different maturities the banks are also given the opportunity to diversify their portfolios. This is not only an opportunity but also a challenge: bidding in different operations with different maturities at different times under uncertainty is a non-trivial task. MROs and LTROs have been separately analyzed in a number of papers. However, there is only limited and indirect evidence on the interdependencies of joint bidding plans in these two operation types. This paper is the first step to fill this gap in the literature using data from the Eurosystem's tender operations. We motivate this line of research by findings from the auction literature suggesting that agents' bidding strategies take the entire sequence of auctions into account.

We use individual bidding data from the Eurosystem's tender operations from the pre-crisis period with competitive bidding to examine banks' joint bidding behaviour in MROs and LTROs. More specifically, we analyze bidding patterns in MROs preceding and following LTROs. We offer three main findings. First, in MROs prior to LTROs banks bid generally at relatively low rates. In operations after the LTRO banks bid at substantially higher rates. The former could be explained by banks viewing the MRO and LTRO as one joint optimisation exercise. Hence, they can bid at lower rates as liquidity needs can be covered in two operations. The latter can be rationalized by more aggressive bidding of banks which went out empty handed from the two preceding operation (MRO and LTRO) but also partly by a best-response of banks which had liquidity needs in that particular operation. Second, banks participating also in the LTRO bid less aggressively in terms of pricing, bid for larger amounts, and more frequently in the MROs. We also provide evidence that banks bidding in the LTRO bid at lower rates in the MRO immediately before the LTRO. Third, we show that banks bidding also in the LTRO follow a "less aggressive" bidding strategy. Also, they are less likely not to participate in MROs of that maintenance period.

The rest of the paper is organized as follows. The next section describes the institutional framework of the Eurosystem. The third section introduces the data and provides a preliminary descriptive analysis. In section 4 we summarize the literature and provide theoretical motivation for the empirical work which is presented in section 5. The last section concludes. We provide additional explanations or material in the appendix.

2 Institutional Framework

The operational framework of the ECB – similar to other major central banks – targets the short term interest rate on the interbank market.[1] By steering the overnight interest rate the ECB pins down the origin of the yield curve and hence transmits its policy stance to the economy. For banks with access to the Eurosystem standing facilities, this short-term rate can fluctuate between the rate of the deposit facility (DF) and the marginal lending facility (MLF).

In order to implement its operational target, the ECB has to set the appropriate liquidity conditions in the interbank market. This happens via loans to banks against eligible collateral (repos). If liquidity is to abundant,

[1] On a more technical level, the ECB's operational target is to keep EONIA close to the main policy rate (e.g. ECB (2001) or http://www.ecb.int/mopo/implement/intro/html/index.en.html). EONIA is a volume weighted index of overnight unsecured transactions computed from the contributions of panel banks in the Euro area. Other central banks target an array of benchmark rates: the Swiss National Bank targets the 3-months LIBOR (Jordan and Kugler (2004)) or the Fed targets the federal funds rate (Meulendyke (2008)).

the overnight rate on the interbank market will drop while overly tight liquidity conditions will let the interest rate rise. Liquidity needs of banks are in principle beyond the control of the central bank. They are composed of liquidity absorbing items like government deposits, banknotes, or minimum reserves. Reserve requirements are determined as a share of short term liabilities[2] and are intended to serve as a mandatory liquidity buffer held at accounts with the central bank. Their operational role is to increase the (structural) liquidity shortage and to smooth movements of short term interest rates. As banks have to hold a pre-specified amount of reserves on average over a maintenance period, there is a substantial variation in the fulfillment pattern (front- or backloading) which varies with the expected path of interest rates. The length of the maintenance periods varies slightly but is approximately four weeks. Minimum reserves are remunerated at the average policy rate over the respective period. Funds deposited with the central bank over and above what is required are not remunerated. Given this setup, banks have an incentive not to hold more reserves than necessary.

The liquidity of the banking system can be steered using liquidity providing instruments as the system suffers from an *aggregate* liquidity deficit. Hence, in order to set the "appropriate" liquidity conditions the Eurosystem auctions central bank liquidity via three different types of operations: main refinancing operations (MRO), longer-term refinancing operations (LTRO), and fine-tuning operations (FTO).[3]

The timing of theses operations was subject to a change which was implemented in March 2004 (see ECB (2003) for more details). The main features of the updated operational framework are that the maintenance periods now start on the settlement day of the MRO following the monthly policy rate meeting of the Governing Council. Given the timing of the meeting, the reserve maintenance period usually starts between the 10th and 15th of any calendar month.[4] Further, the maturity of the weekly MROs was shortened from two weeks to one week. The other relevant change for the banks' bidding behavior is that now MROs do not overlap with the day when rate changes become effective and banks do not have liquidity buffers from previous week's auction. This implies that over- or underbidding due to expected changes in the interest rate should not play any role for bidding behavior. Also, banks do not carry liquidity buffers into the next operation.

In both frameworks, the timing of the MRO within the week is identical. The MRO auction is generally announced on Monday at 15:30. Counterparties can place bids until Tuesday 9:30.[5] Bids are pairs of up to 10 rate/volume-bundles with the main policy rate being the floor. In addition to the other details, the ECB also announces the liquidity neutral benchmark allotment volume. This is the volume which is needed to exactly fulfill the banking sector's aggregate liquidity needs. The allotment decision (total bid amount, total allotment amount, lowest, highest, weighted average, and marginal rate) is announced at 11:20.

LTROs are carried out on a monthly basis. They have a maturity of three months and were originally introduced because they provide "a good opportunity for smaller counterparties, which have limited or no access to the interbank market, to receive liquidity for a longer period" (ECB (2002), p. 5). The change in the operational procedures affected the position of the LTRO within the maintenance period: the allotment was moved from the first to the last Wednesday of the month. Similarly to the MROs, the exact details of the three-month operation are announced on (usually) Tuesday 15:30 inviting banks to submit bids until Wednesday 9:30

[2]The reserve ratio was initially 2% (starting from January 1999) and lowered to 1% in January 2012. Further, there is a lump-sum deduction of EUR 100.000 which exempts small banks from holding reserves. As the ECB sets the reserve ratio, is partly able to control this liquidity absorbing factor.

[3]There is also a fourth type of operation labeled "structural operations" which is used only on a non-regular basis and is intended to adjust the structural liquidity position vis-à-vis the banking system. These operations encompass reverse transactions (repos), issuance of debt instruments or outright transactions.

[4]In the old framework, the start was always on the 23rd of a month.

[5]Note the the weekdays used in the description are valid for weeks without bank holidays. For weeks with holidays the weekdays might differ but the MRO would be still allotted before the LTRO. Yet another change is that in the old framework, the ECB only announced its forecast of the autonomous factors and the market had to calculate a proxy for the subsequent allotment. This left some room for speculation whether the allotment decision was liquidity neutral or not.

and results are published at 11:20. Contrary to the MROs, there is no binding minimum bid rate. There is also no benchmark allotment but a pre-announced fixed volume with rather infrequent changes. Hence, in these auctions the Eurosystem acts as a pure price taker without the intention to signal any monetary policy stance.

FTOs can be liquidity providing or absorbing (with the policy rate then serving as a ceiling) and are used on an ad-hoc basis to smooth out unexpected aggregate liquidity shocks to the system. They can be truly unexpected (exogenous) but were at several occasions endogenous in the sense that banks' total demand in refinancing operations fell short of the banking system's aggregate liquidity needs. This underbidding was mainly driven by interest rate expectations. In such cases, the ECB had to inject liquidity into the system in order to prevent the overnight rate to drift to the rate of the marginal lending facility.

2.1 Literature Review

The MRO and LTRO auctions of the ECB were analyzed in a series of separate papers. Linzert, Nautz, and Bindseil (2007) focus on bidding behavior in the LTROs using detailed bidding statistics. They investigate how a set of exogenous variables (interest rates, costs of collateral, etc.) but also variables like banks' size or country of origin affect bank's bidding behavior and success. In line with expectations they find that costs of collateral and market financing costs are important determinants of banks' behavior. Small banks bid generally at higher rates and secure hence higher allotments. Also, the frequency of participation is heterogeneous with larger banks being more active LTRO bidders. Further, small banks react stronger to interest rate expectations but react less to changes in the costs of collateral. In contrast to the MROs, there is evidence for the winner's curse effect in the LTROs. In line with theory, banks reduce participation, bid rates and bid volumes when interest rate uncertainty increases. This effect is especially pronounced for larger banks indicating that they might have a more active money market desk.

Complementing the analysis from above, Bindseil, Nyborg, and Streubulaev (2009) focus on the MROs. In contrast to the LTROs, when interest uncertainty increases, banks bid more aggressively. This suggests that the fear of going out empty-handed from the auction is more important than the winner's curse and is in line with the hypothesis that banks do not posses (private) information. If they had information about the post-auction market, banks should bid opportunistically and the winner would "overpay" relative to the post-auction value (Milgrom and Weber 1982).

Eisenschmidt, Hirsch, and Linzert (2009) compare banks' MRO bidding behavior before and during the crisis. Their main finding is a polarization in banks' bidding behaviour during the crisis: while more banks place bids above the marginal rate in order to avoid rationing, the share of very low bids also increases. They interpret this as a signal that financially strong banks bid opportunistically as they had access to the interbank market. Stressed banks were more risk averse and wanted to secure ECB funding even if they had to pay – relative to the pre-crisis period – a higher price for liquidity. This is indirect evidence for the hypothesis that the risk of being short-squeezed incentivizes banks to bid at higher rates (Nyborg and Strebulaev 2004). Similar to the other two papers evaluating the ECB operations, it is found that large banks preserve their strategy to underbid small banks. Taking a structural approach, Cassola, Hortaçsu, and Kastl (2009) estimate the willingness of banks to pay at ECB auctions. Their base their argument on the finding that before the crisis, auctions outcomes (rates) were closely linked to published (traded) market rates (EUREPO and EURIBOR). During the crisis, ECB auction rates and market rates become increasingly decoupled. They view this as a sign that some banks were not able to obtain market funding at market rates. Finally, these stressed banks pushed up bid rates, forcing financially sound banks to partially adjust their bid rates and hence reinforced the upward spiral.[6]

[6]There is of course also a large literature on the period with fixed rate tender and heavy overbidding (before June 2000), e.g. Nautz and Oechssler

There is also a well developed literature evaluating bidding behavior in government bond auctions; e.g. Nyborg, Rydqvist, and Sundaresan (2002) for Sweden, Elsinger and Zulehner (2007) for Austria, Bjønnes (2001) for Norway, Cammack (1991) for the US, and Hortaçu and McAdams (2010) for Turkey. The predominant findings confirm results from auction theory that higher uncertainty induces bidders to bid at lower rates, demand less and increase the dispersion of their bids (i.e. bidders react to the winner's curse).

Work on the substitutability of MROs and LTROs has so far been limited; bidding behavior was mostly analyzed without explicitly taking interactions into account. Indirect evidence on a link between bidding strategies in MROs and LTROs is provided e.g. by Cassola, Hortaçsu, and Kastl (2009). They find that MROs and LTROs were substitutes before the crisis but find that after August 2007 bidding behavior in both operations was more aligned (suggesting complementarity). After the outbreak of the crisis, outstanding volumes in an LTRO led to more aggressive bidding in MROs and vice versa prior to the crisis. The reason for the change is that banks under stress were even more under pressure for longer term financing and hence increased their bids also in the MRO. Linzert, Nautz, and Bindseil (2004) conclude with a mixed result. They find that banks which frequently bid in the MROs demand also more in the LTROs but the effect on bid rates and bid rate dispersion is not significant. Banks which had an increasing allotment over the past two MROs prior to the LTRO bid for lower volumes and at lower rates. The effects are rather small and – depending on the specification – statistically only marginally significant. Lastly, Eisenschmidt, Hirsch, and Linzert (2009) test the substitutability hypothesis with a natural experiment by exploiting changes in the share of funds allotted in the LTROs and MROs while keeping aggregate liquidity provision unchanged at the neutral amount. They find that in the pre-crisis period a change in relative allotment volumes did not lead to any significant change in bidding behaviour but during the crisis bid rates in the MROs increased if the MRO allotment share decreased. This indicates that banks were not willing to shift into the LTRO but rather bid at higher rates in the MRO. One explanation is that banks want to retain flexibility instead of being locked in for three months. However, they also find that bidding success in the LTROs induces banks to bid at lower rates in the MRO as some of their funding needs have been satisfied already.

Research on strategic bidding behavior in sequential or regular auctions so far focused on a wide range of fields, goods, or settings. Important early theoretical contributions are Milgrom and Weber (2000), Weber (1983), Scoones (1994), or Wiggans (1994). They mostly find that prices of identical goods in consecutive auctions should be identical. However, the empirical regularity that prices tend to decrease ("afternoon effect") or increase ("morning effect") motivated researchers to develop models in order to rationalize these observations. Explanations for a systematic change of prices between auctions are for instance participation costs to stay in the auction (von der Fehr 1994) or depleted budgets as more expensive objects are auctioned first (Benoit and Krishna 2001). Deltas and Kosmopoulou (2004) develop a theoretical model to show that increasing and decreasing prices over the course of sequential auctions are possible and verify their hypothesis using data on rare old books. Using data from e-Bay auctions, Zeithammer (2006) verifies his theoretical finding that rational bidders reduce current bids if similar goods will be auctioned (in a different auction) sooner. Incorporating learning behavior on the sellers' and buyers' side, Zeithammer (2007) shows that in sequential auctions (in contrast to isolated ones) bidders shade their bids more whenever they expect similar objects to be on sale in the near future. On the other hand, Zulehner (2009) uses data from Austrian cattle auctions and finds that prices tend to fall over the auction days. Traders shade their bids more and stay longer in auctions as opposed to farmers who tend to buy at higher prices; in other words: size matters.

(2006), Nautz and Oechssler (2003), Ayuso and Repullo (2001) or Ehrhart (2001). While there is no consensus about the reasons, the most frequently cited explanations are an overly tight liquidity policy due to an asymmetric loss function of the ECB, expectations of rising rates and, on a more theoretical basis, an inherent instability or even non-existence of an equilibrium in fixed rate tenders.

3 Data

We use individual bidder data from the ECB's tender operations with competitive bidding starting with the MRO allotted on 16th October 2001 and end with the MRO allotted on the 21st August 2007. The first cutoff is motivated by data availability: we use the 2 week EURIBOR – which was quoted first on 15th October 2001 – for computing forward rates.[7] The second date we consider to be the beginning of the financial crisis: one month later the crisis quickly gathered momentum by the UK Treasury providing liquidity support (via the Bank of England) to Northern Rock. This choice ensures that we exclude any potential anticipation effects.[8] We are able to follow individual bidders over time via unique bidder codes.

We also exclude the operations which were underbid: within the specified period banks bid in 10 MROs less than the ECB was willing to allot (measured by the benchmark allotment). This "bidder strike" was mainly due to expectations of falling interest rates and hence a preference to shift refinancing to the next MRO (Bindseil, Nyborg, and Streubulaev 2009).

In the following sections we describe the variables and provide some initial descriptive statistics. In section 3.1 we describe the choice and construction of endogenous variables and exogenous variables are discussed in section 3.2. In section 3.3 we provide an overview about the data by providing some preliminary descriptive statistics. We will occasionally refer to additional material in the appendix.

3.1 Endogenous Variables

The approach here follows the convention in the literature and condenses bank i's bid schedule in operation t into a tuple $\{r_{i,t}, q_{i,t}\}$ with $r_{i,t}$ being the weighted average rate computed as $r_{i,t} = \sum_{k=1}^{K} b_{i,t,k} \times q_{i,t,k} / \sum_{k=1}^{K} q_{i,t,k}$ where $q_{i,t,k}$ denotes the bid volume for bid k. We use this bid rate to compute

discount as the benchmark rate minus the weighted average bid rate, i.e. $discount_{i,t} = R_t - r_{i,t}$ with R_t being the secondary market rate. For the MROs we use the one week swap rate (two week for the old operating framework) while for LTROs we take the corresponding three months swap rate. Although the underlying instrument (EONIA) is unsecured, the swap rate is considered to be – resembling the features of repos – almost risk free. The EONIA swap market is highly liquid and is hence likely to reflect accurately the prevailing market conditions (Hartmann and Valla (2008), Bindseil, Nyborg, and Streubulaev (2009)). Also, it is available for the whole sample period and tracks EUREPO – a European interbank repo rate – rather well (for the overlapping period).[9] The discount gives us an indication by how much banks underbid the benchmark rate. We further investigate bank bidding behavior in terms of bid volume by using the bank's

relative bid quantity defined as the bank's total bid amount relative to the benchmark on the announcement day, i.e. $rel\_q_{i,t} = \frac{q_{i,t}}{\sum_{i=1}^{I} q_{i,t}}$. On the level of operations we define

underpricing as $underpricing_t = R_t - \tilde{r}_t$ where $\tilde{r}_t$ is the weighted average allotment rate and R_t is the secondary market rate as defined above. The

[7] Without this constraint the data horizon could be extended back to the MRO allotted on the 4th July 2000. Before that date the ECB conducted fixed rate tenders.

[8] Other papers also spanning the time period around the crisis choose a similar cut-off date; e.g. Eisenschmidt, Hirsch, and Linzert (2009), Kraenzlin and Schlegel (2012) or Cassola, Hortaçsu, and Kastl (2009). Further, the LTRO allotted on August 23 shows already unusually aggressive bidding behavior which can be interpreted as a sign of stress in the market; hence the decision to exclude it from the analysis. Also, the ECB conducted a series of – rather unusual – liquidity injecting operations in August. As this affects only 2-3 MROs, taking out there operations would not change the results.

[9] We also tried the EUREPO and EURIBOR (an unsecured interbank rate) as alternatives. Both are fixed 11:05 and published at 12:00 and hence not contaminated by the publication of tender results (i.e. post-auction activity). In terms of levels, the swap rate is trading somewhat above EUREPO and below EURIBOR. However, given that the spreads between the different benchmarks are rather stable, the results (especially marginal effects) were essentially unchanged as the level differences are absorbed by a constant.

stopout spread is defined as the marginal allotment rate (stopout rate) minus the minimum bid rate. The average for the period is positive which shows that the rate on the wholesale market was considerable above the minimum bid rate. We define

award ratio as an individual bank's allotted volume relative to its total bid volume. Given that high award ratios can be achieved by bidding at high rates, an elevated award ratio is an indication for aggressive bidding. On the other hand, an uneven distribution of this number indicates that many banks missed their refinancing targets (in either direction) and have been taken by surprise. To measure this, we use the variable

award imbalance as the standard deviation of the individual award ratios. We will use the lagged value of this variable later to proxy for the uneven distribution of liquidity needs. According to Nyborg and Strebulaev (2004), a more dispersed liquidity situation implies more aggressive bidding. This is because more banks are "short" and they try to avoid to be short-squeezed in the post-auction secondary market. In order to measure

participation of banks we plot the number of banks (by operation type) in figure 1. Later, we will report participation also as the number of participations in e.g. MROs of a maintenance period divided by the total number of MROs of that period. For such cases we will report a number between 0 and 1.

3.2 Exogenous Variables

We proxy the

uncertainty in the market by using a forecast of the variance of changes in the swap rates. To do this, we employ an exponential smoothing model where we let an algorithm choose the smoothing parameter such that the overall discrepancy between the one-step-ahead forecast and the realization is minimized. We provide more details on the computation of this number in the appendix.[10] The

swap spread is the EONIA swap rate for the respective operation minus the minimum bid rate. Thereby we measure the bank's outside option to get funds from the market but also the ability of banks to place low bids. Further, the swap rate is also an indicator of interest rate expectations during the life of the contract. The

forward spread is the spread between the forward rate for the specific operation for the next date when the operation will be carried out and the minimum bid rate. For instance, the swap spread for the MRO in the new framework is the one week forward rate (from one week in the future to two weeks). This gives an indication about the expected price of a specific operation for the next date when this operation is available. The

expected auction size for the MRO is measured by the benchmark allotment announced by the ECB on the announcement day of the operation. Prior to the change in the operational procedure we use the published forecast of autonomous factors as a proxy as no liquidity neutral benchmark was announced. For the LTROs we use the intended allotment amount which did not take any liquidity conditions of the banking system into account. We include this variable as Välimäki (2006) shows that a higher expected allotment volume increases banks uncertainty about their own allotment and increases their bid rate.

3.3 Descriptive Statistics

In this subsection we will report detailed statistics of the endogenous bidding variables. The focus is on a comparison of LTROs and MROs in general and their evolution (changes) over time. When reporting averages we first average for a given tender and then over time. More analysis explicitly focusing on the relationship between bidding in MROs and LTROs is provided in section 5. Table 1 provides the descriptive statistics of the

[10] As a robustness check, also estimated a GARCH(1,1) model without a qualitative change of the results.

endogenous variables which can be measured on the individual bank level grouped by banking size. We report these statistics separately for the 299 MROs and 71 LTROs.[11] Following the literature, we use banks' minimum reserve requirement to group them. In section A.1 of the appendix we provide a more detailed description of the grouping strategy.

As a general observation, small banks participate less often in both operations, bid at higher prices, and bid for relatively smaller amounts (table 1). On average, in MROs large banks bid at about 0.8 bp lower than small banks but have as a consequence a lower award ratio. In the LTROs, the difference is 1.5 bps. Participation also varies across groups and operation type: small banks participate in about 16% of the MROs compared to 45% for large banks. Banks bid in general less frequently in the LTROs with the differences across groups persisting.

As a consequence of more aggressive bidding, small banks are in general more successful in terms of obtaining their desired volume as measured by their award ratios. Award ratios are higher in the MRO than in the LTROs. Absolute bid volumes are larger in MROs than in LTROs. This is a consequence of smaller aggregate (per tender) allotment volumes. However, average bid volumes by group are more equally distributed in LTROs. This comes mainly from the fact that small banks bid for roughly the same amount in MROs and LTROs (13 mln vs. 11 mln) while large banks' bid volume drops from 2.2 bn in the MROs to 0.8 bn in the LTROs. This is also reflected in the relative bid quantity with banks in general bidding for relatively larger amounts in the LTROs.

Bidding behavior has not been constant over time. This is partly due to adjustments induced by changes in the economic environment but also due to the change in the operational framework of the Eurosystem. We observe that the number of banks bidding in both operations peaked in early 2002 and dropped thereafter (figure 1). Around the introduction of the new operational framework, participation picked up considerably for the MROs and this level prevailed until the end of the sample. Although also the number of participants in the LTROs increased, this effect was more contained compared to the change in MRO participation. One obvious explanation is that due to the shortening of MRO maturities, banks were – almost mechanically – forced to bid more frequently.

Figure 2 shows the distribution if discounts for the two operation types. In LTROs, this distribution is much smoother and close to a normal distribution while in MROs, the distribution has more skew. This is due to the binding minimum bid rate in the MROs. The absence of such a binding constraint in the LTROs allows bidders to spread out their bids more smoothly. As already show (table 1) banks participate on average more frequently in MROs than in LTROs. However, looking at the distribution of bid frequency (figure 3) reveals that the low average participation rate is due to the very high share of banks bidding only once in an LTRO. Considering banks participating more than once, the differences in the distributions drop considerably but are still substantial.

Lastly, figure 4 shows LTRO financing as a share of total central bank financing by size. Large banks obtain about 20%-30% of their financing in the LTROs while this number is considerable higher for small and medium sized banks; around 40%-60%.

4 Theoretical Motivation

The literature on sequential auctions and strategic bidding offers only a limited set of undisputable conclusions and directly testable hypothesis applicable to Eurosytsem auctions.. Common to most papers is the assumption

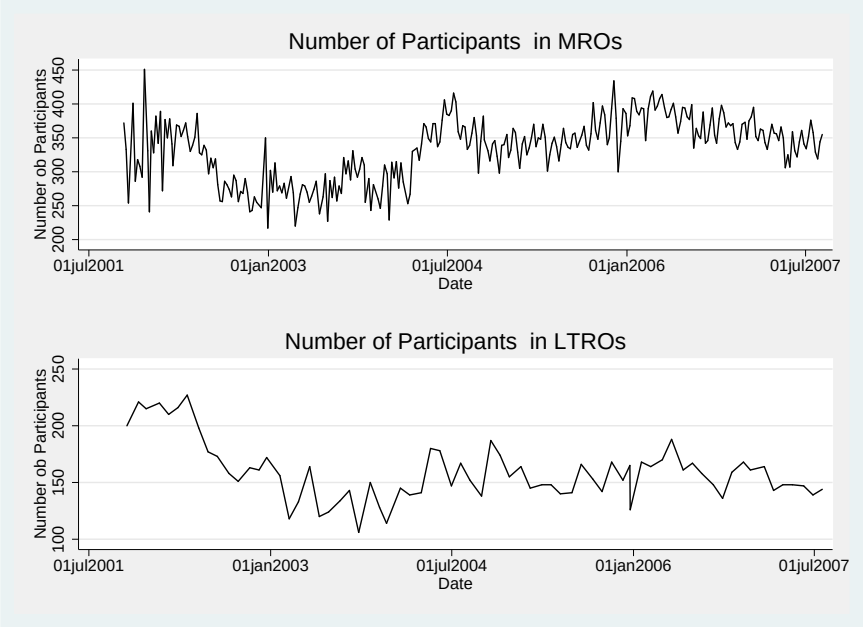
[11] For the sake of brevity, we only only provide means. Detailed descriptive statistics (number of observations, dispersion measures) are available from the author upon request.

Table 1: Summary Statistics Endogenous Variables: MRO vs. LTRO

	MRO				LTRO			
Group	All	Small	Medium	Large	All	Small	Medium	Large
Discount	1.17	0.36	0.94	1.20	-1.31	-2.64	-1.99	-1.10
Participation	28%	16%	32%	45%	14%	8%	16%	20%
Number of Banks	334	76	150	106	158	36	76	47
Award Ratio	0.86	0.93	0.89	0.85	0.84	0.93	0.88	0.83
Bid Volume	770	13	150	2205	298	11	117	795
Relative Bid Quantity	0.44%	0.009%	0.10%	1.21%	1.14%	0.05%	0.48%	3.03%

Notes: Discount is computed as the weighted average where the weights are recomputed for the different groups. Award ratio is computed the ratio of award and bid volume. Bid volume in EUR millions. Discount in basis points.

Figure 1: Participation in MROs and LTROs



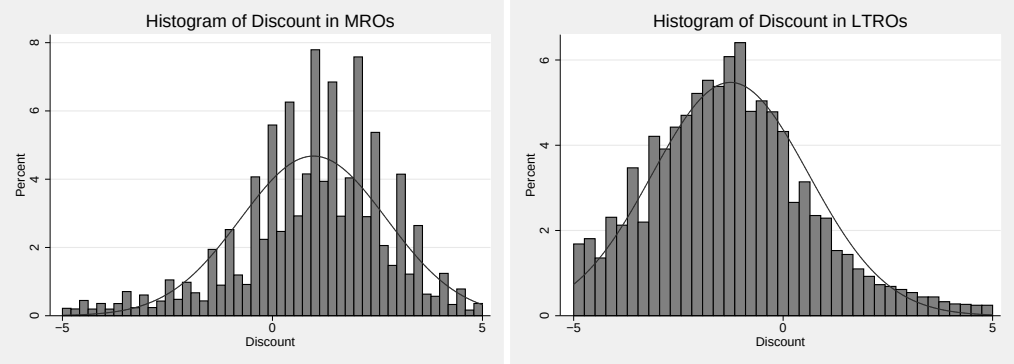
Notes: Time series of banks participating in MROs and LTROs. Note that in the chart we excluded the MRO with tenderid 20030043 (122 bidders). The reason for the small number of participants was the fact that on the same day (8 July 2003) there was a second MRO with a different maturity (tenderid 20030042) which attracted 286 bidders.

that bidders view a sequence of auctions as one "joint problem". Further, bidders who are not only bidding for their own demand and hence stay longer in the auctions but act as wholesalers (traders) tend to buy at lower prices. This is because they do not have private (biased) valuations but rather represent the valuation of the market or of their customers (Milgrom and Weber 2000). Also, participants with a larger demand can spread out their bids over time. Other important factors are the (expected) time to the next auction with similar items on sale, the number of objects (or quantity at stake), past success, and the expected number of competitors in future auctions. These arguments suggest that banks, especially larger ones, might have some flexibility to shift their refinancing needs between operations.

On the other hand, papers focusing on the choice of the funding structure suggest that there is limited scope for a permanent and "voluntary" substitution between MROs and LTROs. First, as shown by e.g. Diamond (1991), Eisenschmidt and Holthausen (2013), etc., the market is endogenously segmented with highly rated banks either borrowing long or short and other banks borrowing in the middle of the maturity spectrum. Hence,

Figure 2: Distribution of Discount

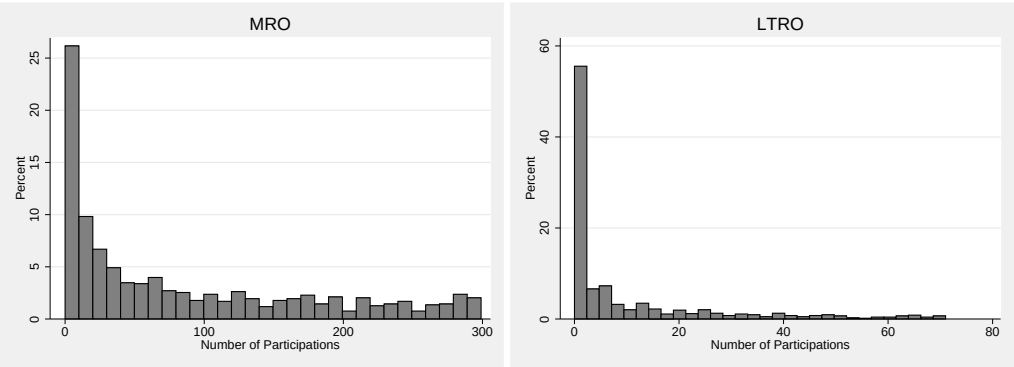
(a) MRO (b) LTRO



Notes: Histogram of discount per demand schedule and operation. The smooth line is the normal distribution.

Figure 3: Participation Frequency in MROs and LTROs

(a) MRO (b) LTRO



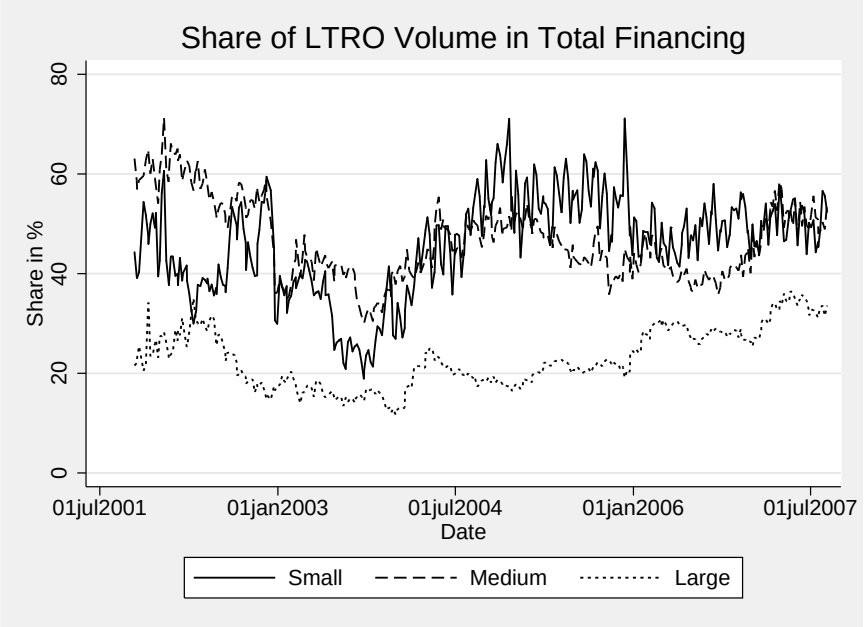
Notes: Histogram of participation frequency in MROs and LTROs. The first bin corresponds to only one participation.

banks' long term refinancing strategy (i.e. match the maturity of assets and liabilities) is a function of deeper underlying factors. Second, the segmentation along the size dimension is also "hard-wired" into the system. Small banks do not have resources to bid frequently, have relatively expensive access to the wholesale market, and are hence willing to pay a higher price for liquidity. Given that a reduction of bidding costs is only possible in the LTROs (to the extent that banks get money for three months instead of bidding on a weekly basis), one can expect that their willingness to substitute into MROs is also limited. Third, with efficient financial markets, arbitrage opportunities should be scarce and hence frequent switching between MROs and LTROs on average not be profitable.

Putting the arguments together, one can conclude that there is limited scope for frequent switching between financing via MROs and LTROs in order to exploit interest rate differentials in the process of the optimization of the bank's funding mix.[12] However, banks can exploit the fact that the substitutability relations between LTROs and MROs is asymmetric along the time dimension: long term money (LTROs) can substitute for short term funding (MROs) but not vice versa. This is not exclusively because the maturity of the LTRO is longer

[12]To be precise, an examination of a single bank's bidding behavior should take changes in the business model, risk appetite of management, and changing exogenous factors into account. These will affect bidding in the long run but should have little effect on the short-run substitution between MROs and LTROs.

Figure 4: LTRO Share in Total Eurosystem Borrowing



Notes: Volumes computed on any allotment day of an operation (including the allotment of that day).

than the maturity of the MRO but because the MRO is allotted on Tuesday while the allotment of the LTRO is on Wednesday. Consequently, the fact that once a month (maintenance period) banks have the opportunity to bid for MRO and LTRO within a short period of time – usually within one or two days – offers opportunities to bid strategically. To be more precise, banks might view bidding in the MRO as a "test run" and then adjust their strategy in the LTRO (or the MRO following the LTRO). This is in line with the literature (especially empirical research on internet auctions) showing that agents bid less aggressively if they expect similar objects to be auctioned soon. Furthermore, the fact that banks have multiple opportunities to bid within a short period of time introduces a higher potential for a shortfall of funds in case a bank misses it's subjective refinancing target from both operations.

The presented stylized facts and results from previous research suggest number of testable hypothesis. First, operations immediately before and after an LTRO are candidates for strategic bidding behavior and should be examined in greater detail. More specifically, if banks view the MRO / LTRO bundle as asymmetric substitutes we should see less aggressive bidding in the MRO before the LTRO. Second, if banks plan to obtain funding in both the MRO and LTRO, they can follow a strategy of bidding at lower rates in "early" operations. Hence, we should see that banks participating in the following LTRO follow a persistently less aggressive bidding strategy and are more likely to stay in the operations. Third, banks participating only occasionally in operations will do this due to two reasons. They might be hit by unexpected negative liquidity shocks or they might participate because the potential to obtain funding at a low price is high (i.e. market funding is more expensive than the expected rate in the tender operations). Whether the former or the latter effect dominates is an empirical question. If the former dominates, bidding of occasional bidders should be more aggressive while if the latter is more important, bid rates should be relatively lower.

Compared to the MROs, it is more challenging to derive testable hypotheses for the LTROs. This is mainly due to the fact that banks bidding only in LTROs are known to be rather special group (small, costly access to interbank market) and their room for maneuver in terms of strategic bidding is rather limited. For the rest, we could e.g. expect that success in past MROs decreases banks' bid rates. Hence, we will focus on tests by

examining bidding conditional on simple bidding patterns in MRO participation.

5 Empirical Analysis

In this section we will initially provide a set of descriptive statistics comparing bidding strategies in MROs with respect to their relative position to the LTRO (section 5.1). Then, we will turn to an analysis of the persistence in bidding behavior (section 5.2). Lastly, we characterize bidding strategies and quantify their effect on bank behavior in section 5.3 using an econometric setup.

5.1 Conditional MRO Bidding Behavior

We start with examining differences in bidding behavior depending on the timing of the MRO where we distinguish between auctions before and after the LTRO. We report endogenous variables on the individual level for MROs sometime before and after the LTRO *within* one maintenance period in table 2. The ranking across groups in terms of bidding behavior does not change: small banks bid more aggressively and have higher award ratios. However, there is a general level effect across all groups with banks bidding in MROs before the LTRO less aggressively. After the LTRO, small banks even have a small negative discount while large banks still bid about 1 bp below the prevailing swap rate. The difference between the pre- and post-LTRO operations is largest for small banks.

The observation that there is a significant difference in bidding behavior and success between MROs pre- and post-LTRO carries over to tender level statistics such as underpricing and stopout-spread while award imbalance is of similar magnitude (table 3). Also, the discount measured on the aggregate level is about 1 bp lower before the LTRO. On the other hand, a comparison of exogenous variables does not reveal any particularly striking pattern which would help to understand the differences in the endogenous variables.

While in table 2 operations before the LTRO were grouped together according to the fact weather they were conducted within the maintenance period *sometime* before or after the LTRO, we look now only at the last MRO before the LTRO and the first MRO immediately after the LTRO. In other words, these statistics aim at capturing bidding behavior at the very last opportunity to bid for short term money before the three month operation but also at the very first opportunity to make up for a shortfall of funds in the previous auctions. We show the results in table 4. Compared to the previous comparison, the quantitatively largest difference is when breaking up the MROs after the LTRO. For the MRO immediately after the LTRO ("post"), the discount drops even for medium sized banks into negative territory. For operations being neither immediately before nor after the LTRO ("other"), the discount is between the two other groups. Note that the difference in discount between "post" and "pre" MROs is relatively large (1.4 bps) but the difference in award ratios is relatively small. This is supportive evidence for the hypothesis that banks bidding immediately after an LTRO try to make up for a too small allotment and thereby bid more aggressively. As a consequence, they realize a relatively large allotment (slightly above the average).

Lastly, in table 5 we examine bidding behavior of banks in MROs conditional on LTRO participation (and vice versa) within one specific maintenance period. As usual, we repeat the exercise on the aggregate level but also grouped by size.

The results in panel (A) display bidding behavior in an MRO conditional on bidding in the LTRO of the same maintenance period. It can be seen that banks bidding in the LTRO bid in MROs at lower rates and have then naturally a lower award ratio. Banks bidding in both operation types during a maintenance period also bid for relatively higher volumes. Banks participating also in the LTRO of the maintenance period also

Table 2: Summary Statistics Endogenous Variables: MROs Pre and Post LTRO

	Pre LTRO				Post LTRO			
Group	All	Small	Medium	Large	All	Small	Medium	Large
Discount	1.64	1.07	1.48	1.65	0.84	-0.14	0.54	0.87
Participation	30%	18%	34%	47%	27%	15%	31%	44%
Number of Banks	351	84	158	109	321	72	145	103
Award Ratio	0.86	0.93	0.89	0.86	0.85	0.94	0.78	0.85
Bid Volume	843	14	160	2479	718	13	142	2009
Relative Bid Quantity	0.40%	0.008%	0.08%	1.13%	0.47%	0.01%	0.11%	1.27%

Notes: Discount is computed as the weighted average where the weights are recomputed for the different groups. Award ratio is computed the ratio of award and bid volume. Bid volume in EUR millions. Discount in basis points.

Table 3: MROs Pre and Post LTRO vs. LTRO: Tender Level Statistics

	MRO		LTRO
Variable	Pre LTRO	Post LTRO	
Number of Observations	124	175	71
Discount	1.22	0.16	-2.79
Underpricing	1.22	0.19	-2.82
Stopout Spread	4.7	6.0	11.5
Award Imbalance	0.21	0.22	0.27
Swap Spread	6.8	7.5	10.1
Benchmark	235	181	28
Forward Spread	10.8	11.9	20.5

Notes: Variables as defined in the text. The upper panel consists of endogenous, the lower panel consists of exogenous variables. Spreads and underpricing defined in basis points computed using weighted averages. Benchmark in EUR millions.

have a higher probability of participating in at least one MRO ("p(Participation)") and consequently bid more often ("Participation") with the latter being of course a mechanical effect. The more interesting statistic is that conditional on bidding at least once in an MRO, banks bid on average more often if they participated in the LTRO. To show this, we first divide the share of banks participating (at least once) in the MROs if they bid in the LTRO by the same share if they did not bid in the LTRO. As can be seen in the first line of panel (C), the probability to participate ("p(Participation)") in an MRO increases by a factor of 2.3 if a bank also bid in the LTRO. Then, we repeat the same calculation for the participation frequency in MROs (panel(C), line 2). The number of total auctions in which a bank participated increases on average by a factor of 2.5 if a bank bid also in an LTRO. Hence, LTRO participation is correlated with an increased bid frequency in the MROs. This holds across all groups and is even more pronounced for smaller banks.

Looking at bidding behavior in the LTROs (panel (B)) conditional in bidding in the MROs reinforces the message that banks' bidding is not independent. The discount of banks which bid in at least one MRO is on average -1.36 basis points while the discount of banks only participating in the LTRO is -2.45. A negative discount indicates that banks overpay relative to the swap rate. However, for the LTROs the swap rate is likely to underestimate the "true" outside option, especially for smaller banks. This comparison clearly reflects that banks bidding only occasionally in LTROs are less experienced, have a lower price sensitivity, and rather want to obtain funding with a high probability as opposed to more active banks. More active banks, as a consequence of less aggressive bidding, realize smaller allotments but they also bid for higher amounts: if a bank only participates in the LTRO it demands around 0.65% of the benchmark allotment or preannounced volume. If it participates also in the MRO demand rises to 1.29%. Furthermore, if a bank bids only in the LTRO ("Not bid in MRO"), participation in LTROs is broadly comparable across size categories. Differences in participation

Table 4: Summary Statistics Endogenous Variables: Pre/Post/Other MROs

	Pre			Post			Other		
Variable	Small	Med	Large	Small	Med	Large	Small	Med	Large
Discount	1.07	1.51	1.60	-0.85	-0.13	0.34	0.54	1.11	1.35
Participation	0.17	0.33	0.45	0.15	0.31	0.45	0.16	0.32	0.45
Number of Banks	80	154	107	73	147	105	78	150	106
Award Ratio	0.92	0.87	0.86	0.94	0.90	0.86	0.93	0.89	0.85
Bid Volume	14	149	2204	13	150	2213	13	149	2186
Relative Bid Quantity	0.01%	0.10%	1.19%	0.01%	0.09%	1.19%	0.01%	0.10%	1.22%

Notes: Discount is computed as the weighted average where the weights are recomputed for the different groups. Award ratio is computed the ratio of award and bid volume. Bid volume in EUR millions. Discount in basis points.

across groups are much larger for the banks which also bid in LTROs.[13]

5.2 Persistence of Bidding Behaviour

In addition to exploiting the cross sectional dimension, in this section we study the persistence of bidding behaviour in MROs. To this end, we use the variable *discount* and group all banks in a given MRO into 5 quintiles with quintile 5 representing a high discount (i.e. less aggressive bidding). Further, we define a bid sequence as a series of MROs between two LTROs including the LTRO representing the end of this sequence. For instance, in the sequence of operations $\ldots$LTRO$_{t-1}$,MRO$_t$,MRO$_{t+1}$,MRO$_{t+2}$,LTRO$_{t+3}$,MRO$_{t+4}$ $\ldots$we would classify MRO$_t$ to LTRO$_{t+3}$ as a "bid sequence" and MRO$_{t+4}$ would then start a new sequence. We adopt this approach to ensure that we have a sufficient long sequence of MROs uninterrupted by an LTRO.

Using this concept, we compute the transition matrix between adjacent MROs whereby the states correspond to the quintile of the distribution. Such a transition matrix tells us whether banks purse a rather stable strategy (i.e. bidding in the same quintile) or whether they are moving up or down. Moving up in the distribution (to a higher rank) corresponds to a higher discount and less aggressive bidding (and vice versa). We compute the transition matrices separately by two different criteria: bank size and the fact whether they participated in the LTRO at the end of the sequence. In order to also capture opting out from an operation, we add this to the "moving down" category. Hence, bidding in the most aggressive category or finally dropping out are classified in the same state.[14] Then, we compute the sum of probabilities to move up or to move down in the distribution *conditional* on the state (i.e. rank) in the previous operation. As the last step, in table 6 we report the difference between banks which participated and the ones which did not participate in the LTRO at the end of the sequence. For instance, in panel (A) of table 6 the number 4.1 (column "All", row "1") is computed as the sum of probabilities to move up to rank 2, 3, 4, or 5 (given that the bank was at rank 1 in the previous operation) for banks which did participate in the LTRO minus the same number for a bank which did not bid in the LTRO.[15]

Positive entries in panel (A) of table 6 indicate that if a bank participates in the LTRO at the end of a sequence of MROs, it is more likely to move up in the distribution of discounts than to stay at the same rank or move down

[13]Comparing participation rates with participation probabilities (as done for the MROs) is a less powerful statistic here. Although banks bidding in MROs have a much higher LTRO participation probability, it is not informative to look at the average number of LTRO participation as most maintenance periods have only one LTRO and hence participation in LTRO implies a participation rate of close to 100%.

[14]The reasoning is that not bidding is probably due to the fact that it does not want to obtain liquidity at the "expected highest price" in the auction (for whatever reason). A bank could always bid at very high rates (thereby being at the lower end of the distribution, i.e. in quintile 1) an obtain liquidity. But as it decides not to do so, we put it into the category with the lowest discount.

[15]Transition matrices with detailed results are available upon request.

Table 5: Endogenous Variables: Conditional Bidding Behavior (1)

Panel (A): Bidding in MRO

	Not Bid in LTRO				Bid in LTRO			
Group	All	Small	Medium	Large	All	Small	Medium	Large
Discount	0.78	0.27	0.84	1.15	0.98	0.38	1.01	1.18
p(Participation)	0.32	0.22	0.35	0.46	0.73	0.56	0.74	0.87
Participation	0.23	0.14	0.27	0.37	0.60	0.40	0.59	0.78
Award Ratio	0.86	0.90	0.86	0.82	0.80	0.90	0.80	0.78
Bid Volume	635	14	140	1937	1184	14	182	2886
Relative Bid Quantity	0.35%	0.01%	0.09%	1.06%	0.60%	0.01%	0.12%	1.44%

Panel (B): Bidding in LTRO

	Not Bid in MRO				Bid in MRO			
Group	All	Small	Medium	Large	All	Small	Medium	Large
Discount	-2.45	-2.73	-2.42	-1.82	-1.36	-2.00	-1.73	-0.53
p(Participation)	0.06	0.05	0.07	0.06	0.28	0.19	0.30	0.33
Participation	0.06	0.04	0.07	0.06	0.27	0.18	0.29	0.32
Award Ratio	0.87	0.90	0.85	0.85	0.76	0.88	0.75	0.69
Bid Volume	165	11	121	712	338	11	114	816
Relative Bid Quantity	0.65%	0.05%	0.52%	2.61%	1.29%	0.04%	0.49%	3.03%

Panel (C): Relative Participation & p(Participation)

LTRO=1/LTRO=0	All	Small	Med	Large
p(Participation)	2.3	2.5	2.1	1.9
Participation	2.6	2.8	2.2	2.1

Notes: Discount is computed as the unweighted average. Award ratio is computed the ratio of award and bid volume. Bid volume in EUR millions. Discount in basis points. In panel (C), p(Participation) is probability to bid in an MRO if bid in the LTRO divided by the probability to bid in the MRO if not bid in the LTRO.

(including dropping out) compared to its peer who did not bid. As can be seen, all entries are positive indicating that banks bidding in the following LTRO followed a less aggressive bidding strategy during the sequence of MROs. Introducing "dropping out" as a separate sixth state does not change the conclusion. In panel (B) we compute the probability to bid more aggressively (i.e. move downwards in the distribution) or drop out. These numbers are all negative indicating that banks which bid only in the MROs were more likely to drop out at some point or to follow a more aggressive bidding pattern if bid in more than one operation. [16]

To further highlight the role of participation, we compute also the probabilities of participation in an MRO conditional on participation in the previous MRO and conditional on bidding in the LTRO. The transition matrices are shown in table 7. The results confirm that if banks bid in the coming LTRO, they bid more frequently in general (last line). Looking at conditional bidding probabilities reveals that banks which intend to bid in the LTRO at the end of the sequence return with a higher probability to an MRO if they did not bid in the previous tender ($\text{Out}_{t-1} \rightarrow \text{Bid}_t$). Also, if they bid in the previous MRO, they are more likely to bid also in the next MRO if they will participate in the LTRO at the end of the sequence ($\text{Bid}_{t-1} \rightarrow \text{Bid}_t$).

Summing up, banks bidding the LTROs are likely to follow a less aggressive bidding strategy but participate more frequently and bid for relatively higher amounts. They also follow in general a less aggressive but more persistent bidding strategy. The described patterns hold across size categories and are hence not driven by size-dependent bidding pattern.

Table 6: Probabilities to move in the transition matrix

	Panel (A) - Δ in p(move up)				Panel (B) - Δ in p(move down)			
Quintile	All	Small	Medium	Large	All	Small	Medium	Large
1	4.1	1.0	3.4	5.1	-4.6	-5.9	-1.5	-6.1
2	7.2	2.0	6.0	8.5	-6.1	-4.1	-2.5	-7.1
3	7.7	4.5	6.6	6.2	-10.1	-3.2	-5.9	-10.2
4	4.6	7.6	4.9	1.8	-11.1	-7.1	-10.1	-7.5
5	-	-	-	-	-8.7	-9.0	-7.5	-5.8

Notes: Probabilities to move up or down do not include the probability to stay in the same quintile. For panel (A) and quintile 5 we do not report numbers as banks cannot move further up in the distribution.

Table 7: Conditional Bidding Probabilities in MROs

	Not Bid in LTRO		Bid in LTRO	
	Out_t	Bid_t	Out_t	Bid_t
Out_{t-1}	94.8	5.2	81.2	18.8
Bid_{t-1}	17.2	82.9	11.0	89.0
$p(\text{Out}_t)/p(\text{Bid}_t)$	76.9	23.1	38.3	61.8

Notes: Out_t (Bid_t) indicates that a bank did (not) bin in an MRO in operation t.

5.3 Econometric Analysis

In this section we continue with an econometric analysis of bidding behavior where we will explain how variations in the *discount* can be rationalized also conditioning on other potentially relevant factors. We will use

[16] The same message can be confirmed by again invoking the cross-sectional perspective and computing the average discount by size and LTRO participation at the end of the sequence. Banks participating in the LTRO at the end of the sequence bid at lower rates (larger discount) and realize lower amounts compared to their peers. They also participate much more frequently and bid for relatively higher amounts than banks not bidding. This is not exclusively driven by the size specific features (i.e. large banks participate more frequently in both operations) but holds for all categories. Results available upon request.

random effects panel regressions with robust standard errors clustered at the bank level.[17] All regressions contain country dummies. In order to account for past success in the auctions, we use "Δ Awrat. LT" (or MT) to denote the change in the award ratio between the last two operations and "Outst. LTRO" to denote the outstanding volume from the LTROs. All other variables are as defined in section 3. Estimates will be shown for the full sample but also separately for the two operational framework. We will indicate this by writing "All", "New", and "Old" at the top of the tables.[18] The next steps are as follows. In section 5.3.1 we characterize the notion of a strategy and explain the construction of variables. Following that, we proceed with regressions where we will start with specifications used in the literature (section 5.3.2) and then gradually move to specifications including variables suggested by the theoretical considerations developed in this paper (section 5.3.3).

5.3.1 Characterization of Bidding Strategies

We characterize bidding strategies for a bank by a vector of the form $\sigma_{t,i} = \{r_{\mathbb{1}}, s_{\mathbb{1}}, o_{\mathbb{1}}, L_{\mathbb{1}}\}_{t,i}$ where r indicates an MRO prior to the LTRO, s denotes a post LTRO MRO, o stands for an other MRO, and L stands for an LTRO. Obviously, this categorization is aligned with the approach taken in the descriptive statistics provided earlier in the paper. The indicator function $\mathbb{1}$ takes on the value of 1 if a bank bid in that operation and 0 otherwise. For instance, $\{r_1, s_1, o_0, L_0\}_{t,i}$ states that in maintenance period t, bank i bid only in the MRO prior and after the LTRO but not in the other MROs or in the LTRO. Using this setup, one can fully characterize all bidding strategies with 15 vectors. The distribution of this strategies is rather uneven with about 60% of the banks in the sample not being active in any operation of a given maintenance period. Another 27% participate only in MROs and 4% bid only in LTROs. The share of banks bidding in both operation types – the "overlap" we use for identifying joint bidding behavior – is about 10%. Among the strategies, the most popular strategy is to bid in all MROs types but not the LTRO (15%), followed by participating in all MRO types and the LTRO (7%), and bidding only in "other" MROs and not the LTRO (4%). The other strategies seem to be less popular (see table 18 in the appendix).

These vectors are only indicators for a given strategy but cannot capture the bidding behavior *within* this strategy. In the example from above we know when a bank bid but do not know how a bank bid in the two operations. To capture the behavior *within* a given a strategy, we expand the set of strategies by forming interaction terms using elements from the set $\{r_{\mathbb{1}}, s_{\mathbb{1}}, o_{\mathbb{1}}\}$ where the variables take on the value of 1 if the operation was of the type before, after, or "other". In the example from above, this gives two variables:$\sigma_{t,i} \times r_{\mathbb{1}}$ and $\sigma_{t,i} \times s_{\mathbb{1}}$.[19] In other words, the first variable is set to 1 for the bid of a bank in the operation prior to the LTRO with the strategy $\sigma_{t,i}$. The second variable is set to 1 for the bid in the operation after the LTRO for a bank with the same bank with strategy $\sigma_{t,i}$. For all other banks both variables are zero. This gives 24 dummy variables which fully characterize bidding in a specific operation for a specific strategy and can be used in an econometric exercise to extract bidding behavior in a specific operation but *conditioning* on the strategy of the bidder. In other words, we do not just use a dummy for, e.g. a pre-LTRO operation, but also indicate which strategy a bank had when it bid.

This characterization allows to form naïve unobserved counterfactuals. Assume that we observe two strategies $\{r_1, s_1, o_0, L_0\}_{t,i}$ and $\{r_1, s_1, o_0, L_1\}_{t,i}$ where the latter includes also bidding in the LTRO. A comparison of the two coefficients gives us the difference in bidding behavior in the MROs as a function of LTRO participation

[17] We do not use a sample selection correction approach as tests for validity indicate that the approach might be itself not valid; see section A.2 of the appendix for more explanations.

[18] Alternatively, one could systematically test for coefficient differences and then use only one model with the appropriate restrictions on coefficients. We plan to do this in future research.

[19] We can also form the interaction term with o but given that in this example a bank did not participate in such an operation, this will give a vector of zeros.

conditioning on bidding in an operation before the LTRO. In addition to only including a dummy, here we are able to look into the "black box" of the pre-LTRO operation. Note that the LTRO-effect is not only identified by exploiting differences within banks over time (as we do not observe sufficient many changes for one bank over time) but by exploiting also the differences between banks within one maintenance period. Although this characterization is far from perfect, it provides us with a tool to construct otherwise unobserved counterfactuals by comparing "statistical twins".

5.3.2 Regression Results: Basic Regressions and Simple Bidding Strategies

The first three models in table 8 replicate the regressions using MRO-data from the literature using established regressors. As the change in the operational framework might have impacted bank behaviour, in addition to using the full sample we also run the regressions separately for the two operational frameworks. For the regressions using the full sample we include a dummy for the new framework and find that the discount increased by about 1 basis point. When interpreting this result one has to take into account that as the length of the operation changed (from two weeks to one week) we accordingly adjusted the benchmark for computing the discount.[20] With the exception of a few cases, the results are qualitatively in line with the results from the previous research.

Medium and large banks bid at higher discounts. If banks had an increasing allotment over the the last two LTROs (Δ Awrat. LT), they bid less aggressively in the MRO. This is due to the fact that banks have a higher funding buffer originating form the last operation and can afford to bid at lower rates. Including the change in the award ratio of the MROs (Δ Awrat. MR), is not significant for the full sample and during the period of the old operational framework. Using the sample for the new period, the sign of this variable is positive confirming the message from above: higher than expected past realizations make banks to bid less aggressively. The two dummies for the last MRO in the maintenance period (Last MR MP) and the last MRO of the year (Last MR Year) are negative. In the last MRO of the maintenance period some banks might be inclined to bid more aggressively to obtain funds from the Eurosystem in order to fulfill their minimum reserve requirements. More aggressive bidding at the end of the year is a known seasonal phenomenon ("window dressing", liquidity hoarding).

Higher uncertainty and higher expected future refinancing costs (forward spreads) increase banks' aggressiveness. This is in line with theoretical research, e.g. Nyborg and Strebulaev (2004), examining the "winner's curse" or "losers nightmare" hypothesis with the negative sign speaking in favor of the latter. As a higher swap spread indicates more room for low bids, the coefficient on this variable should be (and is) positive. Award imbalance is the lagged value of the standard deviation of individual award ratios. A higher dispersion of past awards might indicate a larger dispersion of liquidity needs. If some banks want to avoid being short-squeezed in the secondary market they will bid more aggressively; hence the sign of this variable should be negative. This is the case for the full sample and the old but not for the new framework. After the change, higher dispersion in the previous operations is associated with less aggressive bidding. One explanation is that in the new framework banks do not have a buffer stemming from the last MRO limiting their scope and incentives for strategic bidding. In the old framework, a high allotment (expected or unexpected) in the past week provided incentives to bid at relatively low rates this week due to the presence of a buffer. As a strategic best-response reply, banks with liquidity needs had to bid at higher rates to secure funds in the auction. Given the absence of this adverse incentive, a higher past award imbalance might not induce more competition any more. This is due to the fact that in the new framework banks' position is reset to zero each week and bidding behavior will come closer to true liquidity needs without the necessity for more aggressive "precautionary bidding". In line with this poten-

[20] An exact decomposition of the effect of this change on the discount is not possible as for this we would have to account for the general equilibrium feedback effects. Alternatively, one could examine banks' bid rates in relation to the minimum bid rate.

tial change in behaviour, award imbalance for MROs (LTROs) dropped from 0.25 (0.30) to 0.19 (0.26) in the new framework.[21] The effect of the expected allotment size measured by the published benchmark (or level of autonomous factors) is unclear and depends on the sample. A positive coefficient confirms the hypothesis that higher total liquidity needs induce banks to bid at higher rates (Välimäki 2006). The intuitive explanation is that as the absolute volume of a tender increases, banks' uncertainty around their own (yet unknown) liquidity needs increases; hence a more aggressive bidding increases the probability of getting a higher allotment and insuring against a shortfall of liquidity. The effect of the outstanding liquidity from the LTRO has a very weak and inconclusive effect on bank bidding.

In the last three models in table 8 we add two binary variables capturing MROs before and after the LTRO. In this case, the base group is an MRO of type "other". In these models we practically replicate the descriptive statistics presented earlier but control for an array of other factors. The results of the standard variables used earlier are largely unchanged. The only exception is that for the new framework banks bid at a higher discount in the last MRO of the maintenance period. Further, a higher past allotment in the preceding MRO (i.e. higher "Δ Awrat. MR") increases banks' bid rates on average. This is mainly driven by observations from the old sample. During that period banks had the opportunity to build up liquidity buffers (voluntary or involuntary) and an increasing award ratio might signal increasing liquidity demand as they increased their borrowing (and did not just rolled over). This then induces banks to bid at higher rates.

The last two lines contain dummies indicating the position of the MRO relative to the LTRO. Banks bid significantly differen between pre- and post-LTRO operation. As a robustness check, we also run regressions with a set of dummies capturing how many weeks (or days) an MRO is before an LTRO (see tables 19 and 20 in the appendix). We find that banks are bidding least aggressively in the MRO one week before the LTRO and the discount is lower in the MROs being farther away from the LTRO.

Table 8: MRO Bid Rate Regressions: Traditional Models & Timing Indicators

	Standard Models			With Pre/Post Indicators		
	All	New	Old	All	New	Old
New Framew.	0.965***			0.950***		
Medium	0.509***	0.495***	0.568***	0.520***	0.491***	0.551***
Large	0.648***	0.698***	0.598**	0.659***	0.704***	0.550**
Δ Awrat. LT	0.069***	-0.009	0.197***	0.071***	-0.007	0.213***
Δ Awrat. MR	-0.031	0.037*	-0.016	-0.078***	-0.021	-0.060*
Last MR MP	-0.201***	-0.002	-0.305***	-0.185***	0.205***	-0.588***
Last MR Year	-7.836***	-7.640***	-9.228***	-7.508***	-7.451***	-9.139***
Uncertainty	-0.290***	-0.398***	-0.170***	-0.291***	-0.385***	-0.176***
Swap Spr.	0.200***	0.145***	0.348***	0.185***	0.132***	0.359***
Forw. Spr.	-0.098***	-0.091***	-0.085***	-0.087***	-0.083***	-0.099***
Award Imb.	-0.849***	2.142***	-0.988***	-1.206***	2.005***	-1.297***
Benchmark	-0.004***	-0.006***	0.009***	-0.004***	-0.006***	0.009***
Outst. LTRO	-6.E-08*	-2.E-08	8.E-08	-6.E-08*	-2.E-08	9.E-08
Pre LTRO				0.399***	0.678***	-0.251***
Post LTRO				-0.671***	-0.307***	-1.469***
Constant	1.611***	2.700***	-0.537*	1.706***	2.598***	0.091
R^2	0.28	0.43	0.26	0.30	0.45	0.29
N	98661	64063	34598	98661	64063	34598

Notes: Stars denote levels of significance: * p<0.1; ** <0.05; *** p<0.01. Results including standard errors / t-values available upon request. Random effect models with robust standard errors clustered on the MFI level. Regressions include country dummies. Base category is a small bank with a bid in a operation of type "other".

In table 9 we extend the analysis from above by looking more specifically at bidding before the LTRO

[21] Using a panel-probit model, one can show that the effect of lagged award imbalance on participation if significantly lower in the new framework. Results available upon request.

conditional on LTRO participation. In models "Pre/Post Dummy with Strategy"we repeat the previous exercise but break up the dummy for a bid in the Pre-LTRO operation into two dummies. The variable "Pre LTRO L=1" captures the bid of a bank prior to the LTRO having participated in the LTRO. The variable "Pre LTRO L=0" is a dummy for a bid in a pre-LTRO operation for a bank which did not bid in the LTRO. Both variables are – as expected from the previous models – positive. However, a more stringent test is to check for statistical difference between the two dummies We can reject equality of the two coefficients at conventional levels (see test statistics at the bottom of the table). This implies that banks bidding in the MRO before the LTRO bid at lower rates in general but if they participated also in the next LTRO, they bid even lower. In the last three models of table 9 (labeled "Only Pre-LTRO Sample") we re-estimate the regressions using only the operations before the LTRO and include a dummy if a bank bid in the following LTRO ("Bid in LTRO"). The coefficient on bidding in the LTRO is again positive and significant showing that bidding in the LTRO induces less aggressive bidding in the MRP before the LTRO.

We conclude with the finding that (controlling for various other variables) banks bid less (more) aggressively in the MRO before (after) the LTRO. Further, we also find evidence that banks bid less aggressively in the MRO before the LTRO if they also participate in the following LTRO. Obviously, bidding in the LTRO after a low bid rate in the MRO is endogenous: bidding at opportunistic rates in the MRO will leave the bank with a relatively low allotment forcing it to also come to the LTRO. However, note that we are interested precisely in this endogenous component in the MRO bidding as it reflects the bank's decision before knowing the outcome (of the MRO and LTRO). The notion of banks bidding less aggressively if they bid in the LTRO is not compatible with the argument that banks perceived a bad shock. In such a case, banks would bid more aggressively – the opposite of what is found. It is worth noting that the fit of the regressions in better using the sample from the new operational framework. One explanation is that the new framework is potentially a better laboratory as the sequencing of the operations is more regular. For instance, the old framework contains LTROs at the very end of the maintenance period which makes the preceding MRO to the last MRO of the maintenance period.This makes it more difficult to disentangle the two effects.[22]

5.3.3 Regression Results: Complete Bidding Strategies

Having focused on the relatively simple approach, we show regression results using variables picking up bidding strategies as defined in section 5.3.1 in table 10. The table is organized as follows: the upper part of the table contains the explanatory variables used in the previous regressions. The lower part of the table shows results for the strategy dummies. For instance, the sequence "s/o'' in the column "MRO" indicates that a bank bid in MROs after the LTROs and "other" operations. A "y" if the column "LTRO" indicates that a bank bid in the LTRO of that maintenance period. Lastly, the column "Pos." indicates what kind of position the respective bid had in the classification of MROs where we continue to follow the established convention (e.g. an "r" for MROs before the LTRO). Using the example from above we would use the dummy "s/o y o" to capture a bid from a bank with the strategy "s/o" and LTRO participation in an "other" operation. The variables are grouped logically with the first three blocks (four lines each) containing strategies of banks which bid in two operations, the middle block contains banks which bid in all type of MROs, and the last block shows results for banks which participated in only one operation. Note that the base category (constant) is a small bank bidding in all types of operations (all MROs and LTRO) and is hence shown in the line "r/s/o, cons.".

Looking at the coefficients for the standard variables we observe that the previously established results still

[22]Further, excluding the underbid operations still leaves the following operation (potentially more contested) in the sample. Also, we cannot exclude operations which were underbid by only some banks (i.e. "partially" underbid operations) as we do not have information to identify these operations or banks.

Table 9: MRO Bid Rate Regressions: Simple Strategies

	Pre/Post Dummy with Strategy			Only Pre-LTRO Sample		
	All	New	Old	All	New	Old
New Framew.	0.947***			2.685***		
Medium	0.517***	0.490***	0.546***	0.236*	0.318***	0.211
Large	0.653***	0.701***	0.543**	0.196	0.514***	-0.159
Δ Awrat. LT	0.074***	-0.004	0.215***	-0.079**	-0.040	-0.171**
Δ Awrat. MR	-0.080***	-0.020	-0.063*	-0.076**	0.004	-0.008
Last MR MP	-0.185***	0.205***	-0.588***	-0.910***	0.000	-0.939***
Last MR Year	-7.510***	-7.454***	-9.139***	-7.329***	-7.624***	0.000
Uncertainty	-0.291***	-0.385***	-0.176***	-0.188***	-0.190***	-0.101***
Swap Spr.	0.185***	0.132***	0.359***	0.294***	0.272***	0.331***
Forw. Spr.	-0.087***	-0.083***	-0.100***	-0.001	-0.017***	-0.002
Award Imb.	-1.208***	2.005***	-1.304***	-3.707***	-1.190***	-8.201***
Benchmark	-0.004***	-0.006***	0.009***	-0.013***	-0.018***	-0.001
Outst. LTRO	-6.E-08*	-2.E-08	8.E-08	-2.E-08	9.E-08	-6.E-08*
Pre LTRO L=0	0.371***	0.660***	-0.289***			
Pre LTRO L=1	0.466***	0.724***	-0.176***			
Post LTRO	-0.671***	-0.307***	-1.470***			
Bid in LTRO				0.18***	0.13***	0.27***
Constant	1.713***	2.599***	0.104	1.660***	5.361***	1.588***
R^2	0.30	0.45	0.29	0.43	0.53	0.34
N	98661	64063	34598	23001	15097	7904
F	7.72	4.83	3.60			

Notes: Stars denote levels of significance: * p<0.1; ** <0.05; *** p<0.01. Results including standard errors / t-values available upon request. Random effect models with robust standard errors clustered on the MFI level. Regressions include country dummies. Base category is a small bank with a bid in a operation of type "other", or a bank which did not bid in the LTRO.

hold. For the sake of brevity we skip a detailed discussion here but will focus on the variables capturing bid strategies where we highlight four key findings.

First, for any given strategy, banks bid prior to the LTRO (Pos. "r") with the highest discount. This does not depend on LTRO participation but is valid in general. Second, banks bid in general more aggressively in operations after the LTRO. However, the most aggressive bidding can be attributed to banks which bid in only that operation. Third, banks bidding in all operations ("r/s/o") bid always at relatively "moderate" rates. Note that they do not bid at very low rates before the LTRO and neither do they bid at high rates in the operation after the LTRO. This could be due to the fact that they have regular liquidity needs arising e.g. due to their role as liquidity distributors. It is rather unlikely that this relatively balanced bid strategy is followed by banks which have pressing liquidity needs (and have no market access). Banks hit by a negative liquidity show would bit more – and not less – aggressively. Fourth, banks bidding in only one type of operation have a relatively extreme bid strategy. In post-LTRO operations they bid about 1.8 basis points higher compared to a "regular bidder". Also, if they bid only immediately before LTROs or in "other" operations, their discount relative to the benchmark strategy is higher than of comparable operations from other strategies.

Table 11 shows a compact overview about the hypothesis whether banks bid less aggressively in the MRO if they also bid in the LTRO. The entries in the first 4 lines are p-values from testing the hypothesis H_0 : $\beta_r(\sigma_{i,L=1}) = \beta_r(\sigma_{i,L=0})$ separately by strategy type i. This hypothesis can be rejected for the strategy "r/b"and "r/s/o" and supports our hypothesis (as the coefficient with "y" is higher). However, for the strategy in which the bank bid only once ("r"), there is no significant difference between the pairs of coefficients. For the strategy "r/o" the results are unclear. For the old framework period the coefficient is significantly larger if a bank did not bid in the LTRO while it has the correct sign for the new period. In a nutshell, out of 12 possible cases we find confirmation for our hypothesis for five cases and we cannot reject equality of coefficients for 6 cases.

The coefficients have the "wrong" sign and the difference is significant in only one case (r/s, old period). The inclusion of the whole battery of dummies does not improve the R^2 (compared to the simpler models) much. Further, the relatively week performance of the model using the old sample persists.

In order to complement the individual tests, we conduct two alternative tests for joint statistical significance. The entries in the line "Joint 1" test the hypothesis that $\beta_r(\sigma_{i,L=1}) = \beta_r(\sigma_{i,L=1})$ jointly for all four strategies.[23] This tests whether banks' bidding behavior systematically differs in the pre-LTRO operation by participation in the LTRO. However, a rejection might imply that banks also bid more – rather than less – aggressively. Also, it might imply that they bid more aggressively for some strategies and less aggressively for others. Hence, although the rejection of this hypothesis (at 10% level) suggests that banks systematically bid *differently* by LTRO participation, this is not a conclusive proof of the main hypothesis. Lastly, we perform the test H_0 : $\sum_i^4 \Delta_i \geq 0$ with $\Delta_i = \beta_r(\sigma_{i,L=1}) - \beta_r(\sigma_{i,L=0})$, i.e. whether the sum of the individual differences in coefficients is non-negative. Here we want to test whether banks bid *on average* less aggressively if they bid in the LTRO. The p-values (line "Joint 2") are all above conventional rejection thresholds. This speaks in favor of the main hypothesis as we cannot reject the hypothesis that the sum is non-negative. [24]

Controlling for the full array of possible combinations has the potential of providing the most detailed information. The downside of this approach is, however, that the relatively small number of observations per strategy makes estimates less precise. To alleviate this problem, we compressed the complete strategies into broader categories but still retaining the feature of comparing bidding in an MRO before the LTRO conditional on the LTRO participation. We operationalized this by keeping the split/conditional dummies for the pre-LTRO operations but condensing bids fromm all other operations into one dummy. For instance "Bid in 3 op. types" stands for all other dummies if a bank bid in all three operation types; i.e. all other "r/s/o" dummies but the pre LTRO operation. Similarly, the dummy "r/o | r/s" (either before and "other" or before and after LTRO) summarizes all other bids from a bank participating in 2 operation types while we retain two dummies to control for conditional LTRO bidding. The results are shown in table 12 and are cleaner compared to the regression using the full battery of dummies. For banks bidding in two or three operation types banks bid less aggressively if they bid also in the LTRO. However, for the only "occasional" bidder there is no significant difference (and the sign being "wrong" for the old sample). Further, the result of less aggressive bidding before the LTRO still holds.

Summarizing, we conclude that the relatively large discount in operations before the LTRO is due to banks bidding only in one type of operation or banks bidding immediately before and after the LTRO. Regular bidders are more stable in their bidding strategy. This speaks in favor of banks adjusting their bidding strategy intentionally. A bid due to an unexpected negative liquidity shock would induce more (not less) aggressive bidding. On the other hand, the aggressive bidding after the LTRO is mainly caused by banks who bid exclusively in that operation and not by regular bidders. This can be rationalized by the best-response adjustment of bank behavior: if "short" banks after the LTRO must bid more aggressively, also the ones which happen to have liquidity needs at that particular point in time will adjust their bids up in order to secure their allotment (Cassola, Hortaçsu, and Kastl 2009). This up- and down pattern is also visible but much more muted for the regular bidders. Note that the difference in average MRO bid rates conditional on LTRO participation (e.g. tables 2 or 4) hides the fact that this difference does not come from bidding differently *in general* but bidding differently in the pre and post LTRO operations. Further, we find some evidence that in the MRO before the LTRO banks bid less aggressively if they bid also in the LTRO. The overall support for this hypothesis is stronger for the shorter regressions; a

[23] We do this as joint testing of sequential on-sided hypothesis for more than 2 pairs is not easily interpretable.

[24] When interpreting this result one has to bear in mind that just summing up the coefficients might be misleading. The reason is that the sum of all differences does not take the associated degree of dispersion of the individual coefficients into account. For instance, when doing this for the sample utilizing data from the old operational framework only, the sum is negative. This is in principle in contradiction to our main hypothesis but the the p-value for the hypothesis that this is larger than zero is 0.22.

Table 10: MRO Bid Rate Regressions: Complete Strategies

			All	New	Old
New Framew.			1.181***		
Medium			0.602***	0.520***	0.595***
Large			0.792***	0.756***	0.644***
Δ Awrat. MR			-0.147***	-0.011	-0.116***
Δ Awrat. LT			0.081***	-0.005	0.234***
Last MR MP			-0.171***	0.216***	-0.575***
Last MR Year			-7.596***	-7.424***	-9.179***
Uncertainty			-0.306***	-0.385***	-0.202***
Swap Spr.			0.185***	0.132***	0.329***
Forw. Spr.			-0.088***	-0.084***	-0.085***
Award Imb.			-1.261***	2.026***	-1.695***
Benchmark			-0.005***	-0.006***	0.008***
Outst. LTRO			-7.E-08**	-2.E-08	7.E-08
Strategy					
MRO	LTRO	Pos.			
r/o		r	0.449***	0.938***	-0.495***
r/o	y	r	0.770***	1.096***	0.080
r/o		o	0.120**	0.252***	-0.386***
r/o	y	o	0.251***	0.243***	-0.090
s/o		o	0.373***	0.086	0.331***
s/o	y	o	0.153***	0.135	0.142**
s/o		s	-1.738***	-0.151	-2.305***
s/o	y	s	-0.403***	-0.160	-0.533***
r/s		r	1.593***	0.752***	1.476***
r/s	y	r	1.219***	1.423***	0.500*
r/s		s	0.333*	-0.266	-0.259
r/s	y	s	-0.732*	-0.771***	-1.860***
r/s/o		r	0.509***	0.655***	0.069
r/s/o	y	r	0.620***	0.719***	0.237***
r/s/o		s	-0.271***	-0.286***	-0.530***
r/s/o	y	s	-0.213***	-0.241***	-0.503***
r/s/o		o	-0.070*	-0.025	-0.162***
r/s/o, cons.	y	o	1.334***	2.508***	-0.146
o		o	1.507***	0.332***	1.571***
o	y	o	0.707***	0.173**	0.848***
r		r	1.164***	0.721***	0.952***
r	y	r	1.203***	0.678***	0.790***
s		s	-1.747***	-0.766***	-2.900***
s	y	s	-1.846***	-0.950**	-3.477***
R^2			0.33	0.46	0.32
N			98661	64063	34598

Notes: Stars denote levels of significance: * p<0.1; ** <0.05; *** p<0.01. Results including standard errors / t-values available upon request. Random effect models with robust standard errors clustered on the MFI level. Regressions include country dummies. Base category is the bid of a small bank in an "other" MRO with the strategy to bid in all operations (r/s/o, cons.).

likely reason being that the full battery of dummies captures relatively more noise (due to the small number of observations per cell).

Table 11: Joint Hypothesis Tests

Strategy	All	New	Old
r/o	0.00	0.17	0.00
r/s	0.20	0.03	0.01
r/s/o	0.01	0.14	0.01
r	0.86	0.84	0.56
Joint 1	0.01	0.10	0.00
Joint 2	0.60	0.98	0.22

Notes: First four lines contain p-values for individual test for parameter equality.

Table 12: MRO Bid Rate Regressions: Complete Strategies, cont'd

			All	New	Old
New Framew.			1.169***		
Medium			0.684***	0.529***	0.772***
Large			0.950***	0.765***	0.960***
Δ Awrat. MR			-0.061***	-0.012	-0.034
Δ Awrat. LT			0.081***	0.000	0.222***
Last MR MP			-0.072***	0.256***	-0.391***
Last MR Year			-7.969***	-7.603***	-9.764***
Uncertainty			-0.300***	-0.376***	-0.200***
Swap Spr.			0.188***	0.136***	0.323***
Forw. Spr.			-0.090***	-0.088***	-0.072***
Award Imb.			-0.937***	2.149***	-1.047***
Benchmark			-0.004***	-0.006***	0.008***
Outst. LTRO			-7.E-08**	-2.E-08	6.E-08
Strategy					
MRO	LTRO	Pos.			
r/o | r/s		r	0.669***	0.911***	0.097
r/o | r/s	y	r	0.930***	1.186***	0.362***
Bid in 2 op. types			-0.081**	0.101**	-0.272***
r/s/o		r	0.535***	0.646***	0.153**
r/s/o	y	r	0.654***	0.748***	0.296***
Bid in 3 op. types			-0.129***	-0.134***	-0.276***
r/s/o, cons.	y	o	1.040***	2.491***	-0.927***
r		r	1.264***	0.726***	1.254***
r	y	r	1.305***	0.724***	1.068***
Bid in 1 op. types			1.132***	0.156***	1.274***
R^2			0.31	0.45	0.28
N			98661	64063	34598

Notes: Stars denote levels of significance: * p<0.1; ** <0.05; *** p<0.01. Results including standard errors / t-values available upon request. Random effect models with robust standard errors clustered on the MFI level. Regressions include country dummies. Base category is the bid of a small bank in an "other" MRO with the strategy to bid in all operations (r/s/o, cons.).

5.3.4 Bidding in LTROs

Results from models using data from the LTROs are displayed in table 14. We use the same set of explanatory variables as in the models examining bidding in the MROs. Our results for the standard variables are with a few exceptions in line with previous findings. We find that a higher past MRO allotment ("Δ Awrat. MR") decreases bid rates. Also, the last operation of the year is more contested, compared to other auctions. The effect of uncertainty is unclear. For the old period we find that higher uncertainty increases bid rates while for the new framework this variable has to opposite sign. This is in contrast to (Linzert, Nautz, and Bindseil 2004)

Table 13: Joint Hypothesis Tests, cont'd

Strategy	All	New	Old
r/o | r/s	0.01	0.01	0.07
r/s/o	0.00	0.01	0.02
r	0.85	0.99	0.51
Joint 1	0.00	0.00	0.03
Joint 2	0.95	0.94	0.74

Notes: First three lines contain p-values for individual test for parameter equality.

who find strong evidence for the winner's curse using data from 1999-2003. However, the results are not fully comparable as our sample starts only later using only 19 LTROs (instead of 50). Similarly to Linzert, Nautz, and Bindseil (2004) we find that banks react to interest rate expectations which is a puzzle as there is no constraining minimum bid rate. The sign of the swap spread is expectedly positive. For the award imbalance – similar to the MROs – we find that higher past dispersion increases bid rates in the old framework but has the opposite effect for the new one. Higher outstanding volumes from the LTRO incudes more aggressive bidding. This can be interpreted as regular LTRO bidders are typically relying on this source and hence are likely willing to pay a premium to obtain this funding.

We incorporate bidding in the MROs in two different ways. The first three models use dummies for banks which bid only in one operation type (i.e. identifying the occasional bidder) while the last three models only use a dummy if a bank bid in any of the other MROs of the maintenance period. We find that banks which bid in the LTRO and only before or after the LTRO bid at significantly higher rates compared to banks bidding in more than one operation. However, banks avoiding to participate in these two operation types "did not overpay" compared to their peers. Also, banks bidding only in the LTRO bid more aggressively. This is a well known fact as they seem to have a preference only for longer term financing (in that maintenance period) and are hence willing to pay a mark-up. The rightmost three columns are slimmed down versions of the first models by only using (similar to other papers) a dummy for a bank which bid in any other MRO of that maintenance period. As the base category here is a bank which did not bid in any MRO, we find – as in the other models – that bidding in the MRO allows banks to bid at lower rates. The explanatory power of the models applied to the LTRO data is in general lower (relative to MROs) and shows the difficulty to capture bidding behavior in the LTROs.

6 Conclusion

In this paper we used individual bidding data from the Eurosystem's tender operations to examine banks' strategic behavior in the context of joint bidding in MROs and LTROs. We ask the question whether banks' bidding pattern in MROs depends on their participation in the LTROs. More specifically, we are interested whether banks bid at lower rates in MROs close to the LTRO as they have two bid opportunities within a short period or time.

We have three main findings. First, banks bid differently in operations immediately before and after an LTRO. More specifically, in MROs prior to the LTRO banks bid at relatively low rates. In operations after the LTRO banks bid at substantially higher rates. This can be rationalized by two complementing explanations. To start with, banks which went out empty handed from the MRO and LTRO are forced to bid at more aggressive rates. However, also banks who have liquidity needs in that particular operation are forced to bid at higher rates (as a strategic response) in order to obtain some funding. Consequently, the aggregate bid rate will be higher.

Second, banks which bid in the LTRO bid in general at lower rates compared to non-participants in the

Table 14: LTRO Bid Rate Regressions: MRO Timing Variables

	With MRO Participation Dummy			With Strategy Dummies		
	All	New	Old	All	New	Old
New Framew.	1.498***			1.510***		
Medium	0.219	0.707**	0.173	0.233	0.705**	0.189
Large	2.026***	2.084***	2.731***	2.066***	2.074***	2.786***
Δ Awrat. MR	0.117	0.001	0.171	0.095	-0.092	0.147
Δ Awrat. LT	-0.022	-0.060	0.123	-0.023	-0.062	0.121
Last MR Year	-1.660***	-1.426***	-2.982***	-1.692***	-1.438***	-2.974***
Uncertainty	-0.079	0.392***	-0.166**	-0.087*	0.388***	-0.181**
Swap Spr.	0.297***	0.011	0.458***	0.297***	0.012	0.454***
Forw. Spr.	-0.195***	-0.050***	-0.298***	-0.195***	-0.050***	-0.296***
Award Imb.	-6.028***	0.966***	-4.737***	-6.011***	0.991***	-4.800***
Benchmark	0.005	0.035***	0.270***	0.005	0.035***	0.266***
Outstand. LTRO	-2.E-07**	-1.E-07***	-1.E-06***	-2.E-07**	-1.E-07***	-1.E-06***
pr1pst0n0LT1	-0.359*	-0.302	-0.514**			
pr0pst1n0LT1	-0.548**	-0.405**	0.173			
pr0pst0n1LT1	0.071	0.275*	0.011			
pr0pst0n0LT1	-0.588***	-0.123	-0.569***			
Bid in MRO				0.528***	0.131	0.518***
Constant	2.843*	2.267	-1.183	2.261	2.143	-1.701
R^2	0.18	0.12	0.26	0.18	0.12	0.26
N	11094	6558	4536	11094	6558	4536

Notes: Stars denote levels of significance: * p<0.1; ** <0.05; *** p<0.01. Results including standard errors / t-values available upon request. Random effect models with robust standard errors clustered on the MFI level. Regressions include country dummies.

LTRO. They also bid for larger amounts and bid more frequently in the MROs prior to the LTRO. We provide – albeit somewhat weaker – econometric evidence that banks bidding in the LTRO bid at lower rates in the MRO immediately preceding the LTRO. Further, the relatively large differences in average bid rates of MROs before and after an LTRO are mostly due to banks bidding in only those operations and not to frequent bidders. More frequent bidders are rather rather stable in their bidding patterns over all operations.

Third, we show that banks bidding in the LTRO follow a more persistent bidding strategy. If they bid in the LTRO at the end of a sequence of MROs, their probability to move to a "less aggressive" quintile of the bid distribution is higher. Also, they are less likely to drop out from the operations. In all exercises we control for size in order to account for issues related to access to wholesale markets, resources to participate in operations, etc.

A Appendix

A.1 Imputation of Minimum Reserves

We follow the literature and use the minimum reserve requirements (MRR) to group the banks into different size categories.[25] However, before July 2012 data on MRR were only collected by national central banks and are hence not available for the entire time span for all banks. In order to fill these gaps, we developed an imputation procedure. To start with, we compute the average bidding amount per maintenance period t for bank i and denote this by $\bar{b}_{i,t}$. Denoting the MMR for bank i in period t by $mrr_{i,t}$ we estimate county by country models of the form

$$mrr_{i,t} = a_1 \bar{b}_{i,t}^{a_2 + \mathbb{1} a_3}, \tag{1}$$

where $\mathbb{1}$ is an indicator function (dummy) taking on the value of 1 for the crisis period starting in August 2007. Then, we use the estimated parameters to impute the missing minimum reserve requirements. More complicated models including also other variables did not significantly improve the in-sample forecast performance.

We then re-scale the individual MRR (observed and imputed) by the eurozone *aggregate* MRR. Then, we use these numbers to compute the average rescaled individual MMR, i.e. $\bar{mrr}_i = \frac{1}{T}\sum_{t=1}^{T} mrr_{i,t}$ for all banks. This procedure ensures that we have one proxy per bank and this number is not distorted by the time when a bank enters the dataset as we use the "real" MRR for classification purposes. Finally, we group banks into three groups where banks are considered to be "small" if they are in the lowest quintile, "large" if they are in the upper quintile and banks in quintiles 2-4 are classified in the "medium" category. However, we delete some underbid operations after the grouping exercise which leads to a deviation from the above mentioned relative group sizes.

Table 15 and 16 below provides an evaluation of the imputation exercise. We overestimate the number of small banks and underestimate the share of medium sized banks. Note that the shares do not correspond to quintiles as the number of observations is not evenly distributed across banks as we apply the grouping rule per bank and not per observation so that banks are not allowed to switch between groups. In table 16 we summarize some moments of the observed and imputed data. On can see that the in sample prediction is rather close to the data. We also can replicate small values for the reserve requirement but fail to produce large outcomes. The out of sample prediction with a mean of 196 mln is also close to the observed mean of 192 mln. However, the model has some difficulties to perfectly match the distribution for small and medium sized banks.

Table 15: Distribution of Banks

Group	Observed	Imputed
Small	42.8%	45.3%
Medium	39.9%	38.6%
Large	17.2%	16.1%

A.2 Identification of Selection Bias

In this paper we do not follow previous research using the two-step selection approach by initially estimating a probit model and then including the Inverse Mill's Ratio (IMR) as an explanatory variable in the second stage. The reason is that identification without an exclusion restriction can be in practice very problematic, if not

[25] Alternatively one can also use the bidding volume to group banks, see e.g. Bindseil, Nyborg, and Streubulaev (2009).

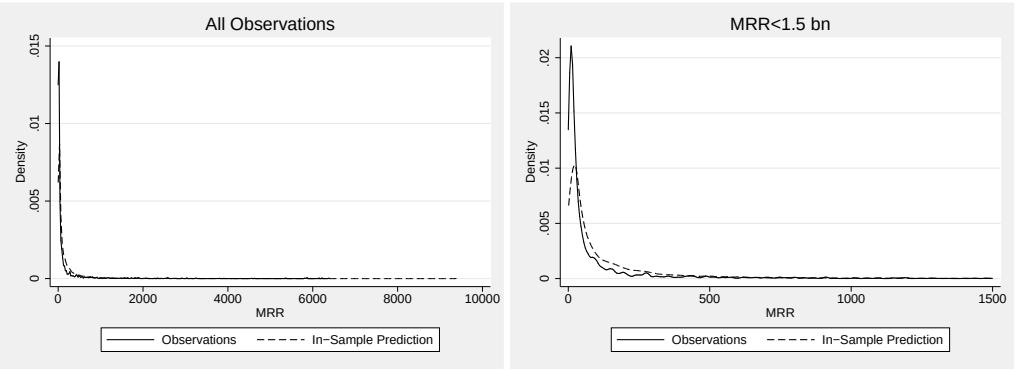
Table 16: Moments of MRR: data vs. imputation

Variable	N	Mean	Std. Dev.	Min	Max
In Sample	10523	201	503	1	9387
Data	10523	192	639	0	6382
In+Out Sample	53175	176	458	0	8141

Notes: Volume in EUR millions.

Figure 5: Backfitting MRR Imputation

(a) All Observations (b) MRR<1.5 bn



Notes: Histogram of observed and imputed MRR. The right graph is a replication of the left with a cut-off point for MRR at 1500 to enhance visibility of small values.

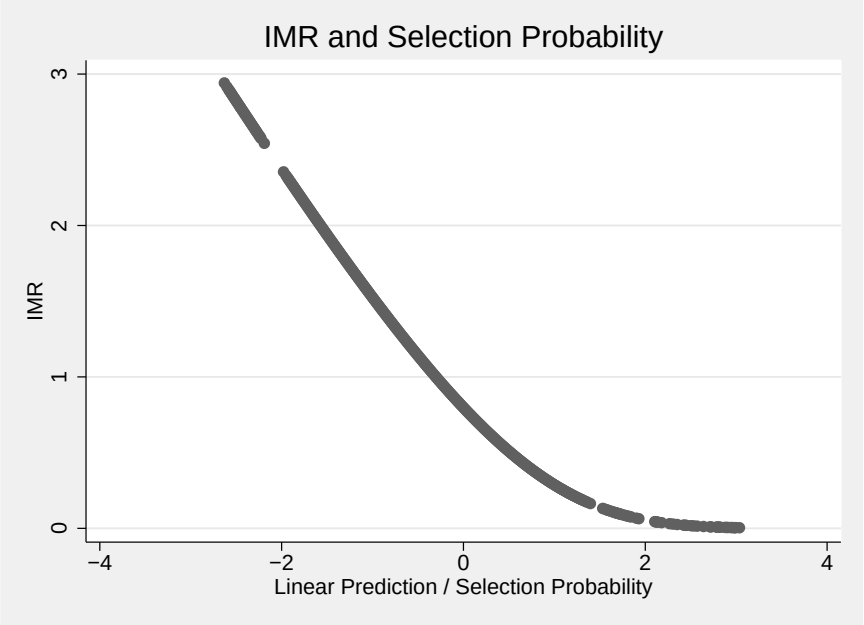
misleading ((Puhani 2000). Technically, the IMR is a linear combination of the explanatory variables; i.e. a function of $x\beta$ with β being the coefficient vector from the fist stage selection equation. If there is little variation in x, then the relationship between explanatory variables and IMR is close to linear which then introduces a severe collinearity problem in the second stage. To show this, we plot the relationship between IMR and the predicted selection probability from the first stage probit model in figure 6 which clearly demonstrates that this relationship is has very little curvature. A more stringent test is to run a regression with the IMR being the dependent variable and explained by the other variables. The results of this regression are in table 17. The first column ("Participation") is the first stage selection process and the second column ("Discout") is the second stage including IMR to control for the selection bias. The column "IMR" shows the results of the regression explaining IMR as a function of the selection/identification variables. The last column provides the standardized (β) coefficients of the IMR-regression. The coefficients of all variables have expected (i.e. economically meaningful) signs. However, two observations stand out. First, the R^2 in the IMR-regression is 0.996 which means that the selection equation is perfectly explained. Second, the two most important coefficients in explaining this are the size dummies. These arguments demonstrate that this approach is technically feasible but not valid as identification is based only on non-linearity which is violated. Hence, results from selection models applied to ECB auction data using this setup should be interpreted with care.

Table 17: Robustness Check of Selection Procedure

	Participation	Discount	IMR	β
IMR		1.473***		
New Framew.	0.099***	1.139***	-0.075***	-0.108
Medium	0.651***	1.277***	-0.489***	-0.703
Large	1.438***	2.334***	-1.037***	-1.224
Δ Awrat. LT	0.025***	0.089***	-0.018***	-0.014
Δ Awrat. MR	-0.086***	-0.112***	0.062***	0.052
Last MR MP	0.000	-0.202***	0.000***	0.000
Last MR Year	-0.014	-7.605***	0.010***	0.004
Uncertainty	0.003*	-0.295***	-0.002***	-0.010
Swap Spr.	0.002**	0.189***	-0.001***	-0.018
Forw. Spr.	0.000	-0.089***	0.000***	-0.007
Award Imb.	0.391***	-0.658***	-0.292***	-0.066
Benchmark	0.000***	-0.004***	0.000***	-0.100
Outst. LTRO	0.000***	0.000***	0.000***	-0.031
Pre LTRO	0.018***	0.404***	-0.013***	-0.017
Post LTRO	-0.024***	-0.713***	0.017***	0.021
Constant	-1.622***	-1.619**	1.982***	
R^2	0.093	0.304	0.996	
N	347170	98661	347170	

Notes: Stars denote levels of significance: * p<0.1; ** <0.05; *** p<0.01. Results including standard errors / t-values available upon request. Random effect models with robust standard errors clustered on the MFI level. Regressions include country dummies. "Participation" denotes the participation/selection equation, "Discount" denotes the second stage regression including Inverse Mill's Ratio (IMR), "IMR" is a regression with IMR as dependent variable, and "β" are the standardized coefficient from the corresponding IMR-model. The explanatory variables are as defined in the main text. Participation estimated with a Probit model, IMR as OLS.

Figure 6: IMR and Selection Probabilities



A.3 Supplementary Material

A.3.1 Distribution of Bidding Strategies

Table 18 shows the distribution of bidding pattern in MROs. The left column (is the proportion of banks not bidding in the LTRO) and the right column shown the frequency of strategies among LTRO bidders. The two columns add up to 100%.

Table 18: Distribution of Bidding Strategies

MRO	No LTRO bid	LTRO bid
r	1.2%	0.4%
r/s	0.5%	0.2%
r/o	2.7%	0.7%
r/s/o	14.5%	6.5%
s	0.9%	0.3%
s/o	2.9%	1.0%
o	4.5%	0.7%
no bid	59.4%	3.5%

A.3.2 Robustness Checks with Timing Variables

Table 19 contains regressions with discount as the dependent variable but adding dummies capturing the distance of each MRO *before* the next LTRO. The first models replicate the results reported in the main text. We measure the distance to an LTRO in days which are then translated into indicators where we use the length of one week as a benchmark. Practically, *distance* is defined as follows: 1=0-8 days; 2=9-16 days; 3=17-23 days; 4=more than 23 days before the LTRO.[26] Note that this is an asymmetric measure capturing the time before the LTRO. The results are shown in figure 7. We show also the difference in participation whereby participation in the operation being 4 weeks away is set to zero. As can be seen, the closer the next LTRO is (4 is far away), the lower is the discount. While operations being two or three weeks away seem to be roughly similar in terms of bidding behavior, operations one month before the next LTRO are clearly more contested and command a much lower discount. The operation being less than one week away has the highest discount. Participation is also monotonically increasing towards the LTRO with small banks bidding about 15% more often one week before the LTRO. When interpreting the results one has to keep in mind that a distance of 4 is an MRO after the LTRO while 1 corresponds to a pre-LTRO operation. Hence, the figure shows that there is a sizable difference between 1 and 4 and weeks with 2 and 3 weeks being clearly in the middle.

The second alternative measure is to look only at the MRO before the LTRO. We do this by including only the dummy for an MRO being 0-2 days before the LTRO. Table 20 contains the regression results. The discount relative to all other operations in significantly higher by about 0.2-0.5 basis points.

[26] Alternatively, one can just capture the number of MROs instead of categorizing them. We chose this option as the sequencing of MROs is not equally distributed and our scaling ensures that we have all MROs in 4 categories.

Table 19: MRO Bid Rate Regressions: Timing Variables

	With Pre/Post Dummies			With Distance Indicators		
	All	New	Old	All	New	Old
New Framew.	0.950***			1.243***		
Medium	0.520***	0.491***	0.551***	0.537***	0.511***	0.573***
Large	0.659***	0.704***	0.550**	0.684***	0.730***	0.608***
Δ Awrat. LT	0.071***	-0.007	0.213***	0.068***	-0.013	0.200***
Δ Awrat. MR	-0.078***	-0.021	-0.060*	-0.071***	-0.005	-0.055*
Last MR MP	-0.185***	0.205***	-0.588***	-0.177***	0.494***	-0.598***
Last MR Year	-7.508***	-7.451***	-9.139***	-7.287***	-7.395***	-8.109***
Uncertainty	-0.291***	-0.385***	-0.176***	-0.270***	-0.360***	-0.139***
Swap Spr.	0.185***	0.132***	0.359***	0.196***	0.126***	0.351***
Forw. Spr.	-0.087***	-0.083***	-0.099***	-0.091***	-0.079***	-0.087***
Award Imb.	-1.206***	2.005***	-1.297***	-1.707***	1.300***	-1.991***
Benchmark	-0.004***	-0.006***	0.009***	-0.006***	-0.008***	0.008***
Outst. LTRO	-6.E-08*	-2.E-08	9.E-08	-6.E-08*	-2.E-08	8.E-08
Pre LTRO	0.399***	0.678***	-0.251***			
Post LTRO	-0.671***	-0.307***	-1.469***			
Dist.: 1w				1.066***	0.900***	1.538***
Dist.: 2w				0.490***	-0.042**	1.243***
Dist.: 3w				0.391***	-0.036*	0.867***
Constant	1.706***	2.598***	0.091	1.109***	2.864***	-1.465
R^2	0.30	0.45	0.29	0.30	0.46	0.27
N	98661	64063	34598	98661	64063	34598

Notes: Stars denote levels of significance: * p<0.1; ** <0.05; *** p<0.01. Results including standard errors / t-values available upon request. Random effect models with robust standard errors clustered on the MFI level. Regressions include country dummies. Base category is a small bank with a bid in a "other" operation (pre/post dummies) or with a bid four weeks away from the LTRO (timing variables).

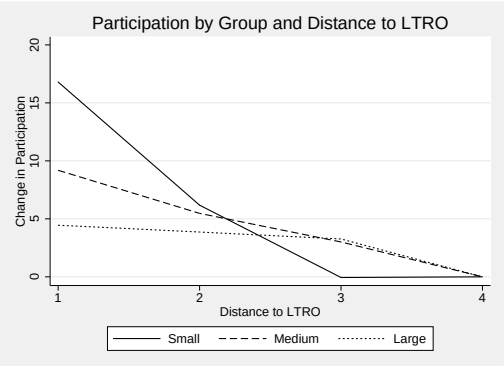
Table 20: MRO Bid Rate Regressions: Timing Variables (2)

	All	New	Old
New Framew.	0.966***		
Medium	0.511***	0.487***	0.570***
Large	0.653***	0.698***	0.602**
Δ Awrat. LT	0.072***	-0.007	0.197***
Δ Awrat. MR	-0.063***	-0.017	-0.022
Last MR MP	-0.077***	0.242***	-0.293***
Last MR Year	-7.772***	-7.615***	-9.178***
Uncertainty	-0.283***	-0.375***	-0.168***
Swap Spr.	0.194***	0.138***	0.342***
Forw. Spr.	-0.094***	-0.088***	-0.080***
Award Imb.	-0.941***	2.176***	-1.028***
Benchmark	-0.004***	-0.006***	0.009***
Outst. LTRO	0.000*	0.000	0.000
Dist.: 0-2 days	0.512***	0.749***	0.162***
Constant	1.466***	2.513***	-0.609
R^2	0.29	0.45	0.26
N	98661	64063	34598

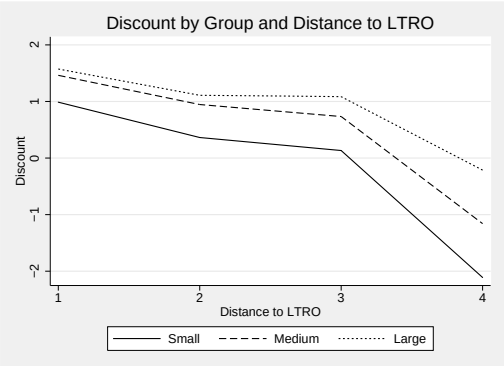
Notes: Stars denote levels of significance: * p<0.1; ** <0.05; *** p<0.01. Results including standard errors / t-values available upon request. Random effect models with robust standard errors clustered on the MFI level. Regressions include country dummies. Base category is a small bank bidding in MRO longer than 2 days away from the LTRO.

Figure 7: Number of Bids, Discount, and Participation by Distance to LTRO

(a) Number of Bids



(b) Discount



Notes: Distance to LTROs measured in days which were translated into weeks. "Distance" is defined as follows: 1=0-8 days; 2=9-16 days; 3=17-23 days; 4=more than 23 days before the LTRO.

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