Title
Bidding and Performance in Repo Auctions: Evidence from ECB Open Market Operations

Authors
Bindseil, Ulrich
Nyborg, Kjell G.
Strebulaev, Ilya A.

Publication Date
2004-02-01

Bidding and Performance in Repo Auctions: Evidence from ECB Open Market Operations[1]

Ulrich Bindseil Kjell G. Nyborg Ilya A. Strebulaev

This draft: February 2004

[1]We wish to thank the ECB's Front Office Division for providing secondary market data and Jean-Louis Schirmann for helpful discussions on the microstructure of the euro area money market. We also wish to thank Philipp Hartmann, Harry Paarsch, Witold Rutkowski, Kristian Rydqvist, Anderson Silva, as well as seminar participants at Arizona State University, Carnegie Mellon, Cass Business School, European Central Bank, Norges Bank (Norwegian Central Bank), Norwegian School of Economics (NHH), University of California - Los Angeles, University of North Carolina, Zürich, and the following conferences, American Finance Association (Washington DC, 2003), Auctions and Market Design (Fondazione Eni Enrico Mattei, Milan, September 2003), European Finance Association (Berlin, 2002), for comments and suggestions. Nyborg would like to thank the ECB's Directorate General Research for its invitation to a research stay in the autumn of 2001, when much of this research was carried out. Strebulaev would like to thank the ECB for the opportunity to visit it for the purpose of this research project. Bindseil: European Central Bank, Kaiserstrasse 29, D-60311 Frankfurt am Main, Germany, email: ulrich.bindseil@ecb.int. Nyborg: UCLA Anderson School of Management, Box 951481, Los Angeles, CA 90095; CEPR. Email: kjell.nyborg@anderson.ucla.edu. Strebulaev: London Business School, Regent's Park, London NW1 4SA, email: istrebulaev@london.edu.

Abstract

Bidding and Performance in Repo Auctions: Evidence from ECB Open Market Operations

Repo auctions are multiunit auctions regularly used by central banks to inject liquidity into the banking sector. Banks have a fundamental need to participate because they have to satisfy reserve requirements. Superficially, repo auctions resemble treasury auctions; the format and rules are similar and there is an active secondary market for the underlying asset. However, using a bidder level dataset of the European Central Bank's main repo auctions, we find evidence that the economic issues in repo auctions may be very different. Unlike what has been documented in the treasury auctions literature, we find no evidence that private information and the winner's curse are important issues. Instead our findings suggest that bidders are more concerned with the loser's nightmare, collateral, and future interest rate reductions by the ECB. Small and large bidders use different strategies, with large bidders performing better.
JEL Classification Numbers: G21, G12, D44, E43, E50.
Keywords: Repo auctions, multiunit auctions, reserve requirements, loser's nightmare, money markets, central bank, collateral, open market operations.

1 Introduction

In central bank repo auctions, banks submit bids for borrowing central bank funds on a collateralized basis. These are among the most economically significant multiunit auctions in practice. They are widely used to conduct open market operations and are at the heart of the money markets in many countries or currency areas. For example, the Federal Reserve Bank holds daily repo auctions for several billion dollars each and the European Central Bank (ECB) holds weekly repo auctions with an average size of around 90 billion euros where hundreds of banks participate. In this paper, we study repo auctions empirically using bidder level data from the ECB. We use this data to map out some of the economic issues that are important in repo auctions in general and also study some issues that are more specific to the euro area. For example, we address issues such as what sort of strategies do bidders employ, how do these affect auction performance, and what are the primary drivers behind bidding and performance? The answers to these questions should provide useful inputs to theorists aiming to build realistic models of multiunit auctions and to the policy makers who design them. On a more descriptive level, the paper also provides an overview of the role repo auctions play in the implementation of monetary policy in the euro area.

Superficially, repo auctions resemble treasury auctions; the format and rules are often the same and there is an active secondary market for the underlying asset. In treasury auctions, the primary concern for the seller is raising funds at as low a rate as possible. Bidders hope to make a profit by reselling in the secondary market. The empirical evidence shows that private information and the winner's curse is a key factor and that underpricing is decreasing in the level of uncertainty [see, e.g., Cammack (1991) and Nyborg, Rydqvist and Sundaresan (2002)]. However, because the set of economic issues are potentially quite different, the conclusions on multiunit auctions drawn from the treasury auction literature do not necessarily carry over to repo auctions.

In repo auctions, the primary concerns for the central bank are to inject the right amount of central bank money to ensure that the short term interbank rate stays around the target level and that banks can cover their liquidity needs, including satisfying reserve requirements. From the bidders' perspective, an important reason for participating in the auction is that they may need the funds to satisfy reserve requirements. Furthermore, the alternatives of borrowing from the standing facility of the central bank or in the interbank market may be more costly. For example, in the euro area the ECB's *lending facility* is 100 basis points above the minimum bid rate in the auction. Similarly, the primary credit facility in the US is 100 basis points above the federal funds target rate.[1] In the interbank market, banks that are short on liquidity face the risk that they will be squeezed, having to pay a premium for obtaining the funds they need. In sum, in repo auctions many banks may be more concerned with the loser's nightmare (Simon, 1994) than the winner's curse; they may be more concerned with covering their liquidity needs than borrowing in the auction with a view to resell (lend) at a profit in the secondary market. It is an open empirical question, which we address in this paper, what factors influence bidders in repo auctions in practice.

Our dataset includes each individual bidder's set of bids in 53 consecutive ECB repo auctions, starting in June 2000 when the ECB switched from fixed rate tenders to discriminatory (pay your bid) auctions.[2] All bids are for two-week money and specify a quantity and a borrowing rate. Unique bidder codes allow us to follow each bidder over time. There are no "customer bids." This allows a potentially less noisy inferences on bidder behavior than what has been possible in the treasury auction literature (see, e.g, Nyborg, Rydqvist, and Sundaresan, 2002). The auctions follow a regular cycle; there is one every Tuesday morning. Thus there are up to five regularly scheduled repo auctions within each monthly reserve maintenance period and at any time there are two sets of repos outstanding. Each auction is timed to coincide with the repayment of loans from a previous auction, providing banks with the opportunity to refinance when loans fall due. Indeed, the repo auctions we study are officially known as the ECB's *main refinancing operations.*

Some of our findings parallel those documented in treasury auctions. For example, the auctions are underpriced in the sense that is cheaper, on average, to borrow in the auctions than in the interbank market. We also find that bidders make use of the rich strategy space that is available to them; they typically submit multiple bids and adjust

[1] For the Fed's revised discount window rules, including the primary credit facility, see the press release at http://www.federalreserve.gov/boarddocs/press/bcreg/2002/200210312/. For the ECB, see http://www.ecb.int.

[2] The ECB's fixed rate tenders are studied empirically by Breitung and Nautz (2001). Nyborg and Strebulaev (2001) develop a theoretical model.

their bids in a systematic fashion to exogenous factors. However, the way they do so is very different from in treasury auctions.

First, we find that as volatility increases, bidders shade their bids less and underpricing falls. This is the opposite of the normal finding in treasury auctions [Nyborg, Rydqvist, and Sundaresan (2002), Keloharju, Nyborg, and Rydqvist (2002), Bjønnes (2001)]. Thus, in contrast with treasury auctions, private information and the winner's curse do not appear to be important considerations in the repo auctions we study. Instead, our finding on volatility may reflect that bidders *need* the money from the auction (to satisfy reserve requirements) and are risk averse with respect to the alternative of borrowing in the interbank market. Such risk aversion could arise if bidders are concerned about the loser's nightmare; the fewer units a bidder wins, the higher is his chance of being squeezed. When the interbank rate exhibits more volatility, it may be more difficult for bidders to predict the stop-out rate in the auction and therefore they shade less to decrease the chance of being squeezed. A theoretical model by Nyborg and Strebulaev (2004) predicts that the possibility of short squeezing induces more aggressive bidding when short positions are larger. So our finding on volatility could arise if a high volatility is associated with more extreme short positions.

Second, we find that auction size matters; bid shading and underpricing are increasing in auction size. In contrast, the evidence from treasury auctions is that auction size has hardly any effect (Nyborg, Rydqvist, and Sundaresan, 2002). Given the collateralized nature of the loans obtained from the auction, our finding suggests that bidders are collateral constrained in the sense that they have limited quantities of the cheapest acceptable collateral. We also find that banks "cycle"; that is, they participate more heavily every second auction. This could be consistent with a loser's nightmare story. If a bank borrowed heavily two auctions ago, then it will have a large refinancing need in the current auction (unless it has taken countervailing trades in the meantime) and therefore bids aggressively. Cycling could also be consistent with bidders being collateral constrained since collateral that was used in last week's auction may not available for this week's auction. All in all, our findings stand in sharp contrast with the findings of the treasury auctions literature and suggest that developing models emphasizing positions, or reserve balances relative to requirements, collateral, and interactions with the secondary market is important to fully understand repo auctions.

The variable that has the most significant explanatory power with respect to bidder behavior is the level of the two week interbank rate relative to the minimum bid rate. As the spread between these two rates fall, bidders shade less, disperse less, and submit fewer bids. Bidders also start dropping out of the auction. These findings suggest that the minimum bid rate is a binding constraint. This may reflect collateral considerations, but can also reflect expectations that the ECB will lower the minimum bid rate in time for the next auction. Such expectations can lead to the situation that banks demand less in aggregate than what they collectively need to satisfy reserve requirements. This is known as *underbidding* and occured twice during the sample period.

Underbidding is viewed as a problem from the ECB's perspective because it disrupts the implementation of monetary policy and leads to an increase in the volatility of interbank rates.[3] It is also costly for the banking sector since the liquidity shortfall must be made up by borrowing at the ECB's lending facility. Banks that borrow more in the auction than what they need to satisfy reserve requirements provide a positive externality to other banks, since this reduces the collective recourse to the use of the lending facility. So underbidding is fundamentally a free-riding problem; when rates are expected to fall, each bank is relying on other banks to borrow sufficiently much in the auction to allow the bank to obtain the reserves it needs in the interbank market at a reduced rate once the ECB announces lower rates for the future. Standard externality arguments [Olsen and Zeckhauser (1966), Bergstrom, Blume, and Varian (1986)], would suggest the underbidding problem to be driven by smaller banks free-riding on larger banks. Instead, we find something of a reverse free-rider problem; in the underbid auctions, the largest bidders cut back demand more than the smallest ones.

We also study differences in bidding behavior and performance among differently sized bidders in more generality. An important feature of the ECB's repo auctions is that there are hundreds of bidders, from large international banks to small local cooperatives. We document that large bidders systematically borrow at lower rates in the auctions than small bidders. This is not driven by market timing or differences in bid shading; large bidders do not borrow more in auctions that are more heavily underpriced and they do not shade

[3]To try to deal with the underbidding problem, in November 2001 the ECB switched from a bi-monthly to a monthly review of the minimum bid rate. This has not helped; since then, several more auctions have been underbid.

their bids more than small bidders. It appears that large bidders do better because they have "smarter" strategies. In particular, they use more bids and have more kurtosis in their bid distribution than small bidders. Large bidders' superior performance may reflect that they have more at stake and therefore put more resources into the bidding process. Another possibility is that it reflects access to a greater range of collateral.

The rest of this paper is organized as follows. Section 2 describes the data and the role of the auctions in the ECB's operational framework. Section 3 raises some theoretical considerations. Section 4 contains the main empirical analysis, and Section 5 studies differences in behavior between large and small bidders. Section 6 concludes. An appendix contains the estimation of the conditional volatility of the two-week rate.

2 Data and Markets

2.1 Background

The ECB conducts its open market operations exclusively as repo auctions where it injects liquidity into the banking sector. Unlike the Fed, the ECB has never conducted operations to remove liquidity. Besides the repo auctions, there are two additional core features of the ECB's operational framework.[4] First, the ECB requires banks in the euro area to hold minimum reserves as an average over the reserve maintenance period.[5] These requirements are announced at the beginning of each maintenance period and the bulk of the reserves are then supplied through the repo auctions (ECB, 2002a). Second, at any time, banks can obtain overnight credit (against collateral) through the marginal lending facility and they can make deposits at the deposit facility. These rates are 100 basis points above and below, respectively, the minimum bid rate in the auction, making the auctions a more attractive source of liquidity for banks. Because the auctions are the main source of reserves for banks and because they *must* satisfy reserve requirements, banks have a need to participate in the auctions. Banks that do not obtain sufficient reserves in the auctions and cannot find what they need in the interbank market, *must* make up the shortfall at the end of the reserve maintenance period by borrowing at the lending facility.

[4]For a more detailed account, see ECB (2002a).

[5]During the sample period, a new reserve maintenance period starts on the 24th of each month.

Short term interbank rates are influenced by the size of the auctions relative to reserve requirements. If the auctions are "small" so that at the end of the maintenance period liquidity is in short supply, banks will have to use the marginal lending facility and the overnight rate will rise. On the other hand, if the auctions are "large" so that liquidity is abundant, banks will have to use the deposit facility and the overnight rate will fall. The ECB's policy is to steer liquidity conditions in a neutral way; that is, to adjust auction volumes so that banks can be expected to precisely fulfill their reserve requirements over the monthly period and so that aggregate reserve surpluses and deficits are equally likely (ECB, 2002b). There is some residual uncertainty, however, because it is difficult to exactly forecast exogenous flows to and from the banking sector, for example due to the collection of taxes, and because the last auction in each maintenance period is usually held a few days before the end of the period. As a result, at the end of the maintenance period the overnight rate typically either spikes up or down, as documented by Hartmann, Manna, and Manzanares (2001) or Figure 2 below. Under a liquidity neutral policy, fluctuations in the overnight rate at other dates in the reserve maintenance period can occur because of expectations of changes to the minimum bid rate and the standing facilities or because of changes in the relative market power between banks that are short and long reserves relative to their average requirements.

2.2 The Auctions

For this study, the ECB compiled a file with individual bidding data and summary statistics for its main repo auctions over a one year period, starting with the auction held on 27 June 2000 and ending with the auction held on 26 June 2001. The dataset contains the complete set of bids, broken down by bidder, in all 53 main repo auctions (main refinancing operations) held during this period.[6] The auctions are scheduled well in advance; the intended timing of all regular operations in a year are announced three months before the start of the year. There is a main refinancing operation every week. The terms are typically announced on Mondays, 3.30 pm through wire services, and the deadline for

[6] Once a month, the ECB also holds *longer-term refinancing operations* with a maturity of three months. We do not study these auctions. The ECB may also hold non-regular, fine-tuning operations with non-standard maturities, for example overnight, but none occurred during the sample period.

submitting bids is typically on Tuesdays, 9:30 am. Results are announced the same day at 11:20 am. Winning bids are settled the following business day. In each auction, each bidder can submit up to 10 bids which are rate-quantity pairs for two week money. The tick size is 1 basis point and the quantity multiple is 100,000 euros. Unlike US Treasury auctions, for example, there are no non-competitive bids. In total, our sample contains 29,833 individual demand schedules from 1,199 different bidders, coming from all twelve euro area countries. The auctions are all discriminatory. The data covers 12 complete reserve maintenance periods. The last auction in the dataset is the first auction in the 13th period.

An important feature of the auctions is the minimum bid rate, which is strictly enforced and announced in advance. This reservation rate was changed only three times during the sample period. It started out at 4.25%, changed to 4.5% in time for the 5 September 2000 auction, then increased to 4.75% in time for the 11 October 2000 auction, and finally fell back to 4.50% for the auctions held on and after 14 May 2001. The minimum bid rate and the standing facilities in force throughout the sample period are illustrated in Figure 1. Although the standing facilities and the minimum bid rates were stable for long periods, they were in principle subject to change at the meetings of the ECB's Governing Council, normally held on the first and third Thursday of each month during the sample period.

The auctions are subject to relatively little supply uncertainty. With the auction announcement, the ECB also publishes an estimate of liquidity needs for the entire banking sector for the following week. Given the ECB's neutral allotment policy, this provides bidders with an unbiased estimate of the expected auction size. However, the ECB does not commit itself to a particular auction size, and it happens that the realized auction size differs from the expected size (see Figure 3). The mean expected size is 89.6 billion euros and the mean realized size is 88.9 billion euros. Some of the difference reflects updates in the ECB's liquidity forecasts after the auction announcement. But some of the difference is also caused by the two underbid auctions (numbers 34 and 42). The standard deviation of the size surprise is 5.8 billion euros (1.7 billion if excluding the two underbid auctions). The absolute value of the difference is 1 billion euros or less in 29 auctions. Thus deviations from the expected auction size tend to be relatively small.

The number of bidders in each auction varies from 240 to 800. Figure 4 provides a histogram of the frequency of participation across bidders. 29 bidders participate in all 53 auctions and 101 bidders participate in only one auction. Table 1 provides participation statistics on a per maintenance period basis. Panel (a) shows, for example, that 2,938 individual bidder demand schedules are submitted in the first maintenance period and 2,441 of these include winning bids. In the 12th maintenance period, these numbers fall to 1,814 and 1,524, respectively. The number of bidders in the first period is 949, but only 623 in the 12th period. Panel (b) shows that slightly more than a third of the banks in the sample bid in an auction in every maintenance period and slightly more than a fourth receive a positive auction allotment every maintenance period. The averages are 7.861 and 7.279 periods, respectively. Panel (c) shows that across banks the average number of auctions where they bid is 24.9 and the average number of auctions where they win some units is 20.2. Finally, the downward time trend in the number of bidders during the sample period is illustrated on an auction by auction basis in Figure 5. In the first auction, there are 800 bidders and in the last auction, there are only 452.

The bidders in the auction are small compared with the auction size. The average bidder demands only .37% of the expected auction size. Bidders are also very heterogeneous. On average, the largest bidder receives 6.8% of awards, with a maximum of 26.6%. On average, 64.6% of bidders in a given auction submit multiple bids. The distribution of the number of bids within individual bidder demand schedules is in Figure 6. The mode is 1, the median is 2, and the mean is 2.4.

2.3 The Secondary Market

Secondary market rates provide a measure of the opportunity cost of borrowing in the auction. We use them to calculate discounts (bid-shading) and underpricing. The level of secondary market rates relative to the minimum bid rate may also affect bidder behavior. Since the funds obtained in the auctions have a two week tenor, we are particularly interested in two week rates. We are also interested in longer term rates in order to compute forward rates, from which we can gauge rate expectations.

We use the two week Eonia swap rate to benchmark the auctions. The Eonia (euro overnight index average) is an overnight rate computed as a weighted average of all overnight unsecured lending transactions in the interbank market initiated within the euro area by a set of panel banks. The Eonia is calculated on a daily basis by the ECB on behalf of the European Banking Federation. It is a widely used reference rate and is the euro equivalent to the federal funds rate in the US. Like the fed funds rate, the Eonia is highly volatile compared with other short term rates (see Figure 2). The two week Eonia swap provides banks with a way to hedge the risk from borrowing overnight over a two week period. The counterparty that pays the fixed leg receives the Eonia rate. Cash flows are nominally exchanged every day, but money does not physically exchange hands before the two weeks are up. By going short (paying fixed) the swap, a bank creates a nearly perfect hedge against borrowing on a daily basis in the interbank market. Thus an alternative to borrowing in the auction is to short the swap and borrow on an overnight basis over two weeks. The Eonia swap market is one of the most liquid segments of the euro area money markets.[7] The other two main two week contracts, deposits and interbank repos, are less liquid. Furthermore, the deposit rate is for unsecured loans and is therefore not directly comparable with borrowing in the auction, which is collateralized. The interbank repo rate is also not comparable, since it is possible to use considerably cheaper collateral in the auction than in an interbank repo, for example mortgage bonds and bank loans. Due to the low credit risk, high liquidity, and good hedging properties of the Eonia swap contract, the two week swap rate is arguably the most appropriate two week rate in terms of benchmarking the auction. This is consistent with the views expressed by traders we have interviewed. But no interbank contract is a perfect match to the loans in the auction.[8] So we will also provide some statistics on how bidding in the auction compares to the deposit and repo rates.

Bid and ask quotations for the three two week rates were recorded from Reuters pages at 9:15 am every day throughout the auction sample period. The swap series, which we also use to compute secondary market conditional volatility, runs from 4 January 1999 to 2 July 2001. The bid-ask spread for the swap rate tends to vary between 2 and 3 basis points. Deposit and repo rate spreads are around 5 to 6 basis points. The mid-point of the bid and ask quotes is taken to be the best estimate of actual transaction rates.

Finally, we use Euribor (Euro Interbank Offered Rates) to compute forward rates.

[7]See the ECB *Euro Money Market* report of 2001, which also documents that the one week to one month maturity range is the one with the highest turnover in the Eonia swap market.

[8]Although the Eonia swap itself has very low credit risk, the Eonia is an unsecured overnight rate and therefore contains credit risk, albeit less than a two week deposit contract.

Euribor are important reference rates for interbank term deposits and is computed using the average rates quoted at 10:45 am every day by the same panel banks as for the Eonia. To gauge rate expectations, we use the one and two month rates to calculate the one month forward rate (the one month rate one month from today to two months from today). Thus, at any date, there is no overlap between the period covered by this forward rate and the current maintenance period.

Figure 2 depicts the swap, 1 month forward, and the Eonia rates during the auction sample period.[9] The spikes and troughs in the Eonia are related to the end of the reserve maintenance period (see above). The figure shows that our sample period covers a period of rising as well as falling rates and rate expectations. This is fortuitous, since it allows us to examine the extent to which bidder behavior and performance is affected by the direction of rate expectations. One might expect this to matter, perhaps because of the presence of the minimum bid rate.

3 Theoretical Considerations

In this section, we discuss the theoretical ideas that have motivated the empirical analysis below or have influenced how we interpret our results.

Winner's Curse

There is a strong common values element to the ECB's repo auctions since there is a very active and competitive secondary market for two week funds. If players have private information about post-auction secondary market rates, they face the winner's curse. We would expect rational bidders to adjust for the winner's curse by bidding more cautiously when uncertainty increases [Wilson (1977), Milgrom and Weber (1982)]. We would therefore expect to see bidders respond to an increase in volatility by decreasing the rates at which they bid and the quantity they demand and by increasing the dispersion of their bids, as discussed by Nyborg, Rydqvist, and Sundaresan (2002) in the context of treasury auctions. Thus, under the hypothesis that bidders have private information about post-auction rates and adjust rationally for the winner's curse, underpricing should also be decreasing in volatility.[10]

[9] The repo and deposit rates track the swap rate. They are therefore omitted from the figure.

[10] An exception could occur if the seller reduces the auction size when bidding is weaker, something

Collateral: Private Values and Downward Sloping Demand

The requirement to provide eligible collateral may introduce a private values component to the auctions. There is a wide range of eligible collateral and different banks may hold different types having different opportunity costs. Additionally, banks may face collateral constraints in the sense that they have to use increasingly expensive collateral as the auction size grows. Thus the collateral requirement may induce downward sloping demand curves at the individual bank level and in the aggregate. If banks are collateral constrained, we would expect to see an increase in auction size to lead to more bid-shading, more bid dispersion, less quantity demanded, and more underpricing.

The Loser's Nightmare

The liquidity neutral policy of the ECB means that at any given point in time, some banks are running reserve deficits relative to their average daily reserve requirements, while others are running surpluses. Whether a bank is short or long reserves is to a large extent subject to exogenous shocks. For example, a bank may suddenly find itself short of liquidity because of large withdrawals. Short banks that do not obtain adequate funds in the auction may risk being squeezed in the interbank market; they may be charged an above fair market borrowing rate. That is, they face the loser's nightmare (Simon, 1994). Shorts may therefore have target amounts in the auction in order to reduce their reliance on the secondary market.[11] In a theoretical model that captures this idea, Nyborg and Strebulaev (2004) show that short bidders who face the risk of being squeezed in the post-auction market have decreasing marginal valuations of the units on offer in the auction. Thus, when there is a lot of uncertainty, bidders may bid more aggressively than usual to avoid being squeezed. Nyborg and Strebulaev also show that when there is a bigger dispersion in bidders' pre-auction positions, i.e., when short positions are more extreme, bidding is more aggressive; shorts have more to lose from winning nothing and longs have more to gain from winning a lot. Although we cannot test this explicitly since we do not have access to the reserve balances of individual banks, we will come back to the idea of the loser's nightmare when interpreting our findings below.

which the ECB does not do.

[11] A trader told us that in his bank they usually operate with a target amount. They are concerned about being substantially short, because other banks are likely to ask very high rates if and when they find out.

4 Empirical Analysis of Bidding and Performance

This section examines how bidder behavior and auction performance is influenced by various exogenous variables such as volatility and auction size. We compare and contrast our findings with those in the treasury auctions literature.

4.1 Descriptive Statistics

Table 2 provides three panels with summary statistics of the exogenous and endogenous variables. The exogenous variables capture interest rate volatility, levels, and expectations as well as auction size and the projected number of bidders. The endogenous variables include bid-shading, intra-bidder dispersion, and underpricing measures. We also include a number of participation and award concentration measures.

4.1.1 Exogenous Variables

The exogenous variables are summarized in Panel (a). The daily conditional volatility of the swap rate is computed from a GARCH(1,1) model with dummies to capture key events within the reserve maintenance period (see the Appendix for details). On auction days, the volatility averages to 4.273 basis points (bp), which is roughly the same as for non-auction days, and varies from 1.176 bp to 8.538 bp. By way of comparison, during the sample period the average daily volatilities of 1 and 12 month EURIBOR is 2.7 bp and 3.6 bp, respectively.[12] The relatively large volatility of the swap rate reflects the high volatility of the underlying Eonia, which has an average daily volatility of around 14 bp.

The expected auction size is the liquidity neutral amount as announced before the auction by the ECB (see Section 2). It averages to 89.585 billion euros and ranges from 5 to 177 billion euros.

The swap spread is the two week Eonia swap rate less the minimum bid rate. Bidders' abilities to shade and spread out their bids may be compromised when the swap rate is close to the minimum bid rate, something which we will examine in the regression analysis below. The average swap spread is 8.2bp and the range is from -5.5 to 48.2 bp. It is unusual for the swap spread to be nonpositive. The four cases where we have a negative

[12] Computed as standard deviations of the first differenced time series.

swap spread reflect strong views held by some players that the ECB would decrease the minimum bid rate for the next auction. Two of the auctions with a negative swap spread are underbid (bid-to-cover below 1).

The forward spread is the one month forward rate (from one month in the future to two months) minus the minimum bid rate. It is meant to capture rate expectations and is constructed to avoid overlap with the current reserve maintenance period. The forward rate therefore does not reflect current liquidity conditions. When rates are expected to fall (rise), banks have a preference for doing the bulk of their borrowings of central banks funds late (early) in the maintenance month. In the regressions below, we will examine to what extent this affects bidding. Under the old fixed rate tender procedure, the bid-to-cover ratio rose as rates were rising. It became increasingly attractive to use collateral to borrow at the fixed rate tender rate and then turn around in the interbank market and lend at a much higher rate. The forward spread has an average of around 15.5 bp and varies from -26.7 bp to 62.7 bp. It is consistently positive throughout the first six maintenance periods and mixed thereafter. The smallest forward spread occurs on the auction held on 10 April 2001, which also has a negative swap spread and is underbid. The forward and swap spreads tend to move together; they have a correlation coefficient of .69.

The last exogenous variable is the projected number of bidders, which we include in order to control for the falling time trend discussed in Section 2. The projected number of bidders is computed by regressing the number of bidders in the current auction on the numbers in the two previous auctions. This is not meant to be the best model for forecasting the number of bidders, but is a simple solution for dealing with the time trend. Letting N_j denote the number of bidders, the estimated regression equation is

$$\begin{array}{cccccccc} N_j & = & 127.67 & + & 0.22N_{j-1} & + & 0.53N_{j-2} & \\ & & (1.96) & & (1.85) & & (4.59), & \end{array} \tag{1}$$

where t-statistics are reported in brackets below the regression coefficients. The regression is adjusted for first order autocorrelation using the Cochrane-Orcutt transformation. Comparing the summary statistics for the projected number of bidders to the statistics for the actual number of bidders [Panel (c)], we see that the projection captures the mean (as it should) but underestimates the actual variability.

4.1.2 Endogenous Variables: Bidding

Panel (b) describes the bidding variables. All of these are calculated on an intra-bidder level; each variable is computed for each of the 29,833 individual demand schedules. Our approach follows Nyborg, Rydqvist, and Sundaresan (2002); we view a bidder's collection of bids in an auction as a distribution and then use the moments to measure bidder behavior. In particular, denote the set of bids (rate, quantity pairs) submitted by bidder i in auction j by $\{(r_{ijk}, q_{ijk})\}_{k=1}^{m_{ij}}$, where m_{ij} is his number of bids. The quantity weighted average rate of these bids is $r_{ij} = \sum_k w_{ijk} r_{ijk}$, where $w_{ijk} = q_{ijk}/\sum_k q_{ijk}$. The discount is then defined as:

$$discount_{ij} = R_j - r_{ij}, \tag{2}$$

where R_j is the secondary market rate (deposit, swap, or repo) right before the auction deadline (see Section 2). The discount is positive for all three two-week rates. The discount relative to the deposit rate is the highest (4.651 bp) , followed by that of the swap rate, (3.352 bp), and finally the repo rate (.487 bp). This reflects that deposit rates tend to be higher than swap rates which in turn are higher than repo rates, due to differences in collateral requirements and credit risk.

The higher order moments are defined along similar lines as the discount:

$$Standard\ deviation_{ij} = STD_{ij} = \sqrt{\sum_{k=1}^{m_{ij}} w_{ijk} \left(r_{ijk} - r_{ij}\right)^2}. \tag{3}$$

$$Skewness_{ij} = \frac{1}{STD_{ij}^3} \left[\sum_{k=1}^{m_{ij}} w_{ijk} \left(r_{ijk} - r_{ij}\right)^3 \right], \tag{4}$$

and

$$Kurtosis_{ij} = \frac{1}{STD_{ij}^4} \left[\sum_{k=1}^{m_{ij}} w_{ijk} \left(r_{ijk} - r_{ij}\right)^4 \right]. \tag{5}$$

In cases where a bidder submits only 1 bid, we define the skewness to be 0 and kurtosis to be 1.[13] The average standard deviation, skewness, and kurtosis are 0.704 bp, -0.018, and 1.529, respectively. However, there is a considerable variation across individual demand schedules.

[13] The rationale is as follows: A single bid can be regarded as the limit as c goes to zero of two bids of identical sizes at prices $b+c$ and $b-c$. The standard deviation is c, the third moment is 0, and the fourth moment c^4. Hence, skewness is zero and kurtosis one. In the limit, as c goes to zero, skewness remains zero and kurtosis one.

The relative bid quantity of bidder i in auction j is $\frac{\sum_k q_{ijk}}{Q_j}$, where Q_j is the expected auction size. The average is .367%. It goes as low as .001% and as high as 80%. The maximum occurs in the smallest auction. The number of bids, m_{ij}, has an average of 2.397 and ranges from 1 up to the admissible maximum of 10.

4.1.3 Endogenous Variables: Performance and Participation

Panel (c) contains variables measuring auction performance and participation. These measures are all on an auction by auction basis.

Underpricing is defined as the two week rate minus the quantity weighted average winning rate. Like the discount, underpricing is measured relative to the three two-week rates. Underpricing is 2.96 bp relative to the deposit rate and 1.64 and -1.35 relative to the Eonia swap and repo rates, respectively. In other words, the average winning bidder pays a rate which is between the swap and repo rates. That underpricing is negative with respect to the repo rate probably reflects that banks use cheaper collateral in the auction than what they can use in the interbank repo market. Using the swap rate as a benchmark, the evidence is that it is cheaper to borrow in the auction than in the interbank market. Since the typical bid-ask spread of the swap rate is around 2-3 bp and underpricing is measured relative to the midpoint of the spread, we see that bidders in the auctions are, roughly speaking, obtaining the funds at the swap bid rate. This confirms interviews we have had with traders who told us that banks do not view bidding in the auctions as a profit-making activity. Nevertheless, they participate because they need the funds. In our discussions below, we will normally take underpricing to be measured relative to the swap rate unless otherwise specified.

The stopout spread is defined as the stop-out rate minus the minimum bid rate and averages to 6.5 bp. The relatively large magnitude of the stopout spread reflects that the secondary market rates were considerably above the minimum bid rates for long periods over the sample period, as seen in the swap spread statistics.

Since, in a given reserve maintenance period, banks earn interest on their reserves equal to the average stop-out rate, it is interesting to see how winning rates compare with stop-out rates. From the variable winrate-stopout, we see that the banking sector tends to pay around 1.64 bp more for their reservable funds than they earn from the ECB. Together, the winrate-stopout and stopout spread variables inform us that the typical rate paid in the auction is approximately 8.1 bp above the minimum bid rate.

The average number of bidders across auctions is 563 and 459 typically win some units. The variation in participants as well as winners is large, going from 240 to 800 and 154 to 705, respectively. The variable manybids measures the percentage of bidders in an auction who submits multiple bids. We see that 64.574% typically do so.

Award concentration is measured by the Herfindahl index on a scale from 1 to 100 and averages to 2.10. This is approximately what it would be if we had 50 equal bidders. Comparing this to the average number of bidders illustrates the considerable size variation that exists across bidders. Award/demand concentration is the Herfindahl index based on award divided by the Herfindahl index based on demand. The average of this ratio is 1.368, showing that award tends to be more concentrated than demand. The average bid-to-cover ratio is 2.06, but varies from 0.47 to 166.66. The highest bid-to-cover occurred in the smallest auction. Finally, the largest (by award) 1, 10, and 50 bidders typically receive 6.8%, 34.3%, and 72.2% of the auction. Keeping in mind that more than 500 banks typically participate in each auction and the average bank demands less than 0.4% of the auction, this is further illustration of the large variation in size among participating banks.

4.2 Regression Analysis

In this section, we run a number of regressions to examine how bidder behavior and auction performance varies with swap volatility, expected auction size, the level of rates, the expectation of rate changes, and the number of bidders. To allow for the possibility that bidders behave differently when rates are expected to rise as compared to when rates are expected to fall, we create two new exogenous variables. To capture falling rate expectations, we define the forward spread(-) to be equal to the forward spread if this is negative, and 0 otherwise. To capture rising rate expectations, we define forward-swap(+) to be the forward rate less the swap rate if this is positive, and 0 otherwise.[14]

[14]Analogously to the forward spread(-), we could also define the variable forward spread(+) as being the forward spread if this is positive, and zero otherwise. A problem with this variable is that it would give rise to a potential multicollinearity problem in our regressions since it has a correlation of .68 with the swap spread.

The regression results are reported in Table 3. To correct for autocorrelated errors, all regressions have been run with the Cochrane-Orcutt transformation. In the regressions of the bidding variables, we have first taken averages of the independent variables for each auction and then run the regressions using these. This is done for two reasons. First, it is to correct for possible correlations in errors within auctions. Second, it is to place equal weight on each auction. If we used the individual intra-bidder observations, we would weigh the earlier auctions more heavily since more bidders participated in these auctions.[15]

Panel (a) in Table 3 contains the regressions on the bidding variables and Panel (b) contains the regressions on the performance and participation variables. We have selected those variables from Table 2 that we think are the most important and interesting. For the kurtosis (Panel a), we run one regression where kurtosis is equally weighted across bidders within auctions and another where it is weighted by the quantity demanded by a bidder (QW kurtosis). This is to highlight an important difference in the strategies of large and small bidders, which we discuss in depth in Section 5.1. All the other bidding variables are equally weighted within auctions. We discuss the regression results by focusing on one exogenous variable at a time, working our way from left to right in the table.

Table 3 shows that the volatility of the swap rate impacts negatively on underpricing and discounts. A one basis point increase in volatility leads to a decrease in the discount by a significant .377 bp and a decrease in underpricing by a significant .538 bp. In other words, banks bid more aggressively when volatility is high. This is the opposite of what previous research has documented for treasury auctions [Nyborg, Rydqvist, Sundaresan (2002), Bjønnes (2001), Keloharju, Nyborg, and Rydqvist (2002)], and is the opposite of what one would expect from winner's curse based arguments. There is also no evidence that bidders cut back demand when volatility is high. It therefore seems that private information and the winner's curse have no role in these auctions. Bidders may simply be too small

[15] By running the bidding variable regressions on an auction-by-auction basis, we may well end up overstating standard errors. Results from running stacked regressions are qualitatively the same as reported in Table 3. Because of the presence of a minimum bid rate, the discount and underpricing regressions should arguably be run as Tobit regressions. Since correcting for autocorrelation is notoriously complicated in the Tobit model, we prefer to report the results using the standard regression model as explained in the text. However, standard Tobit regressions on discounts and underpricing produce results which are qualitatively the same as, and quantitatively very close to, the results reported in Table 3.

to possess significant private information about two-week interbank rates. This is also consistent with the ECB providing information on liquidity conditions and its monetary policy stance on an equal access basis. The only other regressions where volatility is statistically significant are for the standard deviation and the quantity weighted kurtosis; a one basis point increase in volatility increases standard deviation by .043 bp and QW kurtosis by .075. Since the equally weighted kurtosis is not affected by volatility, this is our first illustration of the finding that large bidders use different strategies than small bidders, particularly with respect to the kurtosis of their bids. We discuss the significance of this in Section 5.1 below.

The finding on volatility is puzzling. Why should bidders want to bid more aggressively in the auction when volatility is high?[16] One possibility may be that when volatility is high, the depth in the interbank market is low, thus making the auction relatively more attractive. However, since the relative bid quantity and bid-to-cover is unaffected by swap volatility, this is an unlikely explanation. Another possibility relates to the loser's nightmare. If one thinks about short term rates as being influenced by the relative power between banks whose reserve balances are in surplus versus banks that are in deficits (relative to their average daily requirements), it seems plausible that volatility is positively correlated with how widely dispersed banks' reserve balances are. In other words, volatility may be positively correlated with the number of players that are short and/or a high volatility is associated with more extreme short positions. Under this hypothesis, the results of Nyborg and Strebulaev (2004) discussed in Section 3 imply that discounts and underpricing would be negatively related to volatility, as we see in the data. This could also explain the increase in standard deviation, since Nyborg and Strebulaev also predict that short bidders disperse more. Another possibility is that the negative relation between volatility and discounts is driven by risk aversion; banks may have a stronger preference for borrowing in the auctions rather than the interbank market when the volatility in the latter is high, perhaps because of the loser's nightmare.

Moving on, we see that the expected auction size impacts positively on the discount, standard deviation, and underpricing. For example, a 10 billion increase in auction size leads to a statistically and economically significant .26 bp increase in underpricing. This

[16] We have run the regressions using different models for the volatility, but always with the same results.

supports the hypothesis that players are collateral constrained. As the auction size increases, banks start to use more expensive collateral and therefore spread out their bids more and submit them at lower rates. The negative coefficients on the relative bid quantity and bid-to-cover ratio are supportive of the view that bidders are collateral constrained.

The swap spread is highly significant in most regressions and is also the main reason the R^2's are so high. For each basis point increase in the swap spread, the discount increases by 0.278 basis points. Put differently, for each basis point the swap rate moves away from the minimum bid rate, bidders' average bids move up by only approximately 0.722 bp. A basis point increase in the swap spread increases underpricing by 0.107 bp. The swap spread also has a significant impact on dispersion: standard deviation increases by 0.031 bp per basis point increase in the swap spread and skewness decreases by -.001 bp. The equally weighted kurtosis increases by 0.005 bp while the quantity weighted kurtosis increases by 0.016 bp, which is another illustration that large bidders behave differently from small bidders with respect to kurtosis. The swap spread also impacts positively on the number of bids per bidder. These findings suggest that the minimum bid rate is a binding constraint. When the swap spread is large, bidders have more room to spread out and shade their bids. We also see that more banks participate as the swap spread increases. This may be because of an expectation of a larger underpricing, or it may be because players with relatively expensive collateral find it worthwhile to participate. Finally, the swap spread has no notable effect on the quantity variables, including award concentration and bid-to-cover. This is not surprising because the expected auction size is equal to the amount of reserves that banks need.

Next, we discuss rate expectations. Note as a first "result" here that the regressions in Table 3 are reported without the forward-swap(+) variable as a regressor because in almost all cases it has no effect.[17] That rising rate expectations are not important for discounts and underpricing may at first glance appear surprising, since one might expect banks to be more eager to get reserves early when rates are expected to rise. However, a bank's alternative to borrowing in the auction is to obtain reserves in the interbank market. The insignificance of the forward-swap(+) points to that banks adjust their bids

[17]Including the forward-swap(+), we find that it is significant in only three cases. In particular, it has a significantly positive effect on quantity weighted kurtosis, number of bids per bidder, and manybids (the proportion of players who submit multiple bids).

according to the swap rate rather than the forward rate.

In contrast, it appears that falling rate expectations matter. Looking down the forward spread(-) column in Table 3, we see that as the forward spread gets more negative, bidders shade less and underpricing is smaller. A one basis point decline in the forward spread(-) translates into a .131 decrease in the discount and a .148 bp decrease in underpricing. It seems that the stronger are the expectations that rates will fall, the smaller are discounts and underpricing. This is counterintuitive. We believe this is an artifact of the minimum bid rate. When the market expects rates to fall and the forward spread becomes negative, the swap spread also falls but tends to stay positive because there is considerable resistance among market participants to lend at swap rates below the minimum bid rate. This creates a positive regression coefficient on the forward spread(-) in the discount and underpricing regressions. This is augmented, but not driven by, the four cases where the swap spread is negative.[18] Thus the results on the discount and underpricing are not reflections of falling rate expectations as such. A more true illustration that falling rate expectations leads to weaker bidding is given by the findings that the relative bid quantity and the number of bidders decrease when the forward spread(-) becomes more negative. But without the restriction of the minimum bid rate, we doubt the forward spread(-) would have much significance.

Finally, we see that the projected number of bidders has no effect on the discount or underpricing and a negative effect on award concentration and bid-to-cover. We have also run the regressions without the projected number of bidders, with no notable changes.

4.3 Frequency of Auction Participation

We end this section by investigating whether banks "cycle"; that is, whether they participate more heavily in every other auction. Since the repos in the auctions are for two weeks, a bank could in principle cover its liquidity needs by borrowing only in every other weekly auction. However, to decrease its reliance on a particular cycle of auctions, a bank may wish to participate evenly in every auction; that is, aim to borrow 50% of its daily average reserve requirement in each auction. A bank that starts out with the objective of equal participation in each auction, however, may find itself deviating from that objective

[18] We have run the regressions without these four cases. There are no notable changes.

because of liquidity shocks. Such a bank may find itself cycling if it deals with the shock predominantly by adjusting its demand in the auctions rather than through transactions in the interbank market.

We first examine the frequency with which bidders participate. This is measured by the *run*, which is the time between the current auction the bidder is participating in and the last. For example, if a bidder participates in auction numbers 1, 2, and 7, there is one run of 1 and one of 5. We measure runs based on bids and awards and find that bidders overwhelmingly tend to participate in adjacent auctions. Out of 28,633 bid runs, 22,477 are runs of 1 and 4,206 are runs of 2. Out of 23,158 award runs, 15,766 are runs of 1 and 4,892 are runs of 2. This suggests that bidders attempt to smooth their auction participation. We then calculate the autocorrelation of bid and award sizes for bidders who participate in every maintenance period. This reduces the number of bidders to 407. For each bidder we first calculate the relative bid size (relative to expected auction size) and relative award size (relative to realized auction size) for each auction. Then we compute the two first autocorrelations of these two measures. Finally, we average across all 407 bidders. The results are in Table 4. We see that both bidding and award have negative first order autocorrelation but positive second order autocorrelation. Furthermore, the number of bidders with negative autocorrelation outweigh those with positive autocorrelation. This is reversed for the second order autocorrelation. Thus banks cycle. This is consistent with banks viewing the auctions as the main arena for obtaining their reserves, with the interbank market serving more of a fine-tuning role. This apparent preference for borrowing in the auctions, for many banks, supports the view that the loser's nightmare is an issue in the market for central bank funds.

5 Bidder Heterogeneity and Underbidding

5.1 Large versus Small Bidders

We start by examining the overall performance of large versus small bidders. One might expect large bidders to do better, since by virtue of being large, they have more to gain from investing time, effort, and resources in the bidding process. Furthermore, there is some anecdotal evidence that some small banks submit their bids well before the deadline, thus giving themselves a competitive disadvantage since their bids do not fully incorporate market conditions (e.g. the swap rate) at the time of the auction.

To investigate this, we break the sample up into 12 fixed groups of 100 banks each (99 in the group of smallest bidders) based upon the average relative bid size for each bank across all auctions that the bank participated in. The groups are ordered from smallest (group 1) to largest (group 12). An advantage of working with fixed rather than auction-dependent size groups is that any differences that we find in terms of performance, for example, can be attributed to systematic differences among specific groups of banks rather than differences in private information, refinancing needs, collateral portfolios, etc at given points in time. Another advantage is that by working with fixed groups, we can also examine whether differently sized banks are able to time their purchases to coincide with high underpricing.[19]

Table 5 provides summary statistics for each of the 12 groups. The first row is the average relative bid quantity for each bidder in the group conditioned on participation. There is substantial variation among the groups. The average participating bank in the largest group typically bids for 1.991% of expected auction size and receives 58.8% of that. Banks in the smallest group typically bid for 0.002% and receive 62.6% of that. So in terms of amounts bid for and amounts awarded, banks in the largest size group are about 1,000 times larger than banks in the smallest size group.

The table reveals a substantial difference in the performance of large and small bidders; larger bidders achieve a higher underpricing than smaller bidders.[20] Comparing groups 12 and 1 we see that the larger group has an underpricing of 2.231 bp, while the underpricing for the smaller group is .580 bp. In other words, across auctions, group 12 bidders obtain funds at 1.651 bp less than group 1 bidders. In Table 6, we formally test the hypothesis that differently sized bidders perform differently. The table reports the pairwise differences in mean underpricing between groups, with p-values in brackets. We can see that group 12

[19]Our categorization of "large" and "small" banks is based on bid sizes rather than on balance sheets. What one normally would think of as a large bank, may well be a small bank in terms of bid size, and vice versa. Note that we have constructed a similar table to Table 5 also for auction-dependent size groups, with similar results.

[20]To compute group underpricing, we first compute the individual underpricing for each bidder in the group for each auction where he wins some units. Then we pool these observations and take the equally weighted average.

has a significantly bigger underpricing than all other groups, with the exception of groups 10 and 8 and, to a smaller extent, group 11. Groups 1 and 2 have a significantly smaller underpricing than all other groups. The table confirms that larger bidders borrow cheaper on average than smaller bidders.

That large bidders do better is perhaps not so surprising. The striking thing, however, is that larger bidders have larger underpricing without having a larger discount. In terms of bidding behavior, the difference between large and small bidders is in the number of bids and the kurtosis. Larger bidders tend to submit more bids and have more kurtosis. Unless larger bidders time it so that they borrow more frequently in auctions that are more heavily underpriced, it appears that it is the increased kurtosis and number of bids that is the key to their superior performance. If one starts with two bids, kurtosis can be increased, keeping standard deviation the same, by using three bids and placing more quantity on the middle bid and adjusting the upper and lower bids appropriately. If one imagines that the initial two bids straddle the stop-out rate and that the third bid is placed at the stop-out rate, then the three bid demand schedule will have a lower average winning rate than the two bid schedule. From a bidder's perspective in practice, the stop-out rate is uncertain. But the typical bidder is so small, that his individual demand is unlikely to affect the stop-out rate. If so, it may be advantageous to use more rather than few bids, along the lines we just suggested.

To test whether large bidders achieve their superior performance because they time their purchases, we examine whether they demand more and borrow more in auctions that have large underpricing. For each size group, we run two regressions. We regress each size group's relative bid quantity, b_{jg} and the group's relative award quantity, a_{jg} on a constant and underpricing, u_j, where j denotes the auction and g the group. Note that u_j is the underpricing for the auction as a whole (as defined in Table 2); it is not dependent on the group. We thus obtain two underpricing "betas" for each size group. If large bidders can time their purchases, we should see their beta being positive and that of small bidders being negative. The findings are reported in Table 7. For the "bid betas", only the one for group 2 is significant. For the "award betas", only the one for group 11 is significant, and it is negative. We conclude that there is no evidence that large bidders time their purchases better than small bidders. It seems that their higher underpricing is related to their use of more bids and higher kurtosis.

5.2 Underbidding

We now turn to studying the two underbid auctions, where banks demanded less in aggregate than the liquidity neutral amount. Several auctions held after the end of our dataset have also been underbid. Thus, from time to time, there is a breakdown in the ability of the auctions to bring to the banking sector the liquidity it needs to maintain reserve requirements. Understanding this breakdown is important. From the banking sector's perspective, it is costly. After the two underbid auctions in our dataset, banks borrowed more than 60 billion euros at the marginal lending facility, paying a 100 bp premium over the minimum bid rate. From the ECB's perspective, underbidding is undesirable because it disturbs the implementation of monetary policy. Indeed, to combat underbidding, from March 2004 onwards the ECB is planning to change the tenors of their auctions from two to one week and also to vary the lengths of the reserve maintenance periods to match the time between the meetings of the ECB's Governing Council where the minimum bid rate in the auctions are set (ECB, 2003). These are the most significant changes to the ECB's operational framework since the launch of the euro in 1999.

Table 8 provides summary statistics from the two underbid auctions. These were held on 13 February 2001 and 10 April 2001 and are the 34th and 42nd auctions, respectively, in our dataset. Demand in these two auctions is only 74.2% and 47.1%, respectively, of the liquidity neutral amounts which are 88 and 53 billion euros, respectively. An interesting aspect of these auctions is that the contemporaneous swap rate is below the minimum bid rate in the auction; the swaps spreads are -.5 bp for auction 34 and -5.5 bp for auction 42. Hence a bank could get cheaper funding by shorting the swap (paying fixed) and borrowing on an overnight basis for two weeks as compared with borrowing in the auction.

Given the negative swap spreads, one may ask why bid in the auction at all? Of course, if no banks bid, banks would have to pay the 100 bp penalty of the marginal lending facility for the entire amount they need to satisfy reserve requirements. In this case, the swap rate would certainly move up and it would be desirable to bid in the auction after all. Those that actually stay in the auction when the swap spread is negative may be banks that have particularly large liquidity needs and are more concerned about the loser's nightmare. Furthermore, the depth of the below minimum bid rate quotes were not sufficient to cover the entire auction.

As discussed in the introduction, a plausible hypothesis is that underbidding is driven by small banks who rely on large banks to get the collectively required funds into the banking system. To examine this free-rider hypothesis, we break the bidders up into fixed size groups. To get a finer picture than before, we use different groups than in the previous section; namely, the largest 20, 21-50, 51-100, 101-200, and 201-1199. Table 9 Panel (a) reports the average amount bid for, amount awarded, and number of bidders for these size groups, excluding auctions 34 and 42. We see that normally 16.8 of the top 20 banks participate and bid for a total of 75.3% of the auction. Of the bottom 999 banks, 415.6 normally participate and as a group they bid for 30.0%. Panel (b) reports on the same variables for the two underbid auctions. The comparisons between the underbid and the normal auctions are striking. While the top 20 banks normally buy 34.7%, in the two underbid auctions they buy only 25.3% percent. In contrast, the bottom 999 banks normally buy 14.5%, but in the two underbid auctions they buy 18.7%. Similarly, the 101-200 largest banks normally buy 12.7%, but in the two underbid auctions they buy 16.3%. In other words, the top 20 banks normally buy about 7.6 percentage points *more* than the bottom 1099 banks. In the two underbid auctions, the top 20 buy 9.7 percentage points *less* than the bottom 1099. Panel (c) confirms the statistical significance of these differences between normal and underbid auctions.

As a robustness check on our finding that large bidders cut back more in the two underbid auctions, in Table 10 we examine the eight auctions that straddle each of the underbid auctions. We see that the fractional amount borrowed by the top 20 banks is reduced in both of the underbid auctions relative to the straddling auctions.

The fact that large bidders act as free-riders suggests that they consider themselves fairly small in the big picture. This is perhaps not surprising given that the largest bank in an average auctions gets only around 6% of the auction. But that large banks underbid more than small banks *is* surprising. Our finding may be driven by larger banks having better access to the swap market. Although this market is in principle equally open to all banks, smaller banks often lack the resources, sophistication, and will (at board level) to make use of derivative contracts. Another possibility is that small bidders happened to be more short than large bidders at the time of the underbid auctions.

6 Concluding Remarks

To date, most empirical research on multiunit auctions in financial markets has focused on treasury auctions. The findings of that literature are broadly consistent with the view that treasury auctions are of the common value type and that bidders have private information and adjust rationally for the winner's curse. In this paper, we have studied another important multiunit auction – the European Central Bank's main repo auction – and found little evidence in support of the private information hypothesis. Other factors seem to be driving bidder behavior in these auctions.

First, we find that as volatility increases, bidders become more aggressive and underpricing decreases. This is the opposite of the standard treasury auctions finding and may suggest that the loser's nightmare is more important in the auctions we study than the winner's curse. Testing this more explicitly by examining how bidders' pre-auction positions affect their behavior in the auctions would be a very interesting avenue for future research. Second, we find that bidders react to increased auction size by bidding more cautiously, leading to more underpricing. The standard treasury auction finding is that auction size has little, or no effect. Our finding suggests that bidders have limited quantities of the cheapest admissible collateral. So the management of collateral may be an important part of what is going on in and around repo auctions. Third, we find that the minimum bid rate is a binding constraint and that when the market has strong expectations that the central bank will lower rates, total demand in the auction can be less than what banks collectively need to satisfy reserve requirements. Surprisingly, we find a sort of reverse free-rider problem here in that large bidders reduced demand more than small bidders in the two underbidding episodes in the sample period. We also find that large and small bidders generally employ different strategies and that large bidders perform better on average.

From a theoretical perspective, our findings suggest that an important line of future research on multiunit auctions would be to embed the auctions in a richer setting where players are concerned about their positions in the underlying asset both before and after the auction, perhaps because they may be squeezed if they are short. Some efforts along these lines have already been made by Chatterjea and Jarrow (1998) and Nyborg and Strebulaev (2004). However, we are not familiar with models that consider the sequential feature of repo auctions within the reserve maintenance period. Thinking about the interaction between the auctions and the secondary market is clearly also important from a policy perspective. For example, Nyborg and Strebulaev (2004) show that if the policy objective is to minimize short squeezes and market distortions, then a uniform price auction may be better than a discriminatory auction. However, if the policy objective is to maximize revenue, then a discriminatory auction may be better. Of course, neither of these mechanisms may be optimal in the rich setting of the real world. Our findings, however, suggest that when it comes to optimal auction design, inventory issues and the interaction between the auctions and the secondary market may be as important as information issues in some settings.

7 Appendix: Conditional Volatility Estimation

To estimate the conditional volatility of the two week swap rate, we apply a modified GARCH(1,1) model (Bollerslev, 1986) to daily rate changes. As in Hamilton's (1996) study of the fed funds rate, we use calendar effects to capture the effect of fixed events such as the end and beginning of the maintenance period, ECB Governing Council meetings, the end and beginning of the month, and main and longer term refinancing operations. Not all of these events are in the final specification. Since interest rates tend to be mean-reverting and since conditional volatilities sometimes react asymmetrically to increases and decreases in rates, we also introduce stochastic variables to capture this. In particular, we use a dummy variable which takes the value 1 when the swap rate fell the previous day and 0 otherwise. We also use the "short-end" slope of the term structure of interest rates.

The final model specification and our results are in Table 11. The final specification has been chosen based upon a variety of diagnostic tests. We have examined closely the joint distributions of standardized residuals and standardized squared residuals [see, e.g., Engle and Ng (1993)]. We reject the hypothesis that the residuals or squared residuals could be autocorrelated. It should be noted that our empirical results are robust to many other model specifications for the process of conditional volatility.

References

Bergstrom, T., L. Blume, and H. Varian, 1986, "On the Provision of Public Goods," *Journal of Public Economics*, 29, 25-49.

Bjønnes, G., 2001, "Winners Curse in Discriminatory Price Auctions: Evidence from the Norwegian Treasury Bill Auctions," working paper, Norwegian School of Management.

Bollerslev, T., 1986, "Generalized Autoregressive Conditional Heteroscedasticity", *Journal of Econometrics*, 31, 307-327.

Breitung, J., and D. Nautz, 2001, "The Empirical Performance of the ECB's Repo Auctions: Evidence from Aggregated and Individual Bidding Data," *Journal of International Money and Finance*, 20, 839-856.

Cammack, E., 1991, Evidence on Bidding Strategies and the Information in Treasury Bill Auctions, *Journal of Political Economy*, 99, 100-30.

Chatterjea, A., and R. A. Jarrow, 1998, "Market Manipulation, Price Bubbles, and a Model of the U.S. Treasury Securities Auction," *Journal of Financial and Quantitative Analysis*, 33, 255–289.

European Central Bank, 2001, *The Euro Money Market*, July, Frankfurt am Main, Germany.

European Central Bank, 2002a, *The Single Monetary Policy in Stage Three. General Documentation on Eurosystem Monetary Policy Instruments and Procedures*, Frankfurt am Main, Germany.

European Central Bank, 2002b, "The Liquidity Management of the ECB in the Context of the Operational Framework of the Eurosystem," *Monthly Bulletin*, May, 41-52.

European Central Bank, 2003, "Changes to the Eurosystem's Operational Framework for Monetary Policy," *Monthly Bulletin*, August, 41-54.

Engle, R., and V. Ng, 1993, "Measuring and Testing the Impact of News and Volatility", *Journal of Finance*, 48, 1749-1778.

Hamilton, J. D., 1996, "The Daily Market for Federal Funds," *Journal of Political Economy*, 104, 26-56.

Hartmann, P., M. Manna, and A. Manzanares, 2001, "The Microstructure of the Euro Money Market," *Journal of International Money and Finance*, 20, 895-948.

Keloharju, M., K. G. Nyborg, and K. Rydqvist, 2002, "Strategic Behavior and Underpricing in Uniform Price Auctions: Evidence from Finnish Treasury Auctions," working paper, CEPR.

Milgrom, P. R., and R. J. Weber, 1982, "A Theory of Auctions and Competitive Bidding", *Econometrica*, 50, 1089-1122.

Nyborg, K. G., K. Rydqvist, and S. Sundaresan, 2002, "Bidder Behavior in Multiunit Auctions: Evidence from Swedish Treasury Auctions," *Journal of Political Economy*, 110, 394-425.

Nyborg, K. G., and I. A. Strebulaev, 2001, "Collateral and Short Squeezing of Liquidity in Fixed Rate Tenders," *Journal of International Money and Finance*, 20, 769–792.

Nyborg, K. G. and I. A. Strebulaev, 2004, "Multiple Unit Auctions and Short Squeezes," *Review of Financial Studies*, 17, 545-580.

Olsen Jr, M., and R. Zeckhauser, 1966, "An Economic Theory of Alliances," *Review of Economics and Statistics*, 48, 266-279.

Simon, D. P., 1994, "Markups, Quantity Risk, and Bidding Strategies at Treasury Coupon Auctions," *Journal of Financial Economics*, 35, 43–62.

Wilson, R.B., 1977, "A Bidding Model of Perfect Competition," *Review of Economic Studies*, 44, 511-518.

Table 1

Participation

Panel (a) presents the following statistics for each of the 13 maintenance periods for which we have data: the number of demand schedules submitted in all auctions within the maintenance period, the number of bidders who participated in at least one auction, the number of demand schedules that won some award, and the number of bidders who won some award. Panel (b) tabulates the number of banks that participated and won some award in from 1 to 12 maintenance periods. (This panel excludes the 53rd auction in our sample, since this is the only auction we have data for in the 13th maintenance period). Panel (c) tabulates the number of banks that participated in and won some award in from 1 to 53 auctions. N is the total number of banks who bid and won in our sample.

Panel (a): Demand schedules and bidders per maintenance period

	1	2	3	4	5	6	7	8	9	10	11	12	13
Demand schedules	2938	3608	2606	2362	2954	2302	2033	2601	2190	1620	2353	1814	452
Bidding	949	919	850	822	796	841	779	774	738	680	662	623	452
Winning schedules	2441	2427	1957	1906	2482	2084	1986	2407	1724	1423	1687	1524	262
Winning	865	843	767	746	758	812	772	737	678	604	576	577	262

Panel (b): Number of maintenance periods per bank

	mean	std	1	2	3	4	5	6	7	8	9	10	11	12
Bidding	7.861	4.068	120	85	64	55	50	68	63	72	59	75	81	407
Winning	7.279	4.202	125	78	62	66	52	70	62	69	79	79	83	327

Panel (c): Number of auctions per bank

	mean	std	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-53	N
Bidding	24.861	17.557	254	89	114	81	100	87	69	86	94	225	1199
Winning	20.258	16.034	268	120	122	106	98	87	72	87	84	108	1152

Table 2

Descriptive Statistics

Descriptive statistics on the exogenous variables (Panel (a)), the bidding variables (Panel (b)), and the participation and performance variables (Panel (c)). s.e. denotes the standard error of the mean, and N is the number of observations. Volatility of swap rate is the conditional volatility of the two week swap rate on auction days (see the Appendix). Expected auction size is the liquidity neutral amount, which is computed from the liquidity figures announced by the ECB prior to each auction. Swap spread is the difference between the two week swap rate and the minimum bid rate. Forward spread is the difference between the Euribor forward rate from 1 month to 2 months and the minimum bid rate. Projected number of bidders is obtained by a regression as described in the text. Discount and underpricing are the differences between the secondary market rates (deposit, swap, and repo) and the quantity-weighted average bid rate within each demand schedule and the quantity-weighted average winning rate, respectively. Standard deviation, skewness, and kurtosis are all quantity-weighted intra-bidder measures. Relative bid quantity is the quantity demanded by a single bidder relative to the expected auction size. Relative auction size is the quantity allotted in a given auction relative to the expected auction size. Largest 1, 10 and 50 is the alloted share of the 1, 10 and 50 largest (by award) bidders in a given auction. Manybids is the percentage of bidders who submit more than 1 bid in a given auction. Stopout spread is the difference between the stopout rate and the minimum bid rate. Winrate-stopout is the difference between the quantity-weighted average winning rate and the stopout rate. Award concentration is the Herfindahl index. Award/demand concentration is the Herfindahl index based on awards divided by the Herfindahl index based on demand. Bid-to-cover is the quantity demanded in a given auction divided by the expected auction size. Units of measurement are in the second column.

	units	mean	std	s.e.	min	max	N
Panel (a): Exogenous Variables							
Volatility of swap rate	bp	4.273	1.217	0.167	1.176	8.538	53
Expected auction size	bln	89.585	31.669	4.350	5	177	53
Swap spread	bp	8.132	8.775	1.205	-5.500	48.250	53
Forward spread	bp	15.530	22.077	3.032	-26.652	62.657	53
Projected number of bidders		555.588	78.848	11.041	391.241	711.357	50
Panel (b): Bidding Variables							
Discount (deposit)	bp	4.651	4.372	0.025	-60.500	51.500	29,833
Discount (swap)	bp	3.352	4.476	0.026	-59.500	48.250	29,833
Discount (repo)	bp	0.487	5.342	0.031	-67	42	29,833
Standard deviation	bp	0.704	0.901	0.005	0	28.284	29,833
Skewness		-0.018	0.482	0.003	-4.984	13.712	29,833
Kurtosis		1.529	1.709	0.010	1	189.005	29,833
Relative bid quantity	%	0.367	1.491	0.009	0.001	80	29,833
Number of bids		2.397	1.434	0.008	1	10	29,833
Panel (c): Performance and Participation							
Underpricing (deposit)	bp	2.959	2.545	0.350	-4.645	10.064	53
Underpricing (swap)	bp	1.643	2.492	0.342	-5.645	6.762	53
Underpricing (repo)	bp	-1.347	3.096	0.425	-10.488	5.564	53
Stopout spread	bp	4.849	6.951	0.955	0	43	53
Winrate-stopout	bp	1.640	1.404	0.193	0.145	6.468	53
Number of bidders		562.925	116.188	15.960	240	800	53
Manybids	%	64.574	14.325	1.968	13.750	80.571	53
Number of winners		458.679	115.100	15.810	154	705	53
Award concentration		2.124	1.424	0.196	1.122	8.875	53
Award/demand concentration		1.368	0.627	0.086	0.928	4.615	53
Bid-to-cover		2.064	2.178	0.299	0.471	16.661	53
Largest 1	%	6.819	4.302	0.591	3.131	26.598	53
Largest 10	%	34.340	9.312	1.279	23.848	64.763	53
Largest 50	%	72.201	7.409	1.018	61.973	94.450	53
Relative auction size	%	99.410	8.698	1.195	47.073	109.434	53

Table 3

Regression Analysis

Regressions of the following dependent variables: discount (swap), standard deviation, skewness, kurtosis, quantity-weighted kurtosis, relative bid quantity, number of bids per bidder, underpricing (swap), number of bidders, manybids, largest10, bid-to-cover. The explanatory variables are, from left to right: volatility of swap rate, expected auction size, swap spread, forward spread(-) (forward spread if negative, 0 otherwise) and projected number of bidders. All regressions are run with the Cochrane-Orcutt procedure to correct for autocorrelation. $N = 50$ because we do not have the projected number for the first 3 auctions. t-statistics are in brackets.

	units	C	volatility swap bp	expected size bln	swap spread bp	forward spread (-) bp	proj # bidders 100's	Adj R^2	N
Panel (a): Bidding variables									
Discount (swap)	bp	1.715	-0.377	0.016	0.278	0.131	-0.106	0.733	50
		(0.685)	(-2.261)	(1.777)	(5.063)	(4.076)	(-0.330)		
Std	bp	0.331	0.043	0.001	0.031	0.007	-0.037	0.827	50
		(1.408)	(2.543)	(2.740)	(11.855)	(1.973)	(-1.011)		
Skewness		-0.053	-0.004	-0.001	-0.001	-0.004	0.013	0.559	50
		(-1.043)	(-1.152)	(-4.944)	(-2.029)	(-3.856)	(2.313)		
Kurtosis		1.028	0.013	0	0.005	-0.002	0.049	0.395	50
		(12.084)	(1.328)	(0.398)	(2.229)	(-0.550)	(3.440)		
QW kurtosis		1.569	0.075	0.002	0.016	-0.003	-0.049	0.280	50
		(3.862)	(2.421)	(1.614)	(2.074)	(-0.368)	(-0.792)		
Relative bid quantity	%	2.884	-0.026	-0.010	0.009	0.015	-0.214	0.339	50
		(1.821)	(-0.603)	(-2.132)	(1.097)	(1.674)	(-1.471)		
Number bids per bidder		1.632	0.040	0.003	0.029	0.028	0.003	0.693	50
		(3.558)	(1.401)	(3.334)	(6.103)	(3.623)	(0.054)		
Panel (b): Performance and participation variables									
Underpricing (swap)	bp	-0.434	-0.538	0.026	0.107	0.148	0.207	0.671	50
		(-0.267)	(-3.540)	(3.802)	(3.158)	(4.553)	(0.942)		
Manybids	%	51.819	0.535	0.085	0.497	1.419	0.195	0.693	50
		(3.459)	(0.670)	(3.510)	(3.706)	(6.029)	(0.103)		
Largest 10	%	76.678	1.082	-0.175	0.094	-0.050	-4.474	0.456	50
		(7.321)	(1.297)	(-5.117)	(0.716)	(-0.278)	(-3.718)		
Number of bidders	100's	1.054	0.027	0.011	0.037	0.051	0.447	0.722	50
		(1.339)	(0.438)	(5.109)	(2.878)	(6.101)	(4.169)		
Bid-to-cover		11.457	-0.115	-0.041	0.045	0.075	-0.766	0.315	50
		(4.093)	(-0.528)	(-4.810)	(1.303)	(1.562)	(-2.348)		

Table 4

Autocorrelation of Bids and Awards

First and second autocorrelation coefficients for bids and awards (relative to the expected auction size and allotted quantity, respectively) for bidders who participated in each maintenance period in our sample. The reported mean across bidders is equally weighted. % positive is the percentage of bidders with positive autocorrelations.

	mean	t-stat	% positive	min	max	N
bids, 1st	-0.028	-3.843	31.695	-0.644	0.561	407
bids, 2nd	0.126	12.765	68.796	-0.144	0.846	407
award, 1st	-0.114	-10.106	27.273	-0.721	0.804	407
award, 2nd	0.300	26.278	91.155	-0.432	0.842	407

Table 5

Small versus Large Bidders: Fixed Groups

Each bidder is placed in a group from 1 to 12 based upon his average relative bid quantity throughout the total sample for auctions he participates in. Group 1 consists of the 99 smallest bidders, Group 2 consists of the next 100 smallest bidders, ..., Group 12 consists of the 100 largest bidders. For each group, we report the mean: relative bid quantity, award ratio (quantity awarded as a fraction of quantity demanded), discount (swap), underpricing (swap), standard deviation, skewness, kurtosis, number of bids, and number of auctions participated in.

	1	2	3	4	5	6	7	8	9	10	11	12
Rel bid quant	0.002	0.006	0.010	0.016	0.025	0.037	0.054	0.079	0.121	0.208	0.436	1.991
	(0)	(0)	(0)	(0)	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.005)	(0.010)	(0.057)
Award ratio	0.626	0.662	0.670	0.661	0.622	0.605	0.618	0.568	0.628	0.589	0.573	0.588
	(0.015)	(0.010)	(0.010)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)	(0.007)	(0.006)
Underpr (sw)	0.580	0.879	1.173	1.391	1.781	1.812	1.934	2.118	1.843	2.210	2.108	2.231
	(0.196)	(0.096)	(0.102)	(0.079)	(0.070)	(0.068)	(0.063)	(0.061)	(0.063)	(0.056)	(0.055)	(0.047)
Std dev	0.421	0.790	0.692	0.703	0.785	0.708	0.633	0.753	0.732	0.680	0.676	0.726
	(0.032)	(0.031)	(0.025)	(0.023)	(0.022)	(0.017)	(0.015)	(0.016)	(0.017)	(0.014)	(0.014)	(0.013)
Discount (sw)	3.234	3.193	2.958	2.956	3.330	3.435	3.397	3.781	3.238	3.545	3.451	3.309
	(0.216)	(0.145)	(0.134)	(0.104)	(0.094)	(0.089)	(0.083)	(0.083)	(0.081)	(0.073)	(0.068)	(0.056)
Skewness	-0.014	-0.045	-0.020	-0.033	0.004	0.009	-0.028	-0.006	-0.041	-0.040	0.007	-0.014
	(0.004)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)	(0.008)	(0.011)	(0.009)	(0.010)	(0.010)
Kurtosis	1.060	1.296	1.340	1.411	1.450	1.483	1.426	1.515	1.689	1.536	1.643	1.807
	(0.006)	(0.012)	(0.018)	(0.019)	(0.013)	(0.015)	(0.012)	(0.017)	(0.045)	(0.017)	(0.060)	(0.034)
Num bids	1.411	2.037	2.166	2.312	2.500	2.421	2.286	2.566	2.570	2.403	2.450	2.622
	(0.024)	(0.030)	(0.037)	(0.031)	(0.031)	(0.025)	(0.026)	(0.028)	(0.028)	(0.025)	(0.024)	(0.025)
Num aucts	9.090	16.570	15.680	21.890	22.280	26.150	26.540	27.300	29.270	30.260	33.500	39.800
	(1.111)	(1.440)	(1.392)	(1.601)	(1.743)	(1.637)	(1.643)	(1.661)	(1.776)	(1.740)	(1.506)	(1.442)

Table 6

Pairwise Tests of Differences in Mean Underpricing Between Groups.

Tests for differences in mean underpricing (swap) between the 12 groups in Table 5. The (i, j)th cell is the difference in underpricing (swap) between groups i and j, where i represents rows and j columns. Differences are in basis points. P-values are in parenthesis. Group 12 are the 100 largest bidders and Group 12 the 99 smallest.

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	-0.30	-0.59	-0.81	-1.20	-1.23	-1.35	-1.54	-1.26	-1.63	-1.53	-1.65
	(1)	(0.12)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
2	0.30	0	-0.29	-0.51	-0.90	-0.93	-1.06	-1.24	-0.96	-1.33	-1.23	-1.35
	(0.12)	(1)	(0.04)	(0.00)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
3	0.59	0.29	0	-0.22	-0.61	-0.64	-0.76	-0.95	-0.67	-1.04	-0.94	-1.06
	(0)	(0.04)	(1)	(0.09)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
4	0.81	0.51	0.22	0	-0.39	-0.42	-0.54	-0.73	-0.45	-0.82	-0.72	-0.84
	(0)	(0)	(0.09)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
5	1.20	0.90	0.61	0.39	0	-0.03	-0.15	-0.34	-0.06	-0.43	-0.33	-0.45
	(0)	(0)	(0)	(0)	(1)	(0.75)	(0.10)	(0)	(0.51)	(0)	(0)	(0)
6	1.23	0.93	0.64	0.42	0.03	0	-0.12	-0.31	-0.03	-0.40	-0.30	-0.42
	(0)	(0)	(0)	(0)	(0.75)	(1)	(0.19)	(0)	(0.74)	(0)	(0)	(0)
7	1.35	1.06	0.76	0.54	0.15	0.12	0	-0.18	0.09	-0.28	-0.17	-0.30
	(0)	(0)	(0)	(0)	(0.10)	(0.19)	(1)	(0.04)	(0.31)	(0)	(0.04)	(0)
8	1.54	1.24	0.95	0.73	0.34	0.31	0.18	0	0.28	-0.09	0.01	-0.11
	(0)	(0)	(0)	(0)	(0)	(0)	(0.04)	(1)	(0)	(0.27)	(0.90)	(0.14)
9	1.26	0.96	0.67	0.45	0.06	0.03	-0.09	-0.28	0	-0.37	-0.27	-0.39
	(0)	(0)	(0)	(0)	(0.51)	(0.74)	(0.31)	(0)	(1)	(0)	(0)	(0)
10	1.63	1.33	1.04	0.82	0.43	0.40	0.28	0.09	0.37	0	0.10	-0.02
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0.27)	(0)	(1)	(0.20)	(0.77)
11	1.53	1.23	0.94	0.72	0.33	0.30	0.17	-0.01	0.27	-0.10	0	-0.12
	(0)	(0)	(0)	(0)	(0)	(0)	(0.04)	(0.90)	(0)	(0.20)	(1)	(0.09)
12	1.65	1.35	1.06	0.84	0.45	0.42	0.30	0.11	0.39	0.02	0.12	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0.14)	(0)	(0.77)	(0.09)	(1)

Table 7

Regressions of Bid Quantity and Award by Group on Underpricing

Ordinary least squares regressions of (i) relative bid quantity and (ii) relative award on a constant and underpricing (swap). Both regressions are run for each of the 12 fixed groups in Table 5. Bid and award are relative to the expected auction size and allotted quantity, respectively. Constants are not reported. *t*-stats are given in parenthesis. Group 12 consists of the 100 largest bidders and Group 12 the 99 smallest.

	bid	Adj. R^2	award	Adj. R^2	N
1	0.003	0.049	-0	0	53
	(1.624)		(-0.065)		
2	0.015	0.081	-0.001	0.002	53
	(2.113)		(-0.278)		
3	0.010	0.005	-0.007	0.011	53
	(0.524)		(-0.750)		
4	0.018	0.005	-0.017	0.044	53
	(0.501)		(-1.528)		
5	0.039	0.011	-0.011	0.018	53
	(0.762)		(-0.975)		
6	0.069	0.007	-0.021	0.015	53
	(0.599)		(-0.889)		
7	0.137	0.022	-0.002	0	53
	(1.083)		(-0.072)		
8	0.297	0.051	0.063	0.037	53
	(1.651)		(1.399)		
9	0.132	0.002	-0.043	0.014	53
	(0.327)		(-0.857)		
10	0.384	0.007	0.003	0	53
	(0.583)		(0.039)		
11	0.042	0	-0.396	0.135	53
	(0.024)		(-2.822)		
12	-0.303	0	0.430	0.028	53
	(-0.034)		(1.207)		

Table 8

Underbidding Case Study: Summary Statistics

Means of various statistics for the two underbid auctions, 34 and 42, in our sample.

	units	Auction 34	Auction 42
Date		13 Feb 2001	10 Apr 2001
Tender id		20010007	20010018
Maintenance period		8	10
Auction position		4 of 5	3 of 4
Expected size	bln	88	53
Bid-to-cover		0.742	0.471
Number of bidders		401	240
Relative bid quantity	%	0.185	0.196
Discount (swap)	bp	-0.944	-5.743
Underpricing (swap)	bp	-0.700	-5.645
Standard deviation	bp	0.138	0.070
Skewness		0.043	0.054
Kurtosis		1.150	1.371
Stopout spread		0	0
Winrate-stopout	bp	0.200	0.145
Volatility of swap rate	bp	4.425	4.536
Swap spread	bp	-0.500	-5.500
Forward spread	bp	-3.476	-26.652

Table 9

Underbidding Case Study: Summary Statistics for Five Fixed Groups

Panels (a) and (b): For each of five fixed bid-size based groups, we report means of relative bid quantity (based on expected auction size), award ratio (based on realized auction size), number of bidders, number of winners, average number of bids. The groups have been constructed analogously to those in Table 5. Group 1-20 consists of the 20 largest bidders (by average relative bid quantity), etc. Panel (a) excludes auctions 34 and 42. Panel (b) is for auctions 34 and 42 only.
Panel (c): For each group, tests for differences in mean relative award quantity between the two underbid auctions and all other auctions and the eight straddling auctions (four auctions before and four auctions after). P-values in brackets.

	1-20	21-50	51-100	101-200	201-1199
Panel (a): All auctions, excluding 34 and 42					
Rel. bid quantity: group	75.286	46.205	32.352	28.240	30.047
Award (realized): group	34.692	23.497	14.659	12.682	14.471
Number bidders	16.824	23.824	35.667	64.196	431.863
Number winners	14.804	20.216	29.059	51.235	348.765
Number of bids	2.963	2.524	2.601	2.480	2.373
Panel (b): Auctions 34 and 42					
Rel. bid quantity: group	14.948	15.304	9.092	10.018	11.280
Award (realized): group	25.311	25.289	14.415	16.285	18.700
Number bidders	9	14.500	20.500	38	238.500
Number winners	9	14.500	20.500	38	238.500
Number of bids	1.111	1.103	1.073	1.118	1.289
Panel (c): Tests of differences in mean award ratios					
not underbid vs 34	-7.352	2.038	-1.583	2.811	4.086
	(0)	(0.003)	(0)	(0)	(0)
8 straddling vs 34	-7.602	3.607	-1.433	1.992	3.436
	(0.003)	(0.025)	(0.165)	(0.003)	(0.008)
not underbid vs 42	-13.275	1.570	3.590	4.917	3.198
	(0)	(0.019)	(0)	(0)	(0)
8 straddling vs 42	-16.680	4.914	3.636	3.317	4.812
	(0.010)	(0.013)	(0.006)	(0.051)	(0.036)

Table 10

Underbidding Case Study: The Straddling Auctions

This table provides some descriptive statistics for auctions 34 and 42 and the four auctions preceding and succeeding these auctions. Top 20 refers to the 20 largest bidders and Bottom 999 refers to the smallest 999 bidders (see Table 9). Panel (a) covers auction 34 and panel (b) covers auction 42.

	-4	-3	-2	-1	34	+1	+2	+3	+4
Panel (a): Auction 34									
Expected size	101	104	85	101	88	169	25	153	49
Swap spread	4.500	2	4	0	-0.500	14	2.500	3.500	4.500
Bid-to-cover	1.363	1.140	1.619	1.034	0.742	1.187	4.385	1.241	2.658
Rel. bid quantity: top 20	44.581	41.954	57.950	36.840	19.999	41.193	176.528	44.794	111.445
Award (realized): top 20	28.859	36.566	30.600	35.305	26.948	34.673	33.855	32.114	44.426
Rel. bid quantity: bottom 999	21.889	16.919	22.610	15.318	14.060	15.626	62.076	15.660	35.856
Award (realized): bottom 999	16.748	14.971	15.417	15.009	18.946	13.272	21.307	12.985	14.367

	-4	-3	-2	-1	42	+1	+2	+3	+4
Panel (b): Auction 42									
Expected size	49	135	49	118	53	177	5	80	79
Swap spread	4.500	6	-4.500	0.500	-5.500	17.500	5.500	3.500	5.500
Bid-to-cover	2.658	1.349	1.174	1.094	0.471	1.456	16.661	1.842	2.088
Rel. bid quantity: top 20	111.445	47.956	35.546	50.517	9.897	65.484	611.664	90.232	86.603
Award (realized): top 20	44.426	36.049	28.577	45.528	21.026	49.037	8.755	48.320	40.948
Rel. bid quantity: bottom 999	35.856	18.855	13.779	11.479	8.500	17.433	210.864	19.061	19.793
Award (realized): bottom 999	14.367	13.230	12.124	10.604	18.057	10.114	25.541	11.102	8.881

Table 11

Conditional Volatility of Swap Rate

This table reports the results of the conditional volatility estimation of the two-week swap rate, using a modified GARCH(1,1) model. Panel (a) gives the coefficients of the mean equation, while panel (b) gives the coefficients of the variance equation. Slope is the difference between 12 and 1 month Euribor. Downswap takes the value 1 if the swap rate fell the previous day and 0 otherwise. Endmonth takes the value 1 if the day is the last business day of a month and 0 otherwise, Endres takes the value 1 if the day is the last business day of a reserve maintenance period and 0 otherwise. Mainrepo takes the value 1 if the day is an auction day (main refinancing operation) and 0 otherwise. (-1) stands for the preceding day's observation. For example, endres(-1) is a dummy variable for the first business day in a maintenance period.

	Coefficient	z-statistics
Panel (a): Mean equation		
Constant	-0.003	-1.790
Slope(-1)	0.012	3.592
Downswap(-1)	0.004	2.065
Panel (b): Variance equation		
C	0.0009	4.892
ARCH(1)	0.147	3.326
GARCH(1)	0.594	7.028
Endmonth	-0.002	-6.283
Endres(-1)	-0.001	-5.758
Endres	-0.002	-5.192
Mainrepo	-0.0004	-5.080

Figure 1: Standing Facilities and Minimum Bid Rate

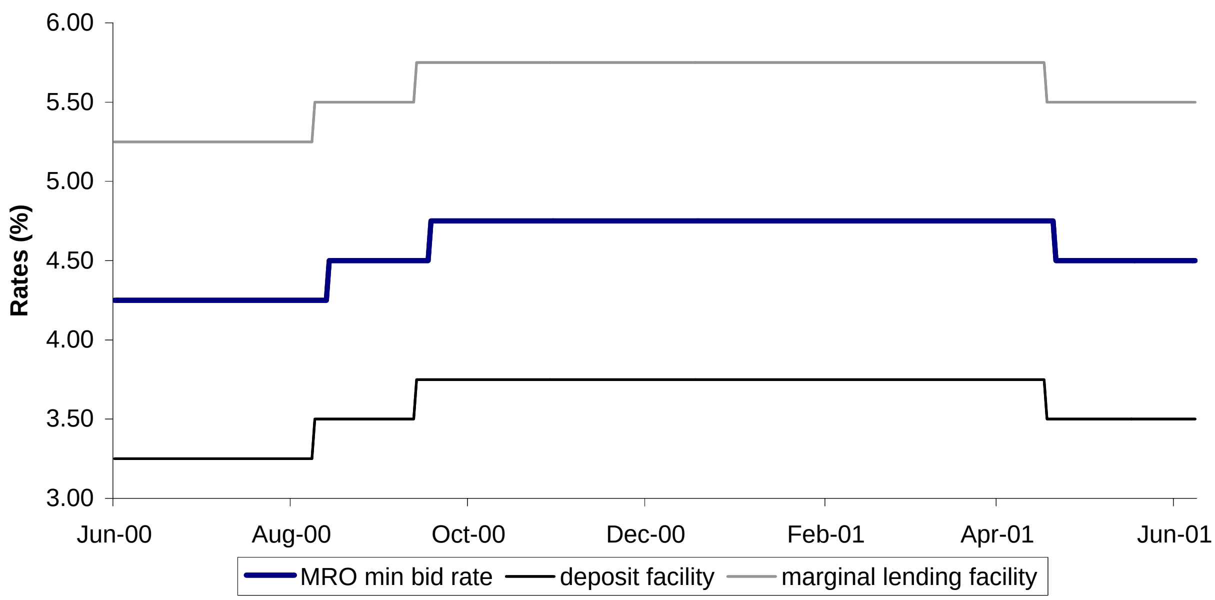

Figure 2: Secondary Market Rates

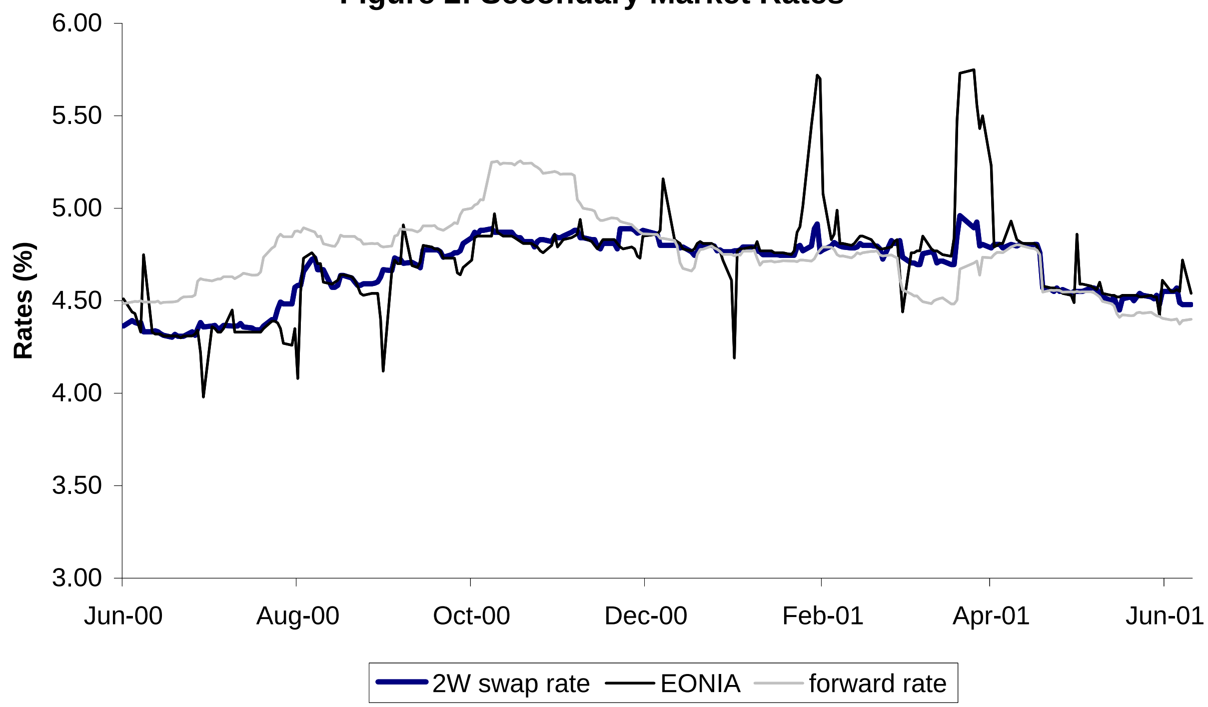

Figure 3: Expected Auction Sizes and Differences between Expected and Realized Auction Sizes (in bn euro)

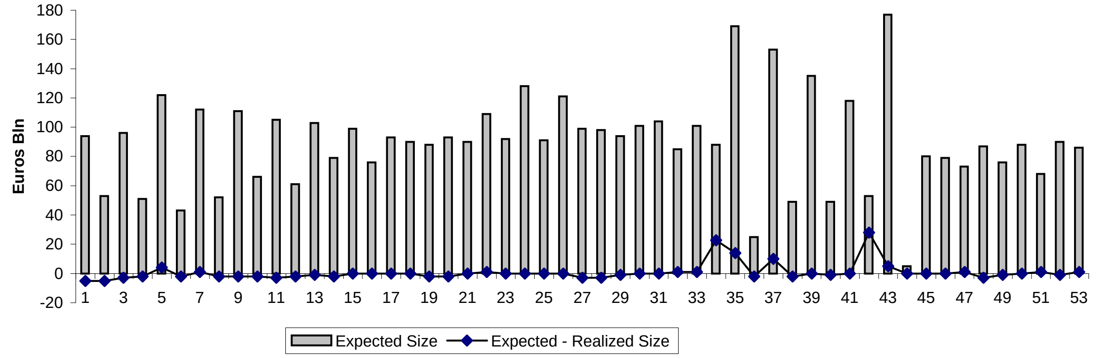

Figure 4: Frequency of Participation

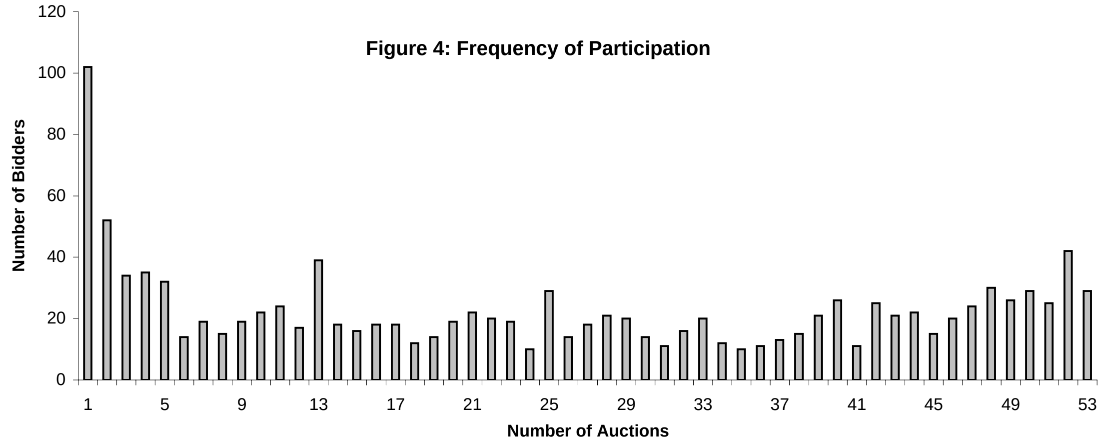

Figure 5: Time Trend of Number of Bidders

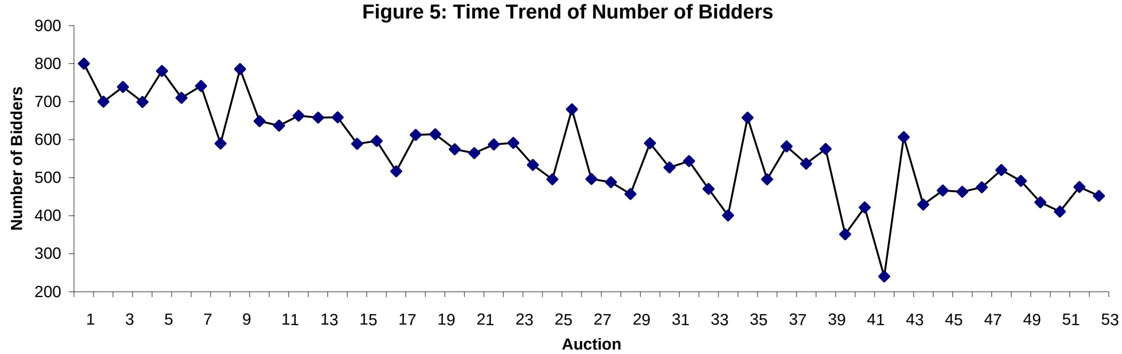

Figure 6: Distribution of Number of Bids