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Abstract

Weekly repo auctions are the European Central Bank's most important policy instrument. Provided that banks bid seriously, these auctions should determine the liquidity of the banking sector in an efficient and transparent way. However, under the fixed rate tender procedure used until June 2000, banks increasingly overbid which eventually forced the ECB to switch to the variable rate tender format. This paper investigates the overbidding phenomenon from a theoretical and an empirical point of view. Our empirical results confirm the weakness of the fixed rate tender format and indicate that the ECB's liquidity management has significantly improved since the switch to the variable rate system.

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1 Introduction

Following the former practice of the German Bundesbank or the Bank of France, securities repurchase agreements (repos) are of overwhelming importance for the European Central Bank's (ECB) money market management and for the control of the monetary base.[1] The repo rate is the ECB's key interest rate that governs short–term interest rates, and the availability of repos determines the liquidity of the banking sector. The provision of repos is determined predominantly in the ECB's *main refinancing operations*, weekly tenders of repos of two weeks maturity, where reserves should be allocated in an efficient and transparent way. This paper investigates the performance of the ECB's repo auctions from a theoretical and an empirical perspective.

Until 21 June 2000 the ECB's main refinancing operations were conducted exclusively as *fixed rate tenders,* where the repo rate is pre–announced by the central bank, and banks simply indicate how much refinancing they would like to receive at that rate. Typically, total bids exceeded the allotment of repos, and banks were rationed proportionally to their bids. The starting point of our analysis is the observation that the quota by which banks were rationed vanished over time. In May 2000, the quota reached an all time low of less than 1%, at which point the ECB was forced to change the auction format in order to stop the severe overbidding. There is no doubt that bids were overstated. In May, total bids increased to more than 8000 billion Euro, which amounts to almost 20 times the monetary base of the whole Eurosystem!

The ECB performs repo auctions not in order to maximize profits but rather to insure the efficient allocation of funds among banks and to gather information about money market conditions. Obviously, providing an appropriate repo volume would be much easier if banks bid something close

[1] In a repo, the ECB buys securities on condition that the seller (the bank) simultaneously repurchases the securities forward. Hence repos are central bank credit collaterised with securities. Some member central banks use credits with pledge rather than repos. For brevity, we will call all refinancing operations 'repos' in the remainder of this paper. For a detailed description of the ECB's set of monetary policy instruments and procedures see ECB (1999a). A more critical assessment is given by Corsetti and Pesenti (1999).

to their true demand for reserves. The usefulness of repo auctions for the conduct of monetary policy therefore depends on banks' bidding behaviour and, thereby, on the auction mechanism applied. This paper presents a theoretical analysis of banks' bidding behaviour as well as an empirical analysis of roughly three years of Bundesbank fixed rate tender data. Our results demonstrate that the proportional rationing scheme of the fixed rate tenders is responsible for the severe overbidding phenomenon by inducing banks to grossly exaggerate their needs for refinancing.

In fact, overbidding has several adverse effects on the banking system and the conduct of monetary policy. First, by inducing banks to misrepresent their true demand, overbidding makes it much harder to reach an efficient allocation of reserves among banks. Second, by artificially depressing the allotment quota, it falsely signaled a much too restrictive liquidity management and obscured the ECB's policy signals. Third, by seemingly offering an arbitrage profit, it leads banks to take unnecessary risks. Moreover, we will show that the auction rules of a fixed rate tender may define a game without equilibrium which reveals a fundamental indeterminacy that seems problematic per se.

The paper is organized as follows. In the two following sections, we describe the institutional setting and present an informal look at the vanishing quota phenomenon. In Section 4 we analyse banks' bidding behaviour in a fixed rate tender from a game theoretic point of view and introduce a simple boundedly rational learning process which mimics some general features of the data. In Section 5 we analyse the Bundesbank's auction data in order to shed more light on the link between the central banks' allotment, banks' bidding behaviour, and the decreasing trend of the resulting allotment quotas.

In June 2000 the ECB switched to variable rate tenders to stop the severe overbidding. In Section 6 we discuss the possible drawbacks of variable rate tenders and the trade–off the ECB faced when abandoning fixed rate in favour of variable rate tenders. The preliminary evidence suggests that the introduction of variable rate tenders has largely improved the ECB's liquidity management. Some concluding remarks are offered in Section 7.

Table 1: The European banking system's liquidity position in June 1999

Liquidity–providing factors		Liquidity–absorbing factors		
Monetary reserves	340	Currency	337	Monetary base 440
Marginal lending facility	0.3	Deposit facility	0.6	
Main refinancing op.	132	Banks' reserves	102	
Longer-term refinancing	45	Govt. deposits	40	
		Other factors (net)	37	

Notes: Period averages of daily positions in billion Euros; see Monthly Bulletin of the ECB, Table 1.5. Rounding errors account for deviations of totals.

2 The ECB's liquidity management

Repo auctions play a pivotal role in the ECB's set of monetary policy instruments. The volume of repo credit available in the ECB's weekly main refinancing operations determines the scarcity of reserves, and thus, the liquidity of the banking sector. Given the repo rate, it is the core practical task for the central bank to decide (1) upon the total volume of the repo, which should be in line with the intended course of monetary policy, and (2) upon the allocation of the total volume to individual banks, which should be compatible with banks' liquidity needs. It is worth emphasizing that a "fair" allocation of repos is of particular importance for the ECB because of the heterogeneity of the European banking sector, see Hämäläinen (2000).[2]

In order to supply an adequate repo volume, the central bank has to estimate banks' demand for reserves. In practice, this requires forecasts of the various positions in the central bank's balance sheet. Table 1 summarizes the factors that are relevant for the liquidity position of the European banking sector.

The liability side of the balance sheet shows that the main liquidity–absorbing factors are currency and banks' reserves, which are almost entirely

[2] Sirkka Hämäläinen is member of the Executive Board of the ECB. A comparison of the operating procedures of the Federal Reserve, the Bank of Japan and the ECB is provided by Borio (2000). For a recent contribution to the analysis of the supply and demand for Federal Reserve deposits, see e.g. Hamilton (1998).

required reserves. Yet the liquidity effects of government deposits with some national central banks are considerable. Particularly the Treasury activities by Italy, France and Spain have posed a challenge to the forecasting ability of the ECB, see ECB (1999c). The asset side of the balance sheet shows the liquidity–providing factors, i.e. the various sources of the monetary base. According to the balance sheet identity an increase in the central bank's liabilities requires that its assets increase accordingly. For example, if the demand for currency is expected to rise (say, due to seasonal factors), the ECB increases its supply of reserves in order to prevent large interest rate fluctuations.

Although the balance sheet seems to offer several alternatives, the ECB's liquidity management is almost completely based on its main refinancing operations. The *longer–term refinancing operations*, monthly tenders of repos with three–month maturity, are only used for providing the banking system with an additional, stable liquidity flow. The *marginal lending facility*, by contrast, provides overnight liquidity and serves only as an emergency credit. And finally, monetary reserves are not used for liquidity management since financial markets could misinterpret buying or selling foreign assets as an exchange rate intervention of the central bank.

The extensive use of main refinancing operations provides the desired flexibility in the conduct of monetary management for two reasons. First, the repo auctions are conducted on the initiative of the central bank. Therefore, the central bank determines the maturity of the repo, the date of refinancing, and even the volume of reserves banks can borrow. By contrast, standing facilities like the marginal lending or the *deposit facility* allow the banks to decide how long, when and to what extent they borrow or deposit reserves.[3] Second, as opposed to the monthly longer–term repos, the main refinancing operations mature and are renewed on a weekly basis. This enables the central bank to adjust the supply of reserves both gradually and at short

[3] In order to limit the use of the lending facility it is provided at a penalty rate well above the repo rate. Therefore, the marginal lending rate establishes a ceiling for the money market rates. Similarly, the ECB's deposit facility should absorb excess overnight liquidity. Thus, the deposit interest rate offered by the ECB is below the prevailing level of interest rates, thereby defining the floor of the ECB's interest rate corridor.

notice.

While the central bank might be in a good position to estimate the appropriate *total* repo volume, it has no precise way of knowing the future liquidity needs of individual banks. The rationale behind the conduct of repo *auctions* is therefore to receive new information about the situation in the money market and the liquidity needs of individual banks. Provided that banks bid their true demand for reserves, repo auctions should improve the efficiency of the central bank's liquidity management. If, however, bids are completely detached from the actual liquidity needs, the information content of bids gets dubious and results of repo auctions could be misleading.

3 The vanishing quota in fixed rate tenders

In the tradition of the Bundesbank, the ECB until June 2000 conducted its main refinancing operations as fixed rate tenders. In a fixed rate tender the central bank sets the repo rate, and banks simply bid the amount of refinancing they wish to obtain at that rate. Having collected all bids, the central bank decides upon the repo volume, i.e. the total allotment A, and each bank gets the same quota (allotment ratio) $Q = \min(1, A/B)$ of its bid, where B is the sum of all bids.[4] One might expect that high values of Q indicate that the central bank supplied reserves generously while low values of Q signal a restrictive monetary policy stance. Unfortunately, it is not as simple as that.

[place Fig. 1 about here]

Figure 1 shows the allotment ratios of the weekly fixed rate tenders performed by the Bundesbank and the ECB until June 2000. The Bundesbank had relied on fixed rate tenders since February 1996 in order to contribute to a smooth transition to the new Eurosystem. Although there is a structural break in the data, the German experience should be helpful for analysing the usefulness of fixed rate tenders for the ECB's liquidity management, in

[4] As a referee pointed out, a strict "100 % allotment rule" has the disadvantage that the central bank cannot control the allocated repo volume.

particular, since a major part of the repo volume is usually allocated to German banks.

At least three features of Figure 1 merit discussion. First, with only two exceptions the quota is far below one. On average, German banks received only 30% of the repo credit they bid for, and in the new Eurosystem the average allotment ratio is even lower. If European banks had bid their true demand for reserves, the monetary policy of the ECB would have been pretty restrictive. In order to see why allotment ratios in fixed rate tenders are typically less than one, note that banks would not participate in a repo auction if refinancing on the interbank money market were cheaper. In fact, the repo rates set by the Bundesbank and the ECB are usually slightly below the prevailing money market rates, see Figure 2 and Ayuso and Repullo (2000).[5] However, if repo credit is an attractive source of refinancing, banks might exaggerate their bids in expectation of a quota less than one. For example, if a bank assumes that the quota Q will be 50%, it might bid twice as much as it actually needs.

Second, the two outliers on 21 August 1996 and on 7 April 1999 are easily explained. Figure 3 shows clearly that it was the drastic decrease in total bids, rather than a movement in the total allotment, which drives the two peaks in the allotment ratio. Furthermore, Figure 2 shows that both outliers precede by one week a cut in the repo rate. Apparently, banks anticipated these rate cuts and refrained from bidding. Banks can easily postpone refinancing for one or two weeks since the Bundesbank's and the ECB's reserve requirement system allows averaging the reserve holdings within the monthly maintenance period. Similarly, in spring 2000 rate hike expectations made it worthwhile to fulfil minimum reserves as early as possible in the maintenance period, which gave banks additional incentives to overbid.[6]

[place Fig. 2 about here]

[5] According to Ayuso and Repullo (2001), the positive spread between money market rates and the repo rate can be explained by an asymmetric loss function for the ECB. Note that whereas the ECB's policy rate is on average below money market rates, the effective Federal Funds rate oscillates around the Federal Funds rate target.

[6] The role of the reserve requirement regime for a central bank's liquidity management is emphasized by Bindseil (2000).

[place Fig. 3 about here]

The third and most puzzling feature in Figure 1 is that the quota obviously decreased over time. It started 1996 above 40%, declined to about 15% at the end of 1998 and reached in May 2000 an all–time low of meagre 0.87%. Does this imply that monetary policy had become *increasingly* restrictive? Surely not, Figure 3 reveals that the decreasing trend in the quota is solely due to increasing bids and not to decreasing allotments. Obviously banks tried to circumvent the rationing of the central bank by increasingly exaggerating their bids.

If banks completely misrepresent their true demand, an efficient allocation of funds among banks becomes impossible. Given the tiny quota a small mistake in a bank's estimate of the upcoming allotment ratio will result in huge deviations of the actual from the desired allotment. Following Hämäläinen (2000, p. 4) "...this uncertainty is costly for counterparties, and it is particularly costly for counterparties in the countries where availability of collateral is restricted or where the marginal cost for collateral is high." Moreover, the results of repo auctions lose most of their informational value if bids and true demand fall so far apart. In the next section we will analyse the strategic bidding behaviour of banks.

4 Strategic bidding in a fixed rate tender

In this section we will analyse a simple, stylised game among the banks – the repo–game – in order to illuminate the observed overbidding in the fixed rate tenders. One possible explanation for overbidding, which is also advanced by the ECB itself (see ECB, 2000), is that banks were expecting interest rate hikes. While this was certainly the case for some periods under consideration, such expectations did not prevail for the entire four and a half years for which the vanishing quota was observed. Thus, interest rate expectations are only part of the story, which, in particular, cannot explain by itself why the allotment quota vanishes over time.

We do not attempt here to present a full fledged model of the ECB's liquidity management and banks' demand for reserves. In particular, we

are agnostic about the determinants of bank's demand for reserves, which inter alia depends on current and expected future interest rates.[7] However, our simple model captures the main strategic aspects present in the ECB's fixed rate tenders. It applies whenever the total (true) demand of banks exceeds the repo allotment by the central bank by a margin however small. Put differently, it applies whenever the repo rate is expected to be lower than alternative refinancing opportunities, e.g. the equilibrium rate on the interbank money market. In this sense, our model has also an implicit price–theoretic perspective. By employing a boundedly rational learning process, the model explains not only why overbidding occurs but also why it becomes worse over time.

4.1 The repo–game

Suppose that the central bank offers a total allotment of $A > 0$ for refinancing of banks at a fixed repo rate. Each bank i, $i = 1, ..., n$, has a true *d*emand D^i for repos at that rate. Let bank i's *b*id for repos be denoted by B^i. Of course, bids need not match the true demand if banks behave strategically. As explained above the actual allotment of repos is determined through a rationing scheme if the sum of the bids, $B := \sum_i B^i$, exceeds the total allotment A. That is, there is a quota given by

$$Q = \min(A/B, 1),$$

and the actual allotment to bank i is $A^i = QB^i$. We assume that banks face a quadratic loss function

$$\pi^i := -\left(A^i - D^i\right)^2 = -\left(\min\left[\frac{A}{B}, 1\right] B^i - D^i\right)^2, \tag{1}$$

which seems plausible since banks incur a loss both, when they receive too little refinancing and when they receive too much. In either case they can use the marginal lending or the deposit facility of the ECB, respectively, but at significantly less favourable interest rates.

[7] Of course, in our empirical analysis we will control for interest rate effects and several other institutional details.

Note first that bidding less than one's demand, $B^i < D^i$, is a strictly dominated strategy. If there is no rationing, each bidder receives the amount he has bid and would strictly prefer to bid his true demand. If there is rationing, one should bid weakly more than one's demand. Thus bidding less is strictly dominated.

Suppose now that total demand for repos did not exceed the total allotment, $A \geq D := \sum_i D^i$. In this case there would exist an obvious equilibrium in which all banks bid truthfully.[8] Clearly, this type of equilibrium is incompatible with the empirical observations of the previous section. If banks had bid truthfully, an implausibly large increase of the true demand for repos would have been necessary to account for the observed bidding behaviour. Thus, in the following we focus on the empirically relevant case of $A < D$. We show that the specified auction rules give rise to a game without an equilibrium whenever banks *true* demand exceed the allotment of the central bank.

Proposition 1 *Let $A < D$. Then, the repo–game does not have an equilibrium.*

Proof. Since no strictly dominated strategy can be part of an equilibrium, we must have $B^i \geq D^i$ and, hence, $Q < 1$, in any potential equilibrium. The expected payoff of bank i against a (joint) mixed strategy distribution $F(B^{-i})$ over the total demand of other banks $B^{-i} := \sum_{j \neq i} B^j$ is given by

$$E\pi^i = -\int_0^\infty \left(\frac{A}{B^i + B^{-i}} B^i - D^i \right)^2 dF(B^{-i}).$$

The first order condition is $\frac{\partial E\pi^i}{\partial B^i} = 0$, where

$$\frac{\partial E\pi^i}{\partial B^i} = -2 \int_0^\infty \left(\frac{A}{B^i + B^{-i}} B^i - D^i \right) \frac{AB^{-i}}{(B^i + B^{-i})^2} dF(B^{-i}). \qquad (2)$$

[8] It can be shown along the lines of the proof of Prop. 1 that no other equilibria exist if $A > D$. If A happens to exactly match D, a coordination game results with an infinite number of equilibria in which all banks exaggerate their bids by the same proportion (see also Bindseil and Mercier, 1999).

Let S^j denote the support of the hypothesized equilibrium strategy of bank j, and let $\tilde{B}^j := \inf S^j$. Let bank i be the bank which exaggerates its demand the least at the bottom of its support, i.e.

$$\frac{\tilde{B}^i}{D^i} = \min_j \frac{\tilde{B}^j}{D^j}.$$

Then we have that

$$B^{-i} = \sum_{j \neq i} B^j \geq \frac{\tilde{B}^i}{D^i} \sum_{j \neq i} D^j. \tag{3}$$

To complete the argument we prove that bank i cannot be indifferent between the pure strategies in S^i by showing that (2) is strictly positive at $\tilde{B}^i$. By continuity of $E\pi^i$ this yields a contradiction to S^i being the support of an equilibrium strategy.

To that aim note that (2) is strictly positive if for all B^{-i} in the support of $F(B^{-i})$ it holds that

$$D^i > \frac{A}{\tilde{B}^i + B^{-i}} \tilde{B}^i. \tag{4}$$

>From (3) and the assumption that $A > D$ follows

$$D^i \geq \frac{\tilde{B}^i}{B^{-i}} \sum_{j \neq i} D^j > \frac{\tilde{B}^i}{B^{-i}} (A - D^i).$$

Solving for D^i yields the desired inequality (4). ■

Game theorists will realize that the reason for the non–existence of an equilibrium is the unbounded strategy space. In practice, there could exist an upper bound through the obligation to post a collateral for bids. However, in a recent announcement the ECB (1999b) clarified that only actual allocations, not bids, have to be collateralised, making the strategy space virtually unbounded from the viewpoint of a single bank.[9]

[9] The total amount of collateral eligible for the ECB's repo transactions is huge and encompasses a very broad spectrum of assets. Still, the availability of collateral and the cost of holding collateral differ considerably across member states. Therefore, the ECB had the impression that requiring banks to have a sufficient amount of collateral available to cover their full bids would violate the principle of equal treatment, see Hämäläinen (2000).

4.2 A myopic best reply process

In a game without equilibrium it is impossible to predict what rational players would do. Boundedly rational players, however, may behave in predictable ways. In particular, we may assume that banks follow a simple myopic best reply process (i.e. banks have adaptive expectations). Let $t = 0, 1, ...$ denote the time index. Then, each bank simply assumes that total bids of all other banks from the previous round (B_{t-1}^{-i}) remain unchanged and chooses a best reply against B_{t-1}^{-i}. If $B_{t-1}^{-i} \leq A_t - D_t^i$, the best reply of bank i is simply to choose D_t^i. If, however, B_{t-1}^{-i} is larger, bank i's best reply is determined by the first order condition of (1). Thus, the best reply process is given by[10]

$$B_t^i = \max \left[D_t^i, D_t^i \frac{B_{t-1}^{-i}}{A_t - D_t^i} \right]. \tag{5}$$

Since actions $B_t^i < D_t^i$ are strictly dominated, all banks will exaggerate their demands at least from the second period on.

If all banks follow this bidding rule, total bids B_t will behave according to the following equation for $t \geq 2$

$$B_t = \sum_i B_t^i = \sum_i \frac{D_t^i B_{t-1}^{-i}}{A_t - D_t^i} = \sum_i \frac{D_t^i}{A_t - D_t^i} \left(B_{t-1} - B_{t-1}^i \right).$$

Assuming that banks are symmetric, i.e. $D_t^j = D_t^i$, for all i, j, we obtain the following difference equation for the evolution of total bids

$$B_t = \frac{(n-1)D_t}{nA_t - D_t} B_{t-1}. \tag{6}$$

Since $A_t < D_t$ by assumption, it follows that $\frac{(n-1)D_t}{nA_t - D_t} > 1$, and the bidding process (6) explodes. Since the number of banks participating in the repo auctions is large (n typically exceeds 800), we can approximate (6) by

$$B_t = \frac{D_t}{A_t} B_{t-1}. \tag{7}$$

[10] Banks would not make a large mistake by simply assuming the quota to be the same as last period's since each bank is small relative to the market. This would result in a slightly different best reply process, namely in $B_t^i = \max[D_t^i, D_t^i/Q_{t-1}]$. The qualitative properties of this process are the same as of (5).

Rewriting (6) in terms of the quota $Q_t = A_t/B_t$ gives

$$Q_t = \frac{A_t}{D_t}\frac{A_t}{A_{t-1}}Q_{t-1}. \tag{8}$$

Letting small letters denote logs of variables, one obtains

$$\Delta b_t = d_t - a_t \tag{9}$$

$$\Delta q_t = (a_t - d_t) + \Delta a_t. \tag{10}$$

Therefore, if $a_t < d_t$, the central bank would have to perpetually increase the allotments in order to prevent the quota from vanishing. Note that the *growth rates* of bids and allotment ratios, rather than the levels, contain information about the unobserved true demand for repos and, thereby, about the tightness of monetary policy.

5 Empirical performance of the Bundesbank's fixed rate tenders

In this section we analyse the performance of fixed rate repo auctions from an empirical point of view. To that aim we will estimate the impact of banks' bidding on the allotments provided by the central bank. If bids contain reliable information about banks' demand for reserves, the central bank's allotments should depend on past and present total bids. Our second main interest concerns the determinants of banks' bidding behaviour. According to the adaptive bidding strategy introduced in the previous section, the observable trend in total bids sheds light on the relation between total allotment and banks' true demand for repo credit, see (9). Therefore, the trend in the bid equation reflects the average stance of monetary policy.

In contrast to the Bundesbank, the ECB's allotment decisions strongly depend on its unpublished forecasts for government deposits of Italy, France and Spain. Without having access to these forecasts, an empirical analysis of the ECB's allotment policy would be incomplete. Therefore, in this section we will concentrate on the Bundesbank's data. Yet, due to the similarities of the Bundesbank's and the ECB's monetary framework, the evidence should

also be illuminating for the prevailing Eurosystem. The Bundesbank employed fixed rate tenders in its main refinancing operations from February 1996 until the end of 1998, which gives us 150 observations.

5.1 Some preliminary data analysis

In a first step we investigated the stochastic properties of the time series under consideration. To that aim we performed unit root tests for the log of the Bundesbank's total allotment, a_t, and the log of total bids, b_t, which clearly indicate that the time series are trend stationary. The following regressions therefore contain a linear time trend, and standard test statistics can be applied.

Under normal circumstances, total allotment increases slightly over time due to monetary expansion. However, in May 1998 the Bundesbank transferred its profit to the German government and sterilized the resulting increase in reserves by reducing the available repo volume. We have therefore introduced a step–dummy $d1_t$ ($d1_t = 1$ for $t > 5/13/1998$ and $d1_t = 0$ otherwise) in the allotment equation. As we have already noted in Section 3, on 21 August 1996 banks drastically lowered their bids since they anticipated a lower repo rate in the following week. We captured the resulting outlier in total bids by including the impulse dummy $d2_t$ (where $d2_t$ equals one if $t = 28/8/96$ and zero otherwise). It is worth emphasizing that the inclusion of the dummies improves the residuals statistics of our regressions but it is not crucial for the main results. Finally, in order to control for the interest rate effects on banks' bidding behaviour we included the spread, $i - r$, between the day–to–day rate r and the repo rate i in the bid equation, see Figure 2. A significant positive spread between the money market rates and the repo rate increases the profitability of repo credit. Hence, one would expect the coefficient of $i - r$ to be positive.

5.2 The interplay between bids and allotments

The equations for the logs of total allotment a_t and total bids b_t presented in Table 2 contain lags up to order four. Higher lag orders were not signifi-

cant, presumably because the maintenance period of required reserves is one month. Note that the allotment equation contains contemporaneous total bids as an explaining variable because the bids are known to the central bank when the allotment is determined.

The results demonstrate that repos were used on a revolving basis, i.e. banks repay maturing repos using new repo credit.[11] As a consequence, the central bank's allotment strongly depends on its allotment two weeks ago. The central bank's allotment decision, however, did not depend on submitted bids. This is confirmed by a Wald test of the parameter restriction "$\forall i \;\; \beta_i = 0$" which gives a p-value of 0.91. Apparently, submitted bids contained *no* valuable information for the Bundesbank's liquidity management.

By contrast, bids did respond to past allotments. The corresponding null hypothesis "$\forall i \;\; \alpha_i' = 0$" can easily be rejected at the 1% significance level. In particular, banks increased their bids if the allotment in the preceding repo auction was low. The impact of the interest rate spread on banks' bidding behaviour is both plausibly signed and highly significant but it is quantitatively not very important.

The estimated average growth rate of the bids, $g_b := \tau'/(1 - \sum_{i=1}^{4} \beta_i') = 0.641\%$, exceeds the growth of the allotments, $g_a := \tau/(1 - \sum_{i=1}^{4} \alpha_i) = 0.191\%$. Hence, the quota decreased on average at a rate of $g_q = g_a - g_b = -0.45\%$. Assuming that banks bid according to the adaptive bidding rule (5), the growth of bids depends on the relation between the repo volume available and banks' actual liquidity needs. Our stylised model (see equation (9)) implies that $\frac{A_t}{D_t} = \exp(-\Delta b_t)$. Using g_b as an estimate for the average growth rate of total bids, we find that

$$\frac{A_t}{D_t} = 0.993.$$

Thus, rationing by the central bank was on average extremely modest. It seems that the Bundesbank matched banks' true demand for reserves surprisingly well – even without any recourse to banks' bidding behaviour.

Yet, the fact that banks were on average rationed by just 0.7% triggered the observed, astounding bidding war. Given this, the question is why the

[11] Note that the same revolving practice is applied in the Eurosystem.

Table 2: Determinants of allotments and bids in the Bundesbank's fixed rate tenders

$$a_t = c + \tau t + \sum_{i=1}^{4} \alpha_i a_{t-i} + \sum_{i=0}^{4} \beta_i b_{t-i} + \sum_{i=0}^{3} \delta_i d1_{t-i} + \varepsilon_t$$

$$\begin{aligned} a_t = {} & \underset{(5.6)}{7.04} + \underset{(3.2)}{1.27 \cdot 10^{-3}}\, t - \underset{(1.9)}{0.15}\, a_{t-1} + \underset{(12.1)}{0.83}\, a_{t-2} - \underset{(1.2)}{0.09}\, a_{t-3} - \underset{(3.9)}{0.25}\, a_{t-4} \\ & + \underset{(0.3)}{0.01}\, b_t + \underset{(0.2)}{0.01}\, b_{t-1} + \underset{(0.3)}{0.01}\, b_{t-2} - \underset{(1.0)}{0.04}\, b_{t-3} - \underset{(0.8)}{0.03}\, b_{t-4} \\ & - \underset{(10.3)}{0.46}\, d1_t + \underset{(2.3)}{0.17}\, d1_{t-1} + \underset{(2.7)}{0.16}\, d1_{t-2} + \hat{\varepsilon}_t \end{aligned}$$

$\bar{R}^2 = 0.85$ $DW = 1.97$ $Q(4) = 3.40[0.49]$ $Q(8) = 5.92[0.66]$

$$b_t = c' + \tau' t + \sum_{i=1}^{4} \alpha_i' a_{t-i} + \sum_{i=0}^{4} \beta_i' b_{t-i} + \gamma'(i-r)_t + \sum_{i=0}^{1} \delta_i' d2_{t-i} + \varepsilon_t'$$

$$\begin{aligned} b_t = {} & \underset{(1.2)}{1.18} + \underset{(2.1)}{1.17 \cdot 10^{-3}}\, t - \underset{(2.1)}{0.20}\, a_{t-1} + \underset{(1.3)}{0.12}\, a_{t-2} + \underset{(1.0)}{0.09}\, a_{t-3} + \underset{(0.8)}{0.08}\, a_{t-4} \\ & + \underset{(8.9)}{0.66}\, b_{t-1} + \underset{(1.9)}{0.13}\, b_{t-2} - \underset{(0.8)}{0.05}\, b_{t-3} - \underset{(1.2)}{0.07}\, b_{t-4} \\ & + \underset{(3.1)}{0.39}\, (i-r)_t + \underset{(7.6)}{0.64}\, d2_t - \underset{(4.3)}{0.33}\, d2_{t-1} + \hat{\varepsilon}_t' \end{aligned}$$

$\bar{R}^2 = 0.96$ $DW = 2.20$ $Q(4) = 2.92[0.57]$ $Q(8) = 11.87[0.16]$

Notes: The system is estimated using iterated three–stage–least squares. a_t and b_t denote the (logs of) total allotment and total bids of the Bundesbank's weekly fixed rate tenders from 2/07/1996 to 12/30/1998. $d1$ and $d2$ are dummies that capture the transfer of the Bundesbank's profit in May 1998 and the outlier in the bid variable due the anticipated cut in the repo rate on 8/28/96. $(i-r)$ is the demeaned spread between the money market and the repo rate. t-values are presented in parentheses and p-values are in brackets. DW is the Durbin-Watson statistic and Q the Ljung-Box statistic for residual correlation.

Bundesbank and, subsequently, the ECB adopted the fixed rate tenders in the first place. Clearly, the crucial advantage of a fixed rate tender is that the central bank provides a clear signal to financial markets about its implicit interest rate target.[12] As predicted by our learning process, this advantage was only slowly outweighed by the overbidding and its associated problems as banks had to exaggerate their bids more and more over time.[13]

6 Variable rate tenders

On 8 June 2000 the ECB decided (see ECB, 2000, p. 37) to switch to the variable rate tender procedure in its main refinancing operations in "...response to the severe overbidding which had developed in the context of the fixed rate tender procedure." Variable rate tenders are multi–unit auctions where bids generally take the form of demand schedules. Taking into account a minimum bid rate announced by the ECB, banks indicate how much refinancing they would like to achieve at up to ten interest rates. Having collected all bids, successively lower interest rates are accepted by the central bank until the total liquidity to be allotted is exhausted. If bids at the lowest accepted rate, the *marginal rate*, exceed the remaining allotment, they are rationed proportionally.[14]

The ECB has opted for the discriminatory auction format where every successful bidder has to pay his bid. Alternatively, one could use the competitive auction where successful bidders always pay the marginal rate.[15] In the following, we discuss the pros and cons of the applied auction formats and present some preliminary evidence on the empirical performance of the

[12] Note that in contrast to the Federal Reserve and the Bank of Japan, the ECB does not announce an explicit target value for the overnight rate, compare e.g. Borio (2000).

[13] This might also explain why fixed rate tenders worked reasonably well in the earlier Bundesbank auctions. Notice further that, in contrast to the ECB, the Bundesbank required a collateral to cover the bids, which, however, was presumably never a binding restriction for many banks.

[14] See Gresik (2001) for an analysis of alternative rationing schemes.

[15] Similar formats are used in the ECB's longer term refinancing operations and the U.S. Treasury Bill auctions. In financial markets, the discriminatory auction is also known as American or multiple rate auction, while the competitive auction is called Dutch, uniform price or single rate auction.

ECB's repo auctions under the current variable rate tender procedure.

6.1 Variable rate tenders and the overbidding problem

Independently of the applied auction rule, rational bidders will always try to circumvent the central bank's rationing at the marginal rate if refinancing at that rate is expected to be particularly cheap. However, in a variable rate tender, overbidding, i.e. bidding exceedingly large quantities, is not an obvious strategy simply because the marginal rate is not known at the auction's outset.[16]

Since only bids at the marginal rate are rationed and the minimum interest rate increments are only 0.01%, i.e. one basis point, bidding at higher interest rates might be a more effective way to avoid the rationing. In a competitive auction, where every successful bidder pays the marginal rate, this bidding strategy has low cost. Interestingly, the competitive auction can therefore induce overbidding not in quantities but in prices. In fact, the Bundesbank used the competitive auction for some time and experienced that banks tended to bid at unrealistically high interest rates, see Nautz (1997). In 1988, the Bundesbank thus switched from the competitive to the discriminatory auction because bidders do not bid at implausibly high interest rates when they have to pay their own bid. The Bundesbank's negative experience with the competitive pricing rule might explain why the ECB generally prefers the discriminatory auction format.

[place Fig. 4 about here]

Figure 4 shows total bids and total allotments of the main refinancing operations performed as variable rate tenders from June 2000 until December 2000. It is obvious that there is neither massive overbidding nor an increase in total bids. Interestingly, total bids actually decreased in the second half of 2000 with the ratio between total allotments and total bids approaching 1 recently. Probably, banks learned that very high bids at interest rates at,

[16] In fact, there is a danger that a discriminatory auction degenerates to a fixed rate tender — with similar overbidding problems — if there is no uncertainty about the marginal rate of the tender, compare Nautz and Wolfstetter (1997).

or close to, the minimum bid rate make no sense. The switch to variable rate tenders clearly solved the ECB's overbidding problem.

6.2 Three possible drawbacks of variable rate tenders

6.2.1 Strategic complexity

While discriminatory variable rate tenders solve the overbidding problem, they also have their potential drawbacks. First, compared with the fixed rate tender where banks simply indicate how much refinancing they would like to receive at a given rate, successful bidding in a discriminatory auction requires experienced and well–informed bidders, see Nautz and Wolfstetter (1997). For example, particularly in times of possible interest rate changes large banks may bid in a more sophisticated way than smaller banks, as found by Breitung and Nautz (2001). This, however, might be in conflict with the ECB's principles of fairness and equal treatment, compare e.g. Hämäläinen (2000).

Yet the weighted average repo rate of the variable rate tender (published in the ECB's monthly reports) is on average only two basis points above the marginal rate indicating that the bulk of the repo credit is allotted at interest rates very close to the marginal rate. Therefore, in spite of the heterogeneity of the European banking sector, the strategic complexity of discriminatory multi–unit auctions does not seem to be a severe problem for the ECB's monetary policy setup.

6.2.2 Weaker controllability of market rates

It is often argued that the most severe disadvantage of variable rate tenders is that the ECB has to sacrifice control over interest rates.[17] When the main refinancing operation is conducted as a fixed rate tender, the pre-announced repo rate is the ECB's key interest rate that signals the intended level of short–term money market rates. Under the variable rate tender procedure,

[17] In fact, the Bundesbank's experience confirms that the volatility of money market rates is higher with variable rate tenders than with fixed rate tenders, see Nautz (1998). By using a pre-announced minimum bid rate, the ECB tries to ameliorate interest rate uncertainty and, thereby, keeps interest rate volatility low.

however, the ECB only announces a minimum bid rate while the *actual* refinancing rates, i.e. the marginal or the average repo rate, are not under the central bank's direct control. One might therefore expect that money market rates are closer to the ECB's key interest rate when the actual repo rate is fixed rather than variable.

[place Fig. 5 about here]

Figure 5 shows the fixed repo rate and the pre-announced minimum bid rate (both labelled as $r(ECB)$) together with the overnight rate Eonia valid at the announcement day of the auction. Apparently, the minimum bid rate is as close to the money market rate as the fixed repo rate. To be sure, we regressed the spread $(Eonia - r(ECB))$ on a constant and a regime dummy VRT, where VRT is one under the variable tender procedure and zero otherwise.[18]

$$Eonia - r(ECB) = \underset{(4.21)}{0.08} + \underset{(0.31)}{0.01}\ VRT \qquad \text{DW} = 1.86 \qquad (11)$$

The regression confirms that the spread between the central bank's key interest rate and the market rate is nearly unaffected by the change of the auction format. There is no evidence that the controllability of short–term interest rates weakened because of the introduction of the variable rate tender procedure.

6.2.3 Bid shading

The distinguishing feature of the variable rate tender format is that it allows banks to bid at higher interest rates in order to ensure the allotment when demand for liquidity is high. Therefore, when banks bid close to their true demand for liquidity, the marginal rate of a variable rate tender should be close to the equilibrium rate of the interbank money market. However, in a discriminatory auction, bidders shade their bids in order to circumvent

[18] The sample covers the ECB's main refinancing operations from 1/07/1999 until 27/12/2000, which gives us 103 observations. DW denotes the Durbin–Watson statistic that checks for the presence of serial autocorrelation. t-values are presented in parentheses.

price discrimination which might have distortional effects on the result of the auction, see Nautz and Wolfstetter (1997).

[place Fig. 6 about here]

Figure 6 depicts the Eonia rate and the marginal rate of the ECB's variable rate tenders. The link between those two interest rates is apparently stronger than the link between the Eonia and the fixed repo rate shown in Figure 5 indicating that the effects of bid shading are not empirically relevant. Whereas the fixed repo rate was on average about 8 basis points below the overnight rate, the difference between the marginal repo rate and the Eonia is only 1.5 basis points and thus sufficiently small to prevent banks from overbidding.[19]

7 Conclusions

The operating framework of a central bank seems to be the least conspicuous facet of monetary policy. However, the way in which monetary policy is implemented can have significant implications for the organization and functioning of money and even capital markets. The newly founded European Central Bank has adopted many features of the Bundesbank's monetary framework. One of those features is the dominant role of weekly repo auctions for the provision of central bank money. By using fixed rate tenders until June 2000, the ECB tried to provide a clear signal about the current interest rate target. However, the fixed rate tenders of the Bundesbank and the ECB suffered from a 'vanishing quota problem'.

In this paper we demonstrate that the auction rules of fixed rate tenders were flawed since they encouraged banks to increasingly exaggerate their demand for reserves. Moreover, our empirical results indicate that the fixed rate tenders induced overbidding even though the central bank's allotment policy more or less met the true demand of the banking sector. When in

[19] Note that a slightly positive spread between interbank rates and repo rates with similar maturities is often viewed as *natural* because refinancing on the interbank market does not require collateral.

May 2000 the allotment quota dropped below 1%, the ECB's repo auctions had become somewhat of a farce.

As a consequence, the ECB in June 2000 abandoned fixed rate tenders in favour of variable rate tenders, and the preliminary evidence from the past 6 months indicates that variable rate tenders are a success. The overbidding problem was clearly solved. And it seems that the ECB did not have to sacrifice control over interest rates as the spread between the overnight rate and minimum rate in the variable rate tenders has not significantly increased as compared to the spread between overnight and fixed repo rate before the switch.

When switching to variable rate tenders the ECB emphasised that "...it will retain the option of reverting to fixed rate tenders, if and when this is deemed appropriate", see ECB (2000, p. 37). In view of the evidence presented in this paper we would strongly advise against such a move.

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