Banks' Behaviour in the European Money Market and the Operational Framework of the Eurosystem

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Abstract

The Eurosystem has stated its intention to reformulate important aspects of its operational framework. Subject to change are inter alia the maturity of the main refinancing operations and the timing of the reserve maintenance period. This paper presents a model to analyze banks' behaviour in the European money market. Its main result is that the suggested alterations are sensible, but that further improvements should be undertaken. The model captures the main elements of current the operational framework for monetary policy of the Eurosystem. It is shown that expectations of interest rate changes may lead to extreme under- and overbidding behaviour in the main refinancing operations and to wildly differing provisions of required reserves across a given reserve maintenance period. The resulting problems can be avoided if first, no overlapping of the maturities of the main refinancing operations is allowed - which corresponds to the suggestion of the ECB - and second, if the required reserves are not remunerated at an average rate.

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1 Introduction

The Eurosystem[1] wants to change important aspects of its operational framework. Two significant proposed changes are the shortening of the maturity of the main refinancing operations and the changing of the timing of the reserve maintenance period. The rationale for changing the operational framework is to reduce the impact of interest rate expectations on the banks' bidding behaviour in the main refinancing operations. Expectations of interest rate changes have led to severe under- and overbidding behaviour in the main refinancing operations.[2]

This paper shows within a theoretical framework, that the proposed alterations go into the right direction but that a further improvement would be not to remunerate reserve requirements at an *average* rate. The main results of this paper are that under the current operational framework of the Eurosystem, there may be

- under- and overbidding in the main refinancing operations,
- extreme uneven provisions of required reserves, and
- a violation of the Eurosystem's principal of equal treatment of all credit institutions independently of their size or where they are located,[3]

and that these problems could be avoided

- if the maturities of the main refinancing operations did not overlap, and
- if minimum reserves were not remunerated at an average rate.

The first aspect corresponds with the suggestion of the ECB. The second is a further alteration, which seems to be sensible, because it refrains the ECB from its self-commitment to change interest rates once a month only.

Related literature can be divided into three categories. The first category consists of empirical and theoretical papers analyzing explicitly causes and problems of the euro

[1]The European System of Central Banks (ESCB) comprises the ECB and the national central banks of all EU Member States. For this reason, the term "Eurosystem" has been chosen to describe the institution being responsible for monetary policy in the euro area, namely the ECB and the national central banks in the euro area (ECB 2001b).

[2]For details concerning the intended alterations see ECB (2002b).

[3]For a description of general requirements, principles and objectives behind the design of the Eurosystem's operational framework see Issing and Gaspar (2001, p. 112-113) and ECB (2001b, p. 59-60).

area banks' over- and underbidding behaviour in the main refinancing operations (see, for example, Ayuso and Repullo 2000, 2001, Nautz and Oechssler 2001). This paper adds to this debate by showing that under the current operational framework of the Eurosystem the observed over- and underbidding behaviour may be due to market expectations of interest rate changes and that a consequence of this bidding behaviour may be a violation of the above mentioned Eurosystem's principal of equal treatment. The second category describes the reserve management of European banks (Nautz 1998). The model of this paper describing banks' behaviour in the money market of the euro area distinguishes from Nautz (1998) by incorporating minimum reserves and considering explicitly specific features of the main refinancing operations as overlapping maturities for example. Furthermore, in this paper an isolated bank is considered, whereas Nautz (1998) considers a representative bank, which implies that the interbank money market plays no role in his analysis, whereas in this paper this market is important. The third category consists of empirical and theoretical papers analyzing the money market in the US, explaining banks' reserve management and/or the observed behaviour of the federal funds rate (see, for example, Campbell 1987, Hamilton 1996, Clouse and Dow 1999, 2002, Furfine 2000, Bartolini, Bertola, and Prati 2001, 2002). In the first place, this paper distinguishes from those papers capturing specific institutional aspects of the money market in the euro area.

The remainder of this paper is structured as follows. Section 2 presents some institutional background on the main refinancing operations and the minimum reserve system of the Eurosystem. Furthermore, information concerning under- and overbidding behaviour and the fulfillment of required reserves are given. Section 3 models a bank's behaviour under the current operational framework of the Eurosystem. Section 4 illustrates a bank's behaviour under a modified framework. Section 5 gives a short summary and concludes the paper.

2 The Main Refinancing Operations and the Minimum Reserve System of the Eurosystem

The Main Refinancing Operations and Under- and Overbidding

The main refinancing operations are the key instrument of the Eurosystem to provide liquidity to the banking sector in the euro area. Banks' liquidity needs and therefore,

their demand for reserves, mainly arise from two factors: reserve requirements and autonomous factors, as banknotes in circulation and government balances at central banks. The reserve requirements roughly account for 54 %, the net autonomous factors for 45 % of the overall liquidity needs of the banking system (ECB 2002a). These liquidity needs are satisfied by the Eurosystem as follows. Roughly 74 % are met through the main refinancing operations, 26 % through long-term refinancing operations and less than 1 % through the marginal lending facility and fine tuning operations (ECB 2002b). This points out the outstanding significance of the main refinancing operations in the ECB's tool box. Therefore, the focus of this paper is on these operations. The main refinancing operations are collateralized credit transactions with a weekly frequency and a maturity of two weeks. They are executed either in form of a fixed rate or a variable rate tender.[4] Credit operations with the Eurosystem have to be based on adequate collateral. In the tender procedures, the bids themselves do not have to be covered by adequate collateral, but only the allotted amount (ECB 1999). The Eurosystem has defined eligible assets, which can serve as collateral.[5] Although differences in the financial structure across Member States of the EMU have been considered when defining the list of eligible assets, the availability of and the marginal costs for collateral vary between the countries within the euro-area (Hämäläinen 2000).

In the past, several main refinancing operations have been characterized by severe under- and overbidding. Overbidding occurs if the aggregate bidding amount exceeds significantly the benchmark allotment, which reflects fairly well actual liquidity needs of the banking sector (see ECB 2002a for details), and vice versa for underbidding. Extreme overbidding could be observed under fixed rate tender, extreme underbidding under both tender procedures. Overbidding under the fixed rate tender can be gauged by an allotment quota (amount allotted divided by the total amount of bids), which was on average about 3 %, and in all tenders less than 7 %. In May 2000, the quota even dropped below than 1 %. Auctions characterized by an extreme underbidding behaviour were conducted in April 1999, in February 2001, in April 2001 and in October 2001. The bids in these auctions did not allow the ECB to allot the amount of reserves according to the actual liquidity needs.[6]

[4]For a detailed description of the main refinancing operations and the other monetary policy instruments of the ECB see, for example, ECB (2000a, 2001b, 2002c).

[5]For details see for example ECB (2002a, p. 38-50).

[6]For a detailed description of the banks' bidding behaviour in the main refinancing operations

Problems resulting from the extreme bidding behaviour are seen in a violation of the Eurosystem's guiding principle of equal treatment of financial institutions (Hämäläinen 2000, Ayuso and Repullo 2000), an inefficient allocation of financial resources, wrong signals to the market participants about the stance of monetary policy, an unnecessary risk taking by banks, and the non-existence of information in the bids about the actual liquidity needs of the banking sector (Nautz and Oechssler 2001, Ehrhart 2001).[7] This paper adds to the debate by showing theoretically that the Eurosytem's principal of equal treatment may be violated under the current operational framework.

Causes of the observed under- and overbidding behaviour are seen, e.g. in a false rationing scheme in case the bids for reserves exceed the amount of reserves the ECB is willing to allot (Nautz and Oechssler 2001) and in a possible asymmetric objective function of the ECB (Ayuso and Repullo 2000, 2001). This paper agrees with the ECB (2000a and 2001a). It shows that under the current operational framework of the Eurosystem the observed over- and underbidding behaviour is due to market expectations of interest rate changes.

The reaction of the ECB to avoid this undesired bidding behaviour has been threefold. First, in June 2000, the Governing Council decided to switch from fixed rate tenders to variable rate tenders as a response to the severe overbidding (ECB 2000b). (From the launch of the euro in January 1999 until June 2000, tenders were conducted exclusively as fixed rate tenders. Since then, only variable rate tenders with a minimum bid rate have been used.) Second, in November 2001, the Governing Council decided to discuss interest rate changes at its first meeting of a month only, because discussing this issue at both of the bi-monthly meetings would lead every two weeks to speculations about interest rate changes (Duisenberg 2001). However, these are not convincing solutions to he under- and overbidding problem. If the ECB refrains totally from using a variable rate tender, only the overbidding problem will be solved, and the ECB will give up an instrument which might be the most appropriate one in specific situations. If the ECB reverts to fixed rate tenders, under- and overbidding may occur again. The decision to take interest rate decisions normally during the Governing Council's first meeting of a month only, does not solve the

from January 1999 until September 2001 see ECB (2001a).

[7]Concerning the information aspect of auctions used as a monetary policy instrument, see also Nautz (1997).

problem either, but simply reduces its incidence and the Eurosystem's flexibility concerning monetary policy decisions. However, the third reaction of the ECB, the proposed changes in its operational framework, goes into the right direction. If they are implemented, the incentive to under- or overbid will be reduced, since expectations of interest rate changes do not influence banks' bidding behaviour any more. But a problem remains that the ECB commits itself to make interest rate decisions once a month only.

This paper shows that under- and overbidding can be avoided if no overlapping of the maturities of the main refinancing operations is allowed - which corresponds to the suggestion of the ECB - and second, if the required reserves are not remunerated at an average rate. The latter would refrain the ECB from its commitment to make interest rate decision once a month only.

The Minimum Reserve System and Uneven Provisions of Required Reserves

In the euro-area, banks are required to hold compulsory deposits on the accounts with the Eurosystem. At present, the minimum reserves amount to 2 % of certain short-term liability items of the balance sheets of the credit institutions. For determining required reserves, the stock of short-term liabilities at the end of a month is considered. The minimum reserve maintenance period starts on the 24th calender day of the next month and ends on the 23th calender day of the then following month. Consequently, during a maintenance period, generally a bank does not face uncertainty about the amount of required reserves.[8] For fulfillment of the reserve requirements, banks can make use of averaging provisions. The requirements are fulfilled if the average of the end-of-calendar-day balances on a bank's reserve account over a one-month maintenance period corresponds to the required amount. Holdings of required reserves are remunerated at the average, over the maintenance period, of the ECB's rate on the main refinancing operations. Remuneration is paid after the respective maintenance period.[9] On the aggregate level, the ECB prefers smooth provisions of reserve requirements, since it enhances the buffer function of

[8]Until 1998, this was the case in the United States, where only on the last two days of the maintenance period did a bank know its reserve requirement with certainty (see Furfine (2000) for example

[9]For a detailed description of the minimum reserve system see for example ECB (2000a, 2001b, 2002c).

reserve holdings against liquidity shocks (ECB 2002a). However, under the current operational framework banks have an incentive to provide reserve requirements extremely unevenly across a maintenance period in specific situations. A good illustration of extreme uneven provisions is the maintenance period January/February 2001. Figure 1 shows that in that period, required reserves were 120 billion euro and that provisions varied from 92 billion euro to 182 billion euro.

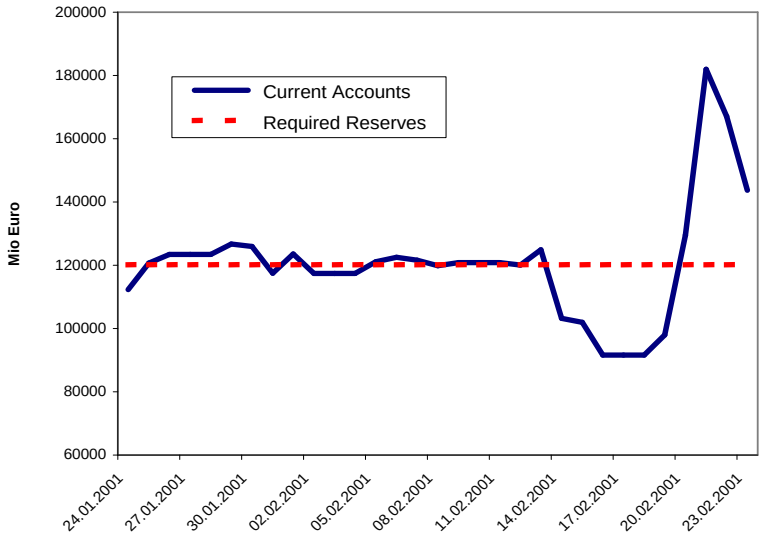

Figure 1: Deposits on Current Accounts and Required Reserves in the Reserve Maintenance Period January/February 2001. Data: ECB.

This paper shows that under the current operational framework of the Eurosystem extreme unequal provisions of required reserves are due to incentives triggered by expectations of interest rate changes. Furthermore, the paper points out that under the above suggested modifications of the operational framework the problem of extreme uneven provisions of required reserves can be avoided.

3 A Bank's Demand for Reserves under the Current Operational Framework of the Eurosystem

The aim of this section is to develop a model explaining a banks's behaviour in the European money market under the current operational framework of the Eurosystem. Therefore, the following model captures the key features of the European money market, described partly in the previous section. Within a two-period model, a bank has to decide on the allocation of its minimum reserve holdings and its bidding

amounts in the tender procedures conducted by the central bank so that its total liquidity costs are minimized. First, these total liquidity costs are derived. Then, the optimization problem is solved under certainty, where there are no changes in interest rates. Finally, the problem is solved under uncertainty. There are expectations of interest rate changes, and it is analyzed how the bank's optimal reserve management and bidding behaviour changes in this case.

3.1 Liquidity Costs

There are two time periods, $t = 1, 2$. These two periods cover a reserve maintenance period. A risk-neutral, isolated, price taking bank is considered, which needs liquidity for covering given autonomous factors A and given reserve requirements RR imposed by a central bank. Concerning required reserves, the bank can make use of averaging provisions. The reserve requirement is fulfilled if

$$RR = \frac{R_1 + R_2}{2}, \tag{1}$$

with $R_t \geq 0$ being the reserve holdings in t.

To cover its liquidity needs, the bank can borrow from the central bank. For borrowing from the central bank, the bank can bid for reserves in a fixed rate tender[10] at the beginning of each period t. K_t, with $K_t \geq 0$, denotes the amount a bank bids for. $k_t K_t$ is the actual amount being allotted, with $0 < k_t \leq 1$. Credit operations executed at the beginning of $t = 1$ have a maturity of two periods. Consequently, credit operations carried out in different periods have overlapping maturities. The stock of credits in t borrowed from the central bank is given by

$$RK_t = k_{t-1}K_{t-1} + k_t K_t, \tag{2}$$

given $k_0 K_0$. Central bank credits have to be collateralized. Collateralization costs are given by

$$Q_t(K_t) = q^i k_t K_t + \frac{q}{2}(k_t K_t)^2, \tag{3}$$

with the parameters $q^i, q > 0$. Equation 3 shows that the bank faces increasing marginal collateralization costs. This equation reflects that the "... availability

[10]The basic results of this paper can be transferred to variable rate tenders.

of collateral and the cost of holding collateral differ considerably across Member States..." (Hämäläinen 2000), since it is assumed that the parameter q^i is bank specific.

In the euro area, a bank cannot only cover its liquidity needs by borrowing from the Eurosystem, but alternatively it can borrow reserves in the interbank money market, where it can also place excess liquidity. This aspect is incorporated in this model by the following equations. In the interbank money market, the bank can demand credit or place excess liquidity at the beginning of each period. All operations in the money market have a maturity of one period. The bank's net position in the interbank market is

$$IB_t = A + R_t - RK_t. \tag{4}$$

A key function of the interbank market is to balance the banks' daily fluctuations of liquidity needs. In this model, this interbank market function could be considered by modelling the autonomous factors A as a random variable or by adding shocks. However, this would make the analysis more complicated without changing the main results. Therefore, we take the interbank market as a pure alternative source for covering liquidity needs to a credit from the central bank. This implies that on an aggregate level, there must be banks bidding for more reserves than they need to cover their own liquidity needs. This is the case in the euro area, where only a fraction of all banks actually takes part in the main refinancing operations.[11] Trading in the interbank market, the bank faces transactions costs

$$Z_t(R_t, RK_t) = \frac{z}{2}\left(IB_t\right)^2, \tag{5}$$

with the parameter $z > 0$. This approach can be compared with the common approach of modelling the liquidity role of reserves, which posits that banks incur increasing costs when liquidity deviates from a target level (see, for example, Campbell 1987 and Bartolini et al 2001). In this paper, the quadratic form reflects increasing marginal costs of searching for banks with matching liquidity needs and those resulting from the need to split large transactions into many small ones to work around credit lines (compare Bartolini et al 2001).

[11] At the end of 2000 for example, 2,542 credit institutions in the euro area fulfilled the criteria for participating in the main refinancing operations, but in 1999 and 2000 the total number of institutions which actually took part in these operations fluctuated between 400 and 600 (ECB 2001b, p. 63).

Defining l_t as the interest rate the bank has to pay for a credit from the central bank, and e_t as the interbank money market rate, total liquidity costs in period t are given by

$$\begin{aligned} C_t(K_{t-1}, K_t, R_t) &= k_{t-1}K_{t-1}l_{t-1} + k_tK_tl_t + IB_te_t \\ &+ Q_t + Z_t - RR(l_t + l_{t-1})I_{[t=2]}. \end{aligned} \tag{6}$$

The first row presents interest payments to the central bank and net interest payments resulting from transactions in the interbank market. The second row reflects collateral and transactions costs, and the remuneration of required reserves. The latter are remunerated at the average, over the maintenance period, of the central bank's rate on its credit operations. The indicator function $I_{[.]}$ takes a value of 1 when $t = 2$, and 0 otherwise, reflecting that interests are paid at the end of the maintenance period.

3.2 Optimization under Certainty

The bank wants to minimize its liquidity costs across the maintenance period, while keeping average reserves over the maintenance period to the required level RR. Disregarding discounting, whose impact is negligible over this short horizon, the bank's objective function becomes

$$\min_{K_t, R_t} \left\{ \sum_{t=1}^{2} C_t \right\}. \tag{7}$$

The bank faces a dynamic optimization problem, because the amount the bank borrows from the central bank in the first period has an important impact on the decisions made during the subsequent period. Defining V_t as the associated value function, the Bellman equation for the intra-maintenance period problem is given by

$$V_1 = \min_{K_1, R_1} \left\{ C_1(K_1, R_1) + V_2(RK_1(K_1), R_1) | R_1 \geq 0, K_1 \geq 0 \right\}, \tag{8}$$

subject to equation 1. This optimization problem is solved backwards, so that first

$$V_2(RK_1(K_1), R_1) = \min_{K_2} \left\{ C_2(RK_1(K_1), R_1; K_2) | K_2 \geq 0 \right\} \tag{9}$$

is determined.[12] Before solving this optimization problem, the following assumptions concerning interest rates are made. The rate on central bank's credit operations is

$$l_t = l_1 \quad \forall t. \tag{10}$$

This means that there is no monetary impulse in form of interest rate changes. The interest rate in the interbank market is given by

$$e_t = l_t + u, \tag{11}$$

with $u > 0$. The mark-up u reflects that only credits with the central bank have to be collateralized.

Optimal Bidding Behaviour in the Second Period

The first order conditions of the optimization problem in $t = 2$ are given by

$$\frac{\partial Q_2}{\partial K_2} + \frac{\partial Z_2}{\partial K_2} - k_2 u = 0. \tag{12}$$

The first order condition shows that expected marginal costs of covering liquidity needs at the central bank and in the money market must be equal. Solving this condition for K_2, one obtains

$$K_2 = \begin{cases} \frac{-q^i + z(A+2RR-R_1-k_1K_1)+u}{k_2(q+z)} > 0 & \text{if} \quad q^i < \overline{q}_2^{i,crit} \\ 0 & \text{if} \quad q^i \geq \overline{q}_2^{i,crit} \end{cases} \tag{13}$$

where

$$\overline{q}_2^{i,crit} = u + z(A + 2RR - R_1 - k_1 K_1). \tag{14}$$

For the sake of simplicity it is assumed that $A + R_t - k_{t-1}K_{t-1} > 0 \quad \forall \quad t$. This means that the bank has to demand for liquidity in each period. In t, the credit from the central bank $k_{t-1}K_{t-1}$ is not sufficient for covering the bank's total liquidity needs. Equation 13 shows that just in case $q^i < \overline{q}_2^{i,crit}$ the bank takes part in the tender procedures at the central bank, otherwise it prefers to cover its total liquidity needs in the interbank market. (Ties are broken in favour of covering liquidity needs in the interbank market.)

[12] Due to equation 1 R_2 is replaced by $2RR - R_1$ so that minimization is over K_2 only.

Knowing the optimal value of K_2, and therefore $V_2(RK_1(K_1), R_1)$, equation 8 can be solved, i. e. the optimal bidding behaviour and the optimal reserve management in the first period can be determined, whereas between two scenarios have to be distinguished: high collateral costs ($q^i \geq \overline{q}_2^{i,crit}$) and low collateral costs ($q^i < \overline{q}_2^{i,crit}$).

Optimal Bidding Behaviour and Optimal Reserve Management in the First Period

The first order conditions for K_1 and R_1 are

$$\frac{\partial Q_1}{\partial K_1} + \frac{\partial Z_1}{\partial K_1} - k_1 u + \frac{\partial V_2(RK_1(K_1), R_1)}{\partial K_1} = 0 \tag{15}$$

and

$$l_1 + u + \frac{\partial Z_1}{\partial R_1} + \frac{\partial V_2(RK_1(K_1), R_1)}{\partial R_1} = 0. \tag{16}$$

Equations 15 and 16 show that optimal bidding behaviour and optimal management of reserve holdings does not only demand marginal costs to be equal from bidding in the tender procedures and transactions in the interbank market, but that additionally intertemporal optimality has to be considered. Equations 15 and 16 allow us to determine the optimal values for K_1 and R_1 and therefore, $R_1 - R_2$. The optimal bidding amount in $t = 1$ is given by

$$K_1 = \begin{cases} \frac{4qz(A+RR-0.5k_0K_0)+4uq-q^i(2q-z)}{k_1q(2q+5z)} > 0 & \text{if} \quad q^i < \overline{q}_2^{i,crit} \\ K_2 = 0 & \text{if} \quad q^i \geq \overline{q}_2^{i,crit}. \end{cases} \tag{17}$$

Equation **??** makes clear that the bank either bids in both or no period. This result is due to the increasing marginal bidding costs. If $K_1 = K_2 = 0$, $R_1 = RR + 0.5k_0K_0$. Inserting these expressions into equation 14 reveals that the critical value for biding in the tender procedures is

$$\overline{q}^{i,crit} = u + z(A + RR - 0.5k_0K_0). \tag{18}$$

This result is plausible. It says that the critical value for the collateralization costs will be higher, the higher the costs for covering liquidity in the interbank market (u and z) and liquidity needs ($A + RR - 0.5k_0K_0$). The latter results from the increasing marginal collateralization costs.

Furthermore, equation 17 implies that the bank bids for more reserves than it actually needs to cover its own liquidity needs ($K_1 > (A + R_1 - k_0K_0)/k_1$) to place this excess liquidity in the interbank market if $q^i < (5/3)u - (2/3)q(A + RR - 0.5k_0K_0)$. Therefore, there is another critical value for q^i, given by

$$\underline{q}^{i,crit} = \frac{5}{3}u - \frac{2}{3}q(A + RR - 0.5k_0K_0). \tag{19}$$

Equation 19 shows that $\underline{q}^{i,crit}$ will be higher the higher interest earnings in the interbank market compared to interest payments to the central bank (u), and the lower the other bidding costs (q) and actual liquidity needs ($(A + RR - 0.5k_0K_0)$).

Result 3.1: *If bidding costs are relatively high ($q^i \geq \overline{q}^{i,crit}$), the bank does not take part in the tender procedures at the central bank, but prefers to cover its total liquidity needs in the interbank market. If bidding costs are relatively small ($q^i < \underline{q}^{i,crit}$), the bank bids for more reserves than it actually needs to cover its own liquidity needs to place the excess liquidity in the interbank market.*

Solving the optimization problem for R_1 leads to

$$R_1 - R_2 = \begin{cases} \frac{2\left[(z+q)q^i - qu - qz(A+RR) + q(q+3z)k_0K_0\right]}{q(2q+5z)} & \text{if} \quad q^i < \overline{q}^{i,crit} \\ k_0K_0 & \text{if} \quad q^i \geq \overline{q}^{i,crit} \end{cases} . \tag{20}$$

Equation 20 shows that there may be uneven provisions of required reserves ($R_1 - R_2 \neq 0$). If $K_t > 0$, $R_1 - R_2$ corresponds to the upper row of equation 20. It shows that R_1 will be the higher compared to R_2, the smaller actual liquidity needs $A + RR$ and the smaller already existing reserves k_0K_0. This is due to the overlapping maturities of the central bank's credit transactions combined with increasing marginal bidding costs. The latter implies that generally the optimal bidding amount must be the same in both periods. The higher k_0K_0, the higher is the amount of already existing reserves in $t = 1$, so that c. p. R_1 is, compared to R_2, the higher the higher k_0K_0. If u or $(A + RR)$ increase, resp. if q^i decreases, K_t will rise in both periods. Therefore, due to the overlapping maturities, R_1 will be lower than R_2 in this case.

The lower row of equation 20, which holds for $K_1 = K_2 = 0$, can be interpreted as follows. If $K_1 = K_2 = 0$ and assuming that in this case $K_0 = 0$ too, there will not be uneven provisions of reserve requirements. In this case the bank covers its total liquidity needs in the interbank market and due to increasing marginal transaction costs in that market, an equal provision of required reserves is optimal.

Result 3.2: *There may be uneven provisions of reserve requirements due to overlapping maturities of the central bank's credits combined with increasing marginal collateralization costs.*

Underbidding (overbidding) occurs if the aggregate bidding volume falls short of (exceeds) the benchmark allotment of the central bank (see section 2). Therefore, one cannot conclude from the above described bidding behaviour of an isolated bank whether under- or overbidding occurs. However, the aim of this paper is to show that expectations of changes in interest rates may induce under- or overbidding. Therefore, the next section analyzes how the bank's bidding behaviour changes if it expects a monetary impulse in form of a decreasing or increasing interest rate on the central bank's credits.

3.3 Optimization under Uncertainty

The bank faces uncertainty about future monetary policy and about the other banks' bidding behaviour. The following equations reflect these uncertainties. The expected interest rate on a central bank's credit in $t = 2$, given the information available in $t = 1$ is

$$E[l_2|t = 1] = l_1 + (1 - w)m \tag{21}$$

where $m \lesseqgtr 0$ denotes the monetary impulse and $(1 - w)$, with $0 < w < 1$, the probability that the monetary impulse takes place. The bank does not face uncertainty about the direction of the monetary impulse. The bank knows whether there may be a contractionary or an expansionary impulse, i. e. it knows the sign of m. But it does not know whether the impulse will actually take place.

Furthermore, the bank faces uncertainty about the other bank's bidding behaviour, which may lead to under- or overbidding, and about the central bank's behaviour in this case. If underbidding occurs and the central bank does not supply the lacking liquidity, aggregate liquidity shortage will lead to an increase in the interbank market rate e. If, on the other hand, overbidding occurs and the central bank satisfies a higher bidding volume than the benchmark allotment, aggregate liquidity surplus will lead to a decrease in the interbank money market rate. These possible decreases or increases in the money market rate are reflected by $x(1-p)$ with $(1-p)$ being the

probability that that there will be scarce or excess liquidity leading to an increase ($x > 0$) or decrease ($x < 0$) in the interbank money market rate. The resulting expected interbank money market rates given the information available in $t = 1$ and in $t = 2$ are given by

$$E[e_2|t = 1] = E[l_2|t = 1] + u + (1 - p)x \tag{22}$$

and

$$E[e_2|t = 2] = l_2 + u + (1 - p)x. \tag{23}$$

Under uncertainty, the bank's objective function becomes

$$\min_{K_t, R_t} \left\{ E\left[\sum_{t=1}^{2} C_t \middle| t = 1 \right] \right\}. \tag{24}$$

The Bellman equation for the intra-maintenance period problem is given by

$$V_1 = \min_{K_1, R_1} \left\{ E\left[C_1(K_1, R_1) + V_2(RK_1(K_1), R_1) \right] \right\}. \tag{25}$$

Again, this optimization problem is solved backwards, so that first

$$\begin{aligned} V_2(RK_1(K_1), R_1) &= \min_{K_2} \{ E\left[k_1 K_1 l_1 + k_2 K_2 l_2 \right. \\ &+ \left. IB_2 e_2 + Z_2 + Q_2 - RR(l_1 + l_2) \right] | K_2 \geq 0 \} \end{aligned} \tag{26}$$

is determined. The resulting first order condition is

$$-k_2(u + (1 - p)x) + \frac{\partial Q_2}{\partial K_2} + \frac{\partial Z_2}{\partial K_2} = 0, \tag{27}$$

and the optimal bidding amount in $t = 2$ is

$$K_2 = \begin{cases} \frac{-q^i + z(A + 2RR - R_1 - k_1 K_1) + u + (1-p)x}{k_2(q+z)} & \text{if} \quad q^i < \overline{q}_2^{i,crit} \\ 0 & \text{if} \quad q^i \geq \overline{q}_2^{i,crit} \end{cases} \tag{28}$$

where

$$\overline{q}_2^{i,crit} = z(A + 2RR - R_1 - k_1 K_1) + u + (1 - p)x. \tag{29}$$

Having determined the optimal value for K_2, the optimal bidding behaviour and the optimal reserve management in the first period can be determined.

Optimal Bidding Behaviour and Optimal Reserve Management in the First Period

The first order conditions for K_1 and R_1 become

$$\frac{\partial Q_1}{\partial K_1} + \frac{\partial E[V_2(RK_1(K_1), R_1)]}{\partial K_1} - k_1 u + \frac{\partial Z_1}{\partial K_1} = 0 \tag{30}$$

and

$$l_1 + u + \frac{\partial Z_1}{\partial R_1} + \frac{\partial E[V_2(RK_1(K_1), R_1)]}{\partial R_1} = 0, \tag{31}$$

which allow us to determine the optimal values for K_1 and R_1, and therefore $R_1 - R_2$.

Optimal bidding behaviour in the first period is given by

$$K_1 = \begin{cases} \max\left\{0, \frac{4qz(A+RR-0.5k_0K_0)+4qu-(2q-z)q^i+2q(1-p)x+2(q+z)(1-w)m}{k_1q(2q+5z)}\right\} & \text{if} \quad q^i < \overline{q}_2^{i,crit} \\ \max\left\{0, \frac{2z(A+RR-0.5k_0K_0)-q^i+2u+(1-p)x+(1-w)m}{k_1(q+2z)}\right\} & \text{if} \quad q^i \geq \overline{q}_2^{i,crit}. \end{cases} \tag{32}$$

Equation 32 shows that the result of the previous section that the bank bids in both or no period does not hold any more. If $q_i < \overline{q}_2^{i,crit}$ (the bank bids in the second period) it may be that the bank does not bid in the first period. The critical value for its collateral costs is given by

$$\{\overline{q}_1^{i,crit} | q_i < \overline{q}_2^{i,crit}\} = \frac{4qz(A+RR-0.5k_0K_0)+4qu+2q(1-p)x+2(q+z)(1-w)m}{2q-z}. \tag{33}$$

If $q_i \geq \overline{q}_2^{i,crit}$ (the bank does not bid in the second period) it may be that the bank does bid in the first period. The critical value of its collateral costs in this case is given by

$$\{\overline{q}_1^{i,crit} | q_i \geq \overline{q}_2^{i,crit}\} = 2z(A+RR-0.5k_0K_0)+2u+(1-p)x+(1-w)m. \tag{34}$$

This change in the bank's bidding behaviour is due to expected interest rate changes. If the bank expects the central bank to decrease interest rates ($(1-w)m < 0$), it may

reduce its liquidity costs by bidding in the second period only. If it is still optimal for the bank to bid in both periods (due to increasing marginal collateralization costs), the comparison of the upper part of equation 32 with equation 17 shows that it will bid for less funds compared to a situation in which there are no expectations of a decrease in the central bank's interest rate. However, these results only hold if

$$-(1-p)x < \frac{q+z}{q}(1-w)m, \tag{35}$$

i.e. if the bank does not expect a compensating or overcompensating effect in the interbank market rate.

If the bank expects the central bank to increase interest rates ($(1-w)m > 0$), it may reduce its liquidity costs and even benefit from placing excess liquidity in the interbank market in the second period by bidding in the first period only, or, if it is still optimal for the bank to bid in both periods, by bidding in the first period for a higher volume compared to a situation in which there are no expectations of an increase in the central bank's interest rate. However, this result too requires that the bank does not expect a compensating or overcompensating effect in the interbank market rate. This means that it will bid in the first period only if

$$-(1-p)x < (1-w)m, \tag{36}$$

and that it will bid for more funds only if 35 holds. This leads us to he following result.

Result 3.3: *Expected future monetary impulses influence present bidding behaviour. If there is a continuum of banks differing in their collateralization costs which are distributed in the interval* $[q^{i,min}, q^{i,max}]$ *with* $q^{i,min} < \overline{q}^{i,crit} < q^{i,min}$ *(see equation 18), more banks bid and a single bank bids for more funds if they expect the central bank to increase the interest rate and if they do not expect a compensating or overcompensating effect in the interbank market rate. Consequently, overbidding may occur. If the banks expect the central bank to decrease the interest rate and if they do not expect a compensating or overcompensating effect in the interbank market rate, less banks bid and a single bank bids for less funds. Consequently, underbidding may occur.*

Optimal reserve management leads to

$R_1 - R_2 =$

$$\begin{cases} \frac{2}{q(2q+5z)}\left((q+z)q^i - qu - qz(A+RR) + q(q+3z)k_0K_0\right) & \\ +\frac{2}{qz(2q+5z)}\left[(q^2+3qz+2z^2)(1-w)m + q(q+2z)(1-p)x\right] & \text{if} \quad q^i < \{\overline{q}_1^{i,crit} | q_i < \overline{q}_2^{i,crit}\} \\ \frac{2}{2q+5z}\left(q^i - u - z(A+RR) + (q+z)k_0K_0\right) & \\ +\frac{2}{z(2q+5z)}\left[(q+z)(1-w)m + q(1-p)x\right] & \text{if} \quad q^i \geq \{\overline{q}_1^{i,crit} | q_i < \overline{q}_2^{i,crit}\} \\ k_0K_0 + \frac{(1-w)m+(1-p)x}{z} & \text{if} \quad q^i \geq \overline{q}_2^{i,crit}. \end{cases} \tag{37}$$

The upper part of equation 37 describes the optimal reserve management of a bank which bids in both periods, the middle part presents the optimal reserve management of a bank which bids in the second period only, and the lower part of a bank which does not bid in the second period.[13] Comparing equation 37 with relevant equation of the previous section 20 shows that expectations of a monetary impulse influence the optimal reserve management of a bank.

If $\{R_1 - R_2 | w, p = 1\} \geq 0$ (see equation 20) an expected contractionary monetary impulse ($(1-w)m > 0$) leads to resp. reinforces uneven provisions of required reserves, unless a compensating or overcompensating effect in the interbank money market rate is expected. The intuition behind this result is: if a bank expects the central bank to increase its interest rate, the costs of reserves are higher in the second period, whereas the benefits are the same in both periods due to the remuneration of reserves at the average rate.

If $\{R_1 - R_2 | w, p = 1\} < 0$ (see equation 20) an expected expansionary ($(1-w)m < 0$) reinforces uneven provisions of required reserves - unless a compensating or overcompensating effect in the interbank money market rate is expected - because the costs of reserves are smaller in the second period, but the benefits are the same in both periods. Consequently, a bank has an incentive to hold more reserves in the second period.

Analogously, if $\{R_1 - R_2 | w, p = 1\} < 0$ an expected contractionary impulse ($(1-w)m < 0$) reduces or reinforces (but into the other direction) uneven provisions of required reserves. The same is true if $\{R_1 - R_2 | w, p = 1\} \geq 0$ and an expansionary impulse is expected.

Result 3.4: *Expectations of interest rate changes influence the optimal reserve management of a bank. If a bank expects the central bank to increase its interest rate*

[13] If $K_2 = 0$ the bank's decision whether it bids in the first period does not influence its optimal reserve management.

and if it does not expect a compensating or overcompensating effect in the interbank market rate, it will increase its reserves in the first period and decrease its reserves in the second period, and vice versa.

3.4 Violation of the Principal of Equal Treatment?

This subsection analyses whether there might a violation of the Eurosystem's principal of equal treatment. For doing so, it is assumed that there are expectations of interest rate changes $((1-w),(1-p)>0)$. Furthermore, it assumed that

$$x \equiv -4m. \tag{38}$$

Concerning the euro area, this means that the EONIA may, as a consequence of the banks' bidding behaviour, increase to the rate of the marginal lending facility if banks expect the ECB to lower the rate on its main refinancing operations by 0.25 percentage points, and that the EONIA may decrease to the rate of the deposit facility if banks expect the ECB to increase the rate on the main refinancing operations by 0.25 percentage points. Four scenarios can occur:

I The central bank actually changes its interest rate and there is a strong reaction of the interbank market rate, i.e. $l_2 = l_1 + m$ and $e_2 = l_2 + u - 4m$.

II The central bank does not change its interest rate, but there is a strong reaction of the interbank market rate, i.e. $l_2 = l_1$ and $e_2 = l_2 + u - 4m$.

III The central bank actually changes its interest rate, and there is only the "normal" reaction of the interbank market rate, i.e.$l_2 = l_1 + m$ and $e_2 = l_2 + u$.

IV The central bank does not change its interest rate, and there is no reaction of the interbank market rate, i.e.$l_2 = l_1$ and $e_2 = l_2 + u$.

For each scenario actual total costs, which are a function of m, $\left(\sum_{t=1}^{2} C_t = CT(m)\right)$ can be determined. The following derivatives (under the assumption $K_t > 0 \ \forall t$) show that in the cases I to III, the impact of a possible monetary impulse on total costs depends on q^i which differs among banks.

$$CT^I_{mq^i} = \frac{-(l_1 + 2z)}{q(2q + 5z)} < 0 \tag{39}$$

$$CT^{II}_{mq^i} = \frac{-12}{2q + 5z} < 0 \tag{40}$$

$$CT^{III}_{mq^i} = \frac{q - 2z}{q(2q + 5z)} > 0 \tag{41}$$

$$CT^{IV}_{mq^i} = 0 \tag{42}$$

Furthermore, it is obvious that a bank which does not take part in the tender procedures ($K_t = 0\ \forall t$) is affected differently by a monetary impulse than a bank for which $K_t > 0$ is true if there is actually a reaction in the money market in form of $x = -4m$ (scenarios I and III).

Result 3.5: *Depending on their marginal collateral costs, banks are affected differently by possible monetary impulses. This may be a violation of the Eurosystem's principal of equal treatment of credit institutions.*

4 A Bank's Demand for Reserves under a Modified Operational Framework

In section 2, a model explaining a bank's bidding behaviour and its management of required reserves has been presented. The model has captured the key elements of the current operational framework of the Eurosystem. It has been shown that problems like uneven provisions of required reserves, over- and underbidding and an unequal impact of monetary impulses on financial institutions depending on their marginal collateral costs may occur. This section shows that under a slightly modified operational framework, these problems can be avoided. The operational framework is modified in two respects. Firstly, there are no overlapping maturities of the central bank's credit operations. Secondly, required reserves are not remunerated at an *average* interest rate at the end of the maintenance period, but at the end of each period t at the rate on the central bank's credit operations in that period.

Liquidity Costs

Since the maturities of the central bank's credit operations do not overlap, the stock of credits borrowed from the central bank is simply given by

$$RK_t = k_t K_t. \tag{43}$$

Total liquidity costs in t include interest payments to the central bank, net interest payments from transactions in the interbank money market, collateral and transaction costs. They are reduced by the remuneration of required reserves:

$$C_t(K_t, R_t) = k_t K_t l_t + IB_t e_t + Z_t + Q_t - R_t l_t. \tag{44}$$

Optimization under Uncertainty

As in the model of the previous section, the bank wants to minimize expected total liquidity costs across the maintenance period, while keeping average reserves to the required level RR. The corresponding objective function is given by

$$\min_{K_1,K_2,R_1} \left\{ E\left[\sum_{t=1}^{2} C_t \middle| t = 1 \right] \right\}. \tag{45}$$

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Equation 44 shows that there is no intertemporal optimization problem. The first order conditions of this static optimization problem simply are

$$-k_1 u + \frac{\partial Q_1}{\partial K_1} + \frac{\partial Z_1}{\partial K_1} = 0, \tag{46}$$

$$-k_2(u + (1-p)x) + \frac{\partial Q_2}{\partial K_2} + \frac{\partial Z_2}{\partial K_2} = 0, \tag{47}$$

and

$$\frac{\partial Z_1}{\partial R_1} + \frac{\partial Z_2}{\partial R_1} - (1-p)x = 0. \tag{48}$$

Equations 46 and 47 make clear that optimal bidding behaviour requires marginal liquidity costs from borrowing at the central bank and in the interbank money market to be equal. Equation 48 demands a required reserve management implying equal marginal costs for reserves in both periods. Solving these equations for K_1 and K_2, one obtains

$$K_1 = \frac{2z(A + RR) + 2u + x(1-p) - 2q^i}{2k_1(q+z)} \quad \text{and}$$

$$K_2 = \frac{2z(A + RR) + 2u + x(1-p) - 2q^i}{2k_2(q+z)}.$$

Equation 49 shows that expected future monetary impulses, in form of expected changes in the rate on the central bank's credit operations does not influence the bank's bidding behaviour. Consequently, in $t = 2$ there will not be scarce or excess liquidity. This implies that $p = 1$, i. e. the mark-up on the rate in the interbank market only reflects collateral costs. Consequently,

$$K_1 = \frac{z(A + RR) + u - q^i}{k_1(q + z)} \quad \text{and} \tag{49}$$

$$K_2 = \frac{z(A + RR) + u - q^i}{k_2(q + z)}. \tag{50}$$

This implies

$$\overline{q}^{i,crit} = u + z(A + RR) \quad \forall t \tag{51}$$

and

$$\underline{q}^{i,crit} = u - q(A + RR) \quad \forall t. \tag{52}$$

Result 4.1: *The bank's bidding behaviour does not depend on expected monetary policy impulses. Only transaction and collateral costs may imply that the bank demands more or less reserves in the tender procedures compared to its actual liquidity needs. Consequently, under- or overbidding due to expectations of interest rate changes cannot occur.*

Solving the first order conditions for R_1, considering that $p = 1$, reveals that

$$R_1 = RR = R_2. \tag{53}$$

Result 4.2: *There is a smooth provision of reserve requirements.*

Assuming there is a monetary impulse, autonomous factors only determine the impact of the monetary impulse:

$$\left.\frac{\partial CT}{\partial m}\right|_{q^i < \overline{q}^{i,crit}} = \left.\frac{\partial CT}{\partial m}\right|_{q^i \geq \overline{q}^{i,crit}} = A. \tag{54}$$

Result 4.3: *The impact of a monetary impulse m does not depend on a bank's marginal collateral costs.*

However, required reserves are another monetary policy instrument. Assuming that the bank knows for sure that there will not be a monetary impulse m,

$$\left.\frac{\partial CT}{\partial RR}\right|_{w=1,q^i<\bar{q}^{i,crit}} = \frac{2(q^i z + q(u + z(A + RR)))}{q + z} \quad \text{and} \tag{55}$$

$$\left.\frac{\partial CT}{\partial RR}\right|_{w=1,q^i\geq\bar{q}^{i,crit}} = 2(u + z(A + RR)). \tag{56}$$

Result 4.4: *The impact of required reserves on a bank depends on its marginal collateral costs.*

5 Summary and Conclusion

Since the launch of the euro in 1999 several tender procedures of the main refinancing operations have been characterized by significant under- and overbidding behaviour of the financial institutions, and several reserve maintenance periods have been characterized by extreme uneven provisions of reserves. By the help of a simple model capturing the key elements of the current operational framework of the Eurosystem, this paper analyzes the causes and consequences of this banks' behaviour and suggests a modified operational framework for the monetary policy of the Eurosystem, under which the described extreme behaviour does not occur.

A main result of this paper is that the extreme behaviour of the banks in the refinancing operations and in the minimum reserve system is due to expectations of interest rate changes. Expecting an increase in interest rates of future main refinancing operations within the current reserve maintenance period, banks have an incentive to underbid, since due to the remuneration of required reserves at the average, over the maintenance period, of the rate on the refinancing operations, banks can reduce their liquidity costs by keeping reserves low now, and high after the monetary impulse. Furthermore, banks may profit from borrowing now at a low rate from the central bank, and placing the liquidity in the interbank market at a higher rate after the monetary impulse. A further result of this paper is that under the current design of the operational framework, banks with different marginal collateral costs may be affected differently by monetary policy impulses. Since in the euro area, marginal collateral costs depend on the Member State of the EMU the

bank is located, the Eurosystem's guiding principal of equal treatment of financial institutions may be violated.

This paper shows that extreme bidding behaviour and uneven provisions of required reserves and therefore, the resulting problems can be avoided by a slightly different design of the main refinancing operations and of the minimum reserve system, namely by abolishing firstly, the overlapping maturities of the main refinancing operations and secondly, the remuneration of required reserves at an *average* rate. The paper shows that under this modified framework, expected interest rate changes do not influence a bank's today's bidding behaviour, since its optimal behaviour today has no impact on its future optimal behaviour. (From a technical point of view, under the current operational framework, banks must solve a dynamic optimization problem, whereas under the suggested modified framework a static optimization problem has to be solved.) Consequently, expectations in interest rate changes cannot lead to under- or overbidding behaviour and to uneven provisions of required reserves. Furthermore, the impact on a bank of a monetary impulse in form of interest rate changes does not depend on its marginal collateral costs. Consequently, the principal of equal treatment of all institutions is not violated in this case.

As elaborated in the introduction, the ECB plans to change its operational framework by, inter alia, abolishing the overlapping maturities of the main refinancing operations. Considering the result of this paper, this alteration is absolutely sensible. But concerning the minimum reserve system, where the ECB plans to change the timing of the maintenance period, so that interest changes would be aligned with the start of a new maintenance period, the result of this paper suggests a further alteration. If the minimum reserves were not remunerated at an average rate, but at the end of the maturity of each main refinancing operation at the rate of this operation, the ECB would be refrained from making interest rate decisions at the first meeting of the governing council within the maintenance period only. Monetary policy could be conducted more flexible.

But one problem still remains. Regarding required reserves, financial institutions are still affected differently due to different marginal collateral costs. In this context, it may be an interesting topic for future research to analyze whether it might be reasonable to waive the collaterlization of the Eurosystem's credit transactions.

References

Ayuso, J., and R. Repullo (2000): "A Model of the Open Market Operations of the European Central Bank," CEPR Discussion Paper No. 2605.

——— (2001): "Why Did the Banks Overbid? An Empirical Model of the Fixed Rate Tenders of the European Central Bank," *Journal of International Money and Finance*, 20, 857–870.

Bartolini, L., G. Bertola, and A. Prati (2001): "Banks' Reserve Management, Transaction Costs, and the Timing of Federal Reserve Intervention," *Journal of Banking and Finance*, 25, 1287–1317.

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.

Campbell, J. Y. (1987): "Money Announcements, the Demand for Bank Reserves, and the Behavior of the Federal Funds Rate Within the Statement Week," *Journal of Money, Credit, and Banking*, 19, 56–67.

Clouse, J. A., and J. P. Dow Jr. (2002): "A Computational Model of Banks' Optimal Reserve Management Policy," *Journal of Economic Dynamics and Control*, 26, 1787–1814.

Clouse, J. A., and J. P. Dow Jr. (1999): "Fixed Costs and the Behaviour of the Federal Funds Rate," *Journal of Banking and Finance*, 23, 1015–1029.

Duisenberg, W. F. (2001): Introductory Statement, ECB Press Conference, Frankfurt, 8 November 2001, (see www.ecb.int).

Ehrhart, K.-M. (2001): "European Central Bank Operations: Experimental Investigation of the Fixed Rate Tender," *Journal of International Money and Finance*, 20, 871–893.

European Central Bank (1999): "Collateral Obligations of Counterparties in the Eurosytem's Main Refinacing Operations," ECB Press Release, 2 February 1999, (see www.ecb.int).

——— (2000a): *The Single Monetary Policy in Stage Three. General Documentation on Eurosystem Monetary Policy Instruments and Procedures*. European Central Bank, Frankfurt.

——— (2000b): "The Switch to Variable Rate Tenders in the Main Refinancing Operations," *ECB Monthly Bulletin, July 2000*, pp. 37–42.

——— (2001a): "Bidding Behaviour of Counterparties in the Eurosystem's Regular Open Market Operations," *ECB Monthly Bulletin, October 2001*, pp. 51–63.

——— (2001b): *The Monetary Policy of the ECB*. European Central Bank, Frankfurt.

——— (2002a): "The Liquidity Management of the ECB," *ECB Monthly Bulletin, May 2002*, pp. 41–53.

——— (2002b): "Measures to Improve the Efficiency of the Operational Framework for Monetary Policy," (Public Consultation, see www.ecb.int).

——— (2002c): *The Single Monetary Policy in the Euro Area - General Documentation on Eurosystem Monetary Policy Instruments and Procedures*. European Central Bank, Frankfurt.

Furfine, C. H. (2000): "Interbank Payments and the Daily Federal Funds Rate," *Journal of Monetary Economics*, 46, 535–553.

Hämäläinen, S. (2000): "The Operational Framework of the Eurosystem," Welcome address at the ECB Conference on the Operational Framework of the Eurosystem and the Financial Markets in Frankfurt, 5-6 May 2000, (see www.ecb.int).

Issing, O., V. Gaspar, I. Angeloni, and O. Tristani (2001): *Monetary Policy in the Euro Area - Strategy and Decision-Making at the European Central Bank*. Cambridge University Press, Cambridge (UK).

Leonardo Bartolini, G. B., and A. Prati (2002): "Day-To-Day Monetary Policy and the Volatility of the Federal Funds Interest Rate," *Journal of Money, Credit, and Banking*, 34, 137–159.

Nautz, D. (1997): "How Auctions Reveal Information: A Case Study on German REPO Rates," *Journal of Money, Credit and Banking*, 29(1), 17–25.

——— (1998): "Banks' Demand for Reserves When Future Monetary Policy is Uncertain," *Journal of Monetary Economics*, 42, 161–183.

Nautz, D., and J. Oechssler (2001): "The Repo Auctions of the European Central Bank and the Vanashing Quota Puzzle," Discussion paper No. 79, SFB 373, Humboldt-University Berlin, this version: September 2001, (see: www.wiwi.uni-frankfurt.de/professoren/nautz/).