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A MODEL OF THE OPEN MARKET OPERATIONS OF THE EUROPEAN CENTRAL BANK*

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We model the two types of tenders used by the European Central Bank in its open market operations. We assume that the ECB minimises a loss function that depends on the difference between the interbank rate and a target rate that characterises the stance of monetary policy. When the loss function penalises interbank rates below the target more heavily, fixed rate tenders have a unique equilibrium with high overbidding, while variable rate tenders have multiple equilibria with moderate overbidding. Our empirical analysis is consistent with the predictions of the model and supports the hypothesis of an asymmetric loss function.

The monetary policy instruments chosen by the European Central Bank (ECB)[1] in order to implement its monetary policy are minimum reserves, open market operations and standing facilities. The minimum reserves help to ensure that the euro area banking system has an aggregate liquidity deficit which is covered by two main types of open market operations: the main refinancing operations and the longer-term refinancing operations. The former (latter) are liquidity providing collateralised transactions with a weekly (monthly) frequency and a maturity of two weeks (three months).[2] The banks can also obtain or place overnight liquidity at the marginal lending and deposit standing facilities.

The refinancing operations can be conducted via either fixed rate or variable rate tenders. In *fixed rate tenders* the ECB announces an interest rate and the banks bid the amount of reserves they want to borrow at this rate. If the aggregate amount bid exceeds the liquidity that the ECB wants to provide, each bank receives a pro-rata share of this liquidity. In *variable rate tenders* the banks bid the amounts they want to borrow and the interest rates they are willing to pay. In this case, bids with successively lower interest rates are accepted until the total liquidity to be allotted is exhausted.

Up to now the longer-term refinancing operations have been conducted as variable rate tenders. On the other hand, from the beginning of the Monetary Union in January 1999 until June 2000 the main refinancing operations were conducted as fixed rate tenders. A striking feature of these tenders was the increasingly high degree of overbidding by the banks. The allotment ratio (i.e. the

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[1] Strictly speaking we should refer to the monetary policy of the Eurosystem, which comprises the ECB and the national central banks of the countries that have adopted the euro. However since the Eurosystem has no legal personality and is governed by the decision-making bodies of the ECB, with a slight abuse of terminology, in this paper we will simply use the latter term.

[2] In its meeting of 23 January 2003, the Governing Council of the ECB decided to reduce the maturity of the main refinancing operations to one week as from the beginning of 2004.

ratio between the allotted amount and the total amount bid) during this period went down from around 10% to below 1%, with a median value of 6.1%. In fact, the decision to switch to variable rate tenders taken by the Governing Council of the ECB in June 2000 was justified as '... a response to the severe overbidding which has developed in the context of the current fixed rate tender procedure.'[3] Figure 1 represents the total amount bid from January 1999 until September 2001. The series reached a peak in June 2000, with an amount above 8,000 bn Euro, and fell to an average of 145 bn Euro after the switch to variable rate tenders.

The purpose of this paper is to propose a theoretical model of the tender procedures used by the ECB. The model has a large number of identical risk neutral banks that can obtain liquidity from the central bank or in an interbank market. The central bank provides liquidity through a fixed or a variable rate tender. It is assumed that the interbank interest rate is a decreasing function of the liquidity allotted by the central bank in the tender and also depends on the realisation of a liquidity shock. Unlike in standard multiple unit common value auctions,[4] in our setup the seller (the central bank) does not want to maximise revenue. Instead, the central bank wants to steer the interbank rate towards a target rate that characterises the stance of monetary policy.[5] Formally, we assume that the central bank minimises the expected value of a *loss function* that depends on the difference between the interbank rate and the target rate. This expectation is taken conditional on the information collected by the central bank on the future realisation of the liquidity shock.

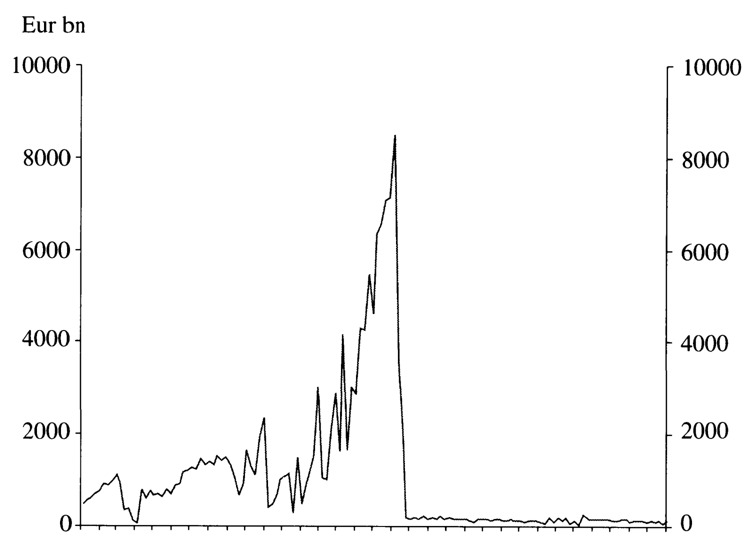

Fig. 1. *Total Bids* (January 1999–September 2001)

[3] The switch to variable rate tenders had been advocated among others by the 1999 *International Capital Markets* report of the International Monetary Fund, and the 2000 *Monitoring the European Central Bank* report of the Centre for Economic Policy Research.
[4] Like the auctions of Treasury securities; see, for example, Bikhchandani and Huang (1993).
[5] In the 1999 *Annual Report* it is stated that 'The ECB tended to orient its allotment decisions towards ensuring an average interbank overnight rate close to the tender rate.'

We show that when the loss function of the central bank is symmetric, fixed and variable rate tenders have the same multiple equilibrium outcomes. Moreover, in these outcomes there is always some overbidding. On the other hand, when the loss function of the central bank is asymmetric in the sense of penalising interbank rates below the target more heavily, then the nature of equilibria does not change for variable rate tenders, but fixed rate tenders have now a unique equilibrium characterised by high overbidding.

The intuition for these results is the following. When the loss function is asymmetric, the central bank is more concerned about letting the interbank rate fall below the target and, for this reason, it supplies less liquidity than that required to keep the expected interbank rate equal to the target rate. In fixed rate tenders, the differential between the interbank rate and the rate at which the liquidity is provided generates a profit for the banks which is increasing in the quantity allotted. Hence they have an incentive to increase the size of their bid. In equilibrium, the banks trade off this profit against the expected penalties for bidding above their collateral.[6] In contrast, in variable rate tenders, the banks fully compensate the differential between the expected interbank rate and the target rate by offering to pay higher interest rates, so in equilibrium they are indifferent as to the amount bid as long as it does not exceed their collateral.

Given the difference in outcomes under symmetry or asymmetry of the loss function of the central bank, we use data from the 139 fixed and variable rate tenders conducted during the period January 1999–September 2001 to estimate the asymmetry parameter of the loss function of the ECB. The results indicate that this parameter is significantly different from zero, even when we correct the interest rate series for the effect of expectations of changes in the target rate. This is consistent with the bidding behaviour of the banks in these tenders. In addition, the switch to variable rate tenders that took place in June 2000 provides a natural experiment to test our theoretical model. We show that the evidence is in line with the predictions of the model.

Hence we conclude that a very plausible explanation of the overbidding behaviour of the banks in the fixed rate tenders conducted until June 2000 is the bias in the objective function of the ECB, in particular its reluctance to see interbank rates fall below the tender rate. This behaviour would in turn be consistent with the desire of a newly created central bank to gain credibility quickly for its anti-inflationary monetary policy.[7] In addition, the explosive growth of the bids during the fixed rate tender period could be related to the banks' learning about the tolerance of overbidding by the ECB.

The theoretical literature on this topic starts with Nautz and Oechssler (1999), who construct a model of strategic bidding in fixed rate tenders in which there is no interbank market and the banks minimise a quadratic loss function in the deviations between the liquidity allotted by the central bank and the liquidity required by them. Their main result is that the fixed rate tender

[6] These penalties were formally in place until November 2000, and without them an equilibrium of the fixed rate tender game would not exist.

[7] The models of Backus and Driffill (1985) or Barro (1986) suggest that such a central bank is likely to set more 'hawkish' targets and pursue them in a more 'hawkish' manner.

game does not have an equilibrium. Catalão Lopes (2000) compares the performance of fixed and variable rate tenders in the context of a model with two banks that can trade their excess liquidity in an interbank market. She shows that switching from fixed to variable rate tenders ameliorates the overbidding problem. Nyborg and Strebulaev (2001) examine how the design of fixed rate tenders affects the banks' equilibrium bidding behaviour and the incidence of short squeezes. Välimäki (2001) presents an equilibrium model of the interbank market in order to analyse the performance of two alternative fixed rate tender procedures: the standard tender and the full allotment tender (in which the central bank provides the amounts bid in full). Lastly, Bindseil (2002) analyses optimal tender procedures and optimal allotment policies in a model with bidding costs.

There is also some empirical literature on this topic. Breitung and Nautz (2001) estimate bid functions for the fixed rate tender period, showing the significance for the explanation of overbidding of both the spread between the overnight rate and the tender rate and the spread between the 1-month interbank rate and the tender rate, the latter capturing expectations of interest rate changes. Ayuso and Repullo (2001) test two hypotheses on overbidding: the tight liquidity and the expectations hypothesis. The results show that once they control for the short spread, the effect of the 1-month spread is small and statistically not different from zero, so they support the tight liquidity hypothesis. Välimäki (2002) further explores this issue by estimating the ECB's liquidity supply function, showing that the effect of the short spread is not monotonically increasing, so he concludes that the ECB did not meet the increased demand for reserves when interest rates were expected to rise. Nyborg *et al.* (2002) look at the individual bidding behaviour of the banks under variable rate tenders, with especial reference to the underbidding episodes, which they explain by expectations of interest rate cuts. Finally, there is an experimental study by Ehrhart (2001) showing that the design of fixed rate tenders leads to overbidding.

Our paper introduces three novel features in relation to this literature. First we endogenise the behaviour of the central bank by postulating a loss function that depends on the deviations between the interbank rate and a target rate that characterises the stance of monetary policy. Second we assume that there is an efficient interbank market in which the banks can always get liquidity, so their objective in participating in the tenders is not to cover their liquidity needs but to profit from differentials between the interbank rate and the tender rate. Third, we introduce expected penalties for banks bidding above their collateral.

The paper is organised as follows. Section 1 presents the model. Sections 2 and 3 analyse the equilibrium of fixed and variable rate tenders, respectively. Section 4 contains our empirical results, and Section 5 offers some concluding remarks. Appendix A presents a simple model of the interbank market that is used to motivate the equilibrium interest rate equation that appears in the text, Appendix B contains the proofs of all the Lemmas and Propositions, and Appendix C explains our procedure for correcting the interest rate series for the effect of expectations of interest rate changes. All Appendices can be found on http://www.res.org.uk/economic/ta/tahome.asp.

1. The Model

Consider a model with two dates ($t = 0,1$) and two types of agents: a central bank, and a continuum of measure one of identical risk neutral private banks. At date 0 the central bank provides an amount of *liquidity* l using one of several possible tender procedures to be described in detail below. At date 1 there is an interbank market where the private banks can trade their excess liquidity at an interest rate r.

The equilibrium *interbank rate* is given by

$$r = \alpha - \beta l + \varepsilon, \tag{1}$$

where α and β are positive coefficients, and ε is a *liquidity shock*. Equation (1) has two main features. First, the equilibrium interbank rate at date 1 depends negatively on the liquidity l provided by the central bank at date 0. Second, it is subject to a random shock. Both features are rationalised in the model of the interbank market presented in Appendix A.

At date 0 the central bank observes a *signal* η which is correlated with the liquidity shock ε. Specifically, we assume that

$$\varepsilon = \eta + u, \tag{2}$$

where η and u are independent random variables with zero mean, so $E(\varepsilon \mid \eta) = \eta$. We also assume that η has a compact support $[\underline{\eta}, \bar{\eta}]$, and we let $F(u)$ denote the cumulative distribution function of u.

The interpretation of these shocks is as follows: ε captures the effect on the equilibrium interbank rate of autonomous liquidity creation and absorption factors (like changes in cash holdings, net government deposits with the central bank etc.), η captures the central bank's estimate of ε based on its forecast of these factors, and u is the error term.

The central bank wants to steer the equilibrium interbank rate r towards a *target rate* $\hat{r}$ that characterises the stance of monetary policy. By (1), if the liquidity injection were done at date 1, the central bank could effectively ensure that $r = \hat{r}$ by setting

$$l = \frac{\alpha - \hat{r} + \varepsilon}{\beta}.$$

However, in our framework the central bank decides on l before the liquidity shock ε is realised, so the equilibrium interbank rate r will in general differ from the target rate $\hat{r}$. This assumption is justified by the fact that central banks do not continuously intervene in the interbank market in order to neutralise the impact of liquidity shocks. Thus date 1 in our model should be interpreted as the period between two consecutive open market operations. In the case of the ECB this period is typically a week, while in the case of the Federal Reserve or the Bank of England it is only one day, or less.[8]

[8] For a detailed description of the operational framework of these central banks, see Bank for International Settlements (2001) and Bank of England (2002).

In setting the liquidity injection l at date 0 we will assume that the central bank minimises the conditional expected value of a *loss function* that depends on the quadratic difference between the interbank rate r and the target rate $\hat{r}$. Specifically, we assume the following functional form

$$\mathrm{E}[(r - \hat{r})^2 + \gamma 1_{[r<\hat{r}]}(r - \hat{r})^2 \mid \eta], \tag{3}$$

where $1_{[r<\hat{r}]}$ is an indicator function that takes the value 1 when $r < \hat{r}$. Although the parameter γ could in principle be negative, for reasons that will be clear below we will restrict attention to the case $\gamma \geq 0$. If $\gamma > 0$ the central bank loss function is asymmetric, with interbank rates below the target $\hat{r}$ penalised more heavily than rates above the target. If $\gamma = 0$ the loss function is symmetric.

Given this objective function, the following result characterises the desired liquidity injection of the central bank.

LEMMA 1 *The central bank desired liquidity injection is described by the function*

$$s_\gamma(\eta) = \frac{\alpha - r_\gamma + \eta}{\beta}, \tag{4}$$

where r_γ is increasing in γ with $r_0 = \hat{r}$.

The liquidity supply function $s_\gamma(\eta)$ is linearly increasing in the signal η. This means that the central bank will want to inject more liquidity when it anticipates tight conditions in the interbank market (i.e. observes a high η). On the other hand, for $\gamma > 0$ we have $r_\gamma > r_0$, so a central bank with an asymmetric loss function will want to provide, *ceteris paribus*, less liquidity than a central bank with a symmetric loss function.

Substituting the supply function $s_\gamma(\eta)$ into the interest rate (1), and taking into account the definition of the disturbance u in (2), gives

$$r = r_\gamma + u. \tag{5}$$

Since r_γ is increasing in γ with $r_0 = \hat{r}$, it follows that a central bank with a symmetric loss function tries to achieve an interbank rate r that, on average, is equal to the target rate $\hat{r}$, while a central bank with an asymmetric loss function aims at higher average interbank rates.

2. Equilibrium Analysis of Fixed Rate Tenders

Suppose that at date 0 the central bank provides liquidity to the banks through a fixed rate tender. In this procedure the representative bank submits a *bid* b and receives an *allotment* l at the target interest rate $\hat{r}$, which is announced by the central bank prior to the tender.

The bid b can exceed the amount of *collateral* c that the bank holds but in this case there is a positive probability that the central bank will impose a penalty on the bank. We assume that the expected value of such penalty takes the simple functional form

$$\frac{\delta}{2}\left[\max\left(0,\frac{b-c}{c}\right)\right]^2,$$

where $\delta > 0$ is a parameter that captures the bank's perception of the probability and magnitude of the penalty. Hence for $b \leq c$ there is no penalty, while for $b > c$ the expected penalty is a quadratic function of the excess bid relative to the bank's collateral.

The rationale for this assumption is the following. The first version of the ECB's *General Documentation on Monetary Policy Instruments and Procedures,* published in September 1998, established that 'counterparties are expected always to be in a position to cover their tender bids by a sufficient amount of eligible underlying assets,'[9] and also contemplated '... the possibility to check underlying assets available to counterparties in order to detect cases of excessive bidding and to impose penalties if such excessive bidding is evidenced.'[10] However, in a press release issued on February 1999 the ECB stated that '... the valid interpretation of the *General Documentation* allows tender bids not actually covered by collateral at the time of submission of the bids, and just requires the financial capacity to have the collateral on the date of settlement of the tender.' In our view, this interpretation created some ambiguity about whether penalties for excessive bidding were being ruled out. In fact it was not until November 2000 (after the switch to variable rate tenders in June 2000) that the *General Documentation* was first revised, formally establishing that 'counterparties are expected always to be in a position to cover the amounts allotted to them by a sufficient amount of eligible underlying assets.' Hence, our expected penalty function is a simple way to capture the situation during the period in which penalties for 'excessive bidding' were still formally in place, but it was difficult for the ECB to measure the collateral of each bank accurately, which included not only its holdings of eligible assets but also its borrowing potential.[11] Moreover, it allows for adjustments in the value of the key penalty parameter δ as the learning on the tolerance of overbidding by the ECB progressed.

We assume that the minimum desired liquidity injection (that is, the one that corresponds to the lowest signal $\underline{\eta}$) is positive, so

$$s_\gamma(\underline{\eta}) > 0, \tag{6}$$

and that the representative bank has sufficient collateral to cover the maximum desired liquidity injection (that is, the one that corresponds to the highest signal $\bar{\eta}$), so

[9] Not surprisingly, this was the requirement in the fixed rate tenders conducted by the Bundesbank prior to the Monetary Union.

[10] 'Excessive bidding is considered to have taken place if the counterparty could not possibly have delivered sufficient underlying assets to cover its tender bid, when taking account of its holdings of securities and its borrowing potential' (ECB, 1998, p.30).

[11] There was also the problem that, due to the differences in banking practices and traditions, the availability of collateral might have differed between banks headquartered in different countries of the euro zone, so any overbidding penalty could imply unequal treatment. Both reasons might explain why the ECB did not in fact resort to penalties to fight overbidding.

$$s_\gamma(\bar{\eta}) < c. \tag{7}$$

In a fixed rate tender, if s denotes the liquidity that the central bank wants to provide and b^* is the aggregate amount bid, the bank receives the allotment

$$l = \min\left(b, \frac{s}{b^*}b\right). \tag{8}$$

According to this expression, the bank gets the amount b it bid unless the aggregate bid b^* exceeds the amount s that the central bank wants to inject, in which case the bank gets the fraction s/b^* of the amount bid b.

The tender procedure is modelled as a noncooperative game between the central bank and the representative bank. The game is sequential: the central bank decides on s after observing the aggregate bid b^*. Moreover, we assume that the representative bank knows the loss function of the central bank (in particular, the value of the asymmetry parameter γ) but it does not observe (nor does the central bank reveal) the value of the signal η on the liquidity conditions in the interbank market at date 1.

Since we have a continuum of measure one of banks, in a symmetric equilibrium it must be the case that $b = b^*$, so the central bank provides an amount of liquidity

$$l = \min(b^*, s). \tag{9}$$

Substituting this expression into the interest rate equation (1), gives the following equilibrium interbank rate

$$r = \alpha - \beta \min(b^*, s) + \varepsilon. \tag{10}$$

The next result characterises the dominant strategy of the central bank in the fixed rate tender.

LEMMA 2 *In the fixed rate tender the central bank chooses* $s = s_\gamma(\eta)$.

The reason why $s = s_\gamma(\eta)$ is a dominant strategy is easy to explain. In deciding on its provision of liquidity, the central bank has to take into account the constraint that the liquidity injection l cannot exceed the aggregate bid b^*. If this constraint is not binding (that is, if $s_\gamma(\eta) \leq b^*$), by Lemma 1 we have $s = s_\gamma(\eta)$. On the other hand, if this constraint is binding, any $s \geq b^*$ will be optimal, so we can take $s = s_\gamma(\eta)$.

The representative bank chooses its bid b in order to maximise

$$\mathrm{E}[l(r - \hat{r})] - \frac{\delta}{2}\left[\max\left(0, \frac{b-c}{c}\right)\right]^2. \tag{11}$$

The first term in this objective function is the expected return obtained by placing in the interbank market at the interest rate r the quantity l allotted by the central bank at the rate $\hat{r}$. This is justified in the model of the interbank market presented in Appendix A. The second term is the expected penalty for bidding above the bank's collateral introduced above.

The following result characterises the equilibrium of the fixed rate tender.

PROPOSITION 1 *In the fixed rate tender, when the loss function of the central bank is asymmetric* ($\gamma > 0$) *there is a unique equilibrium in which the representative bank bids* $b = m(\delta)c$, *where*

$$m(\delta) = \frac{1}{2} + \sqrt{\frac{1}{4} + \frac{1}{\delta}\mathrm{E}[s_\gamma(\eta)](r_\gamma - \hat{r})}, \quad (12)$$

whereas when the loss function is symmetric ($\gamma = 0$) *any bid* $b \in [s_0(\bar{\eta}), c]$ *constitutes an equilibrium. In either case, the central bank provides an amount of liquidity equal to* $s_\gamma(\eta)$ *and the expected equilibrium interbank rate is* r_γ.

Proposition 1 establishes that when $\gamma > 0$ the equilibrium bid b will be a multiplier $m(\delta) > 1$ of the bank's collateral c. It is interesting to note that $m(\delta)$ is decreasing and satisfies $\lim_{\delta \to 0} m(\delta) = \infty$ and $\lim_{\delta \to \infty} m(\delta) = 1$. Hence the equilibrium bid of the representative bank is decreasing in the penalties for excessive bidding, tending to infinity with zero penalties and to the bank's collateral with infinite penalties.

To explain the intuition for this result notice that when the loss function of the central bank is asymmetric, the equilibrium interest rate equation (10) together with Lemma 1 imply that

$$\mathrm{E}(r) = \mathrm{E}\{\alpha - \beta \min[b^*, s_\gamma(\eta)] + \varepsilon\} \geq \mathrm{E}[\alpha - \beta s_\gamma(\eta) + \eta + u] = r_\gamma > \hat{r}.$$

Hence the expected equilibrium interbank rate will always be above the interest rate $\hat{r}$ at which the central bank allocates funds in the tender. Since the expected penalty for overbidding has a zero slope for $b = c$, the representative bank has an incentive to bid $b > c$.

On the other hand, when the loss function of the central bank is symmetric, the equilibrium interest rate equation (10) together with Lemma 1 imply that

$$\mathrm{E}(r) = \mathrm{E}\{\alpha - \beta \min[b^*, s_0(\eta)] + \varepsilon\} \geq \mathrm{E}[\alpha - \beta s_0(\eta) + \eta + u] = r_0 = \hat{r},$$

with strict inequality for (high) realisations of η for which $b^* < s_0(\eta)$. Hence if $b^* < s_0(\bar{\eta})$ we have $\mathrm{E}(r) > \hat{r}$, so the representative bank has an incentive to bid $b > c$, which contradicts the assumption $b^* < s_0(\bar{\eta}) < c$. Therefore we must have $b^* \geq s_0(\bar{\eta})$, in which case $\mathrm{E}(r) = \hat{r}$. Since bidding above c has a negative expected payoff, we conclude that any bid $b \in [s_0(\bar{\eta}), c]$ constitutes an equilibrium.

The preceding discussion can be summarised as follows. Proposition 1 implies that, on average, the equilibrium interbank rate r will be above the central bank target rate $\hat{r}$ if and only if the loss function of the central bank is asymmetric. Hence when $\gamma > 0$ there is a unique equilibrium where the banks bid above their collateral, whereas when $\gamma = 0$ there is a continuum of equilibria where the banks bid no more than their collateral.[12] In both cases, the central bank provides an amount of liquidity equal to $s_\gamma(\eta)$, so assumption (7) ensures that, as required by the ECB, the banks are able to provide sufficient collateral for the equilibrium allotment.

[12] Thus the equilibrium correspondence jumps discontinuously at the point $\gamma = 0$.

It is interesting to note that when $\gamma > 0$ the overbidding increases as the banks' perception of the likelihood of being fined goes down. Hence we can interpret the exponential growth of the bids during the fixed rate tender period as the result of a continuous decrease in the penalty parameter δ, reflecting the updating by the banks of their prior on the tolerance of overbidding by the ECB.

We next analyse what would happen if prior to the tender the central bank reveals its information η (or, equivalently, announces its desired liquidity injection $s_\gamma(\eta)$).[13] The sequence of moves in the game between the central bank and the representative bank is now reversed, with the central bank moving first.

PROPOSITION 2 *If in the fixed rate tender the central bank pre-announces the liquidity it intends to provide, when $\gamma > 0$ there is a unique equilibrium in which the representative bank bids $b = m(\delta, \eta)c$, where*

$$m(\delta,\eta) = \frac{1}{2} + \sqrt{\frac{1}{4} + \frac{1}{\delta} s_\gamma(\eta)(r_\gamma - \hat{r})}, \qquad (13)$$

whereas when $\gamma = 0$ any bid $b \in [s_0(\eta), c]$ constitutes an equilibrium. In either case, the central bank provides an amount of liquidity equal to $s_\gamma(\eta)$ and the expected equilibrium interbank rate is r_γ.

The intuition for this result is the following. When $\gamma > 0$, if the central bank announces a higher desired liquidity injection, since the expected equilibrium interbank rate is independent of the announcement, the banks have an incentive to bid more aggressively, so the multiplier $m(\delta, \eta)$ is increasing in η. On the other hand, when $\gamma = 0$ we have $E(r) > \hat{r}$ if and only if $b^* < s_0(\eta)$, so we now rule out equilibrium bids below $s_0(\eta)$.

The results in this Section indicate that overbidding by the banks in fixed rate tenders is explained by the asymmetry of the loss function of the central bank, specifically its reluctance to see interbank interest rates fall below the target rate $\hat{r}$. In this case the central bank supplies less liquidity than that needed to ensure that $E(r) = \hat{r}$, so it is rational for the banks to overbid. Moreover, if there were no penalties for excessive bidding an equilibrium would not exist. On the other hand, if the loss function of the central bank is symmetric, there is a continuum of equilibria in which the banks are always rationed, unless the central bank preannounces its desired liquidity injection, in which case there is also an equilibrium without overbidding.

3. Equilibrium Analysis of Variable Rate Tenders

In variable rate tenders the representative bank submits a *bid b* at an *interest rate* $\tilde{r}$. The central bank orders the bids according to the interest rate offered and successively lower interest rates are accepted until the total liquidity to be allotted is exhausted. In the single rate auction (also called uniform or 'Dutch') the interest rate applied for all satisfied bids is the *marginal tender rate* r_m (the lowest interest

[13] Observe that since the function $s_\gamma(\eta)$ is increasing and the representative bank knows the parameter γ, then learning the value of $s_\gamma(\eta)$ is equivalent to learning η.

rate accepted). In the multiple rate auction (also called discriminatory or 'American') the interest rate applied is the rate offered for each accepted bid.

In variable rate tenders the behaviour of the central bank is identical to the one described in the previous Section, namely it chooses to supply the amount of liquidity $s_\gamma(\eta)$. This follows from the assumption that the central bank only cares about the deviations of the equilibrium interbank rate r from the target rate $\hat{r}$, and not about the marginal (or the average) rate applied to successful bids.

We next examine the equilibrium outcome of the two types of variable rate tenders.

3.1. *The Dutch Auction*

In the Dutch auction, the representative bank chooses its bid b and offered interest rate $\tilde{r}$ in order to maximise

$$\mathrm{E}[l(r - r_m)] - \frac{\delta}{2}\left[\max\left(0, \frac{b-c}{c}\right)\right]^2, \tag{14}$$

where

$$l = \begin{cases} b, & \text{if either } \tilde{r} > r_m = \tilde{r}^*, \text{ or } \tilde{r} = r_m < \tilde{r}^* \\ \min\left(b, \dfrac{s}{b^*}b\right), & \text{if } \tilde{r} = r_m = \tilde{r}^* \\ 0, & \text{if } \tilde{r} < r_m = \tilde{r}^* \end{cases} \tag{15}$$

$$r_m = \begin{cases} \tilde{r}, & \text{if } \tilde{r} < \tilde{r}^* \text{ and } s > b^* \\ \tilde{r}^*, & \text{otherwise} \end{cases} \tag{16}$$

and b^* and $\tilde{r}^*$ denote, respectively, the amount bid and the interest rate offered by all the other banks (assuming a symmetric equilibrium).

In words, the representative bank gets the amount bid b if it offers an interest rate $\tilde{r}$ above the marginal tender rate r_m, or if it offers the marginal tender rate r_m and this rate is below the interest rate $\tilde{r}^*$ offered by the other banks. It gets $\min[b, (s/b^*)b]$ if it offers the marginal interest rate r_m and this rate coincides with the interest rate $\tilde{r}^*$ offered by the other banks. Finally, it gets 0 if it offers an interest rate $\tilde{r}$ below the marginal tender rate r_m. As before, the objective function also incorporates the expected penalty for bidding an amount in excess of the bank's collateral c.

Notice that when $\tilde{r} = \tilde{r}^*$ (which obtains in a symmetric equilibrium) the only difference between this objective function and the one in the previous Section is the fact that now the bank pays the marginal interest rate $r_m = \tilde{r}^*$, instead of the target rate $\hat{r}$, for the quantity allotted.

It is important to stress that in the analysis that follows the representative bank is assumed to know both the interest rate $\hat{r}$ that characterises the stance of monetary policy, and the value of the parameter γ that characterises the loss function of the central bank. This raises the issue of how the central bank may signal the target rate $\hat{r}$. We will discuss it at the end of this Section.

The next result characterises the symmetric equilibrium of the Dutch auction.

Proposition 3 *In the Dutch auction, any bid $b \in [s_\gamma(\bar{\eta}), c]$ at the interest rate $\tilde{r} = r_\gamma$ constitutes an equilibrium in which the central bank provides an amount of liquidity equal to $s_\gamma(\eta)$ and the expected equilibrium interbank rate is r_γ.*

Proposition 3 shows that when the loss function of the central bank is symmetric the outcome of the Dutch auction is the same as the outcome of the fixed rate tender: the banks bid a sufficiently large amount (that implies that they are always going to be rationed) at the expected equilibrium interbank rate $r_0 = \hat{r}$. On the other hand, when the loss function is asymmetric there is no longer a unique equilibrium with $b = m(\delta)c > c$ but a continuum of equilibria in which the banks bid a sufficiently large amount at the expected equilibrium interbank rate r_γ.

Thus in the Dutch auction the nature of equilibrium is the same for all $\gamma \geq 0$. The reason for this result is that the banks correct for the bias in the loss function of the central bank by offering an interest rate that equals the expected equilibrium interbank rate and for which their payoff is always zero. Since there is no spread between the expected interbank rate and the marginal rate of the auction, the banks have no incentive to bid an amount above their collateral.

We next analyse what happens when the central bank reveals η (or, equivalently, announces its desired liquidity injection $s_\gamma(\eta)$) prior to the tender.

Proposition 4 *If in the Dutch auction the central bank pre-announces the liquidity $s_\gamma(\eta)$ it intends to provide, any bid $b \in [s_\gamma(\eta), c]$ at the interest rate $\tilde{r} = r_\gamma$ constitutes an equilibrium in which the central bank provides an amount of liquidity equal to $s_\gamma(\eta)$, and the expected equilibrium interbank rate is r_γ.*

The only difference between this result and Proposition 3 is that now the range of equilibrium bids is $[s_\gamma(\eta), c]$, rather than $[s_\gamma(\bar{\eta}), c]$, so there is always an equilibrium without overbidding. Moreover, one can argue that the announcement of intended liquidity injection by the central bank may serve as coordination device for the banks in the presence of multiple equilibria, in which case the equilibrium in which the banks bid $b = s_\gamma(\eta)$ may actually obtain.

3.2. *The American Auction*

In the American auction, the representative bank chooses its bid b and offered interest rate $\tilde{r}$ in order to maximise

$$\mathrm{E}[l(r - \tilde{r})] - \frac{\delta}{2}\left[\max\left(0, \frac{b-c}{c}\right)\right]^2, \tag{17}$$

where l is defined in (15) and (16).

Comparing (14) with (17) it is clear that the American auction is identical to the Dutch auction except that now the bank always pays the interest rate $\tilde{r}$ offered, instead of the marginal tender rate r_m. Despite this difference, following the arguments in the proofs of Propositions 3 and 4 one can show that the equilibrium outcomes of the American auction are the same as those of the Dutch auction. Hence the representative bank bids $b \in [s_\gamma(\bar{\eta}), c]$ (or $b \in [s_\gamma(\eta), c]$ when the central bank reveals η) at the interest rate $\tilde{r} = r_\gamma$,[14] and its equilibrium payoff is equal to zero.

It should be noted that the equilibrium outcomes of both tenders do not change if, as contemplated in the ECB's *General Documentation*, each bank can submit bids for up to 10 different interest rates: no bank has an incentive to submit bids at rates other than the one corresponding to the expected equilibrium interbank rate r_γ.[15]

A concern that arises in the case of variable rate tenders is how the central bank may signal the stance of monetary policy. In fixed rate tenders, this is achieved by the announcement of the interest rate $\hat{r}$ at which the liquidity is provided. In variable rate tenders the marginal interest rate is endogenously determined, so this signal is no longer available. In its decision of June 2000 to switch from fixed to variable rate tenders in the main refinancing operations, the ECB addressed this problem by introducing a minimum bid rate, and stating that 'for the purpose of signalling the monetary policy stance, the minimum bid is designed to play the role performed, until now, by the rate in fixed rate tenders'. In the context of our model one can check that the constraint that the interest rates offered by the banks be greater than or equal to the target rate $\hat{r}$ does not alter any of the arguments in the proofs of Propositions 3 and 4, so we have exactly the same characterisation of equilibria.

A second concern is whether the volatility of the interbank rate might be higher with variable rate tenders. But as long as the central bank can signal the target rate $\hat{r}$ effectively, by (5), the results in Propositions 1–4 imply that $\text{Var}(r) = \text{Var}(u)$ regardless of the type of tender and regardless of whether the central bank pre-announces its intended liquidity injection.

The results in this Section show that if the loss function of the central bank is asymmetric, switching to variable rate tenders makes it possible to achieve equilibria with moderate overbidding at no cost in terms of the volatility of the interbank rate. Moreover, in the case where the central bank pre-announces its desired liquidity injection an equilibrium without overbidding may be selected by the banks.

4. Is the Loss Function of the ECB Asymmetric?

In previous Sections, we have shown that the equilibrium outcomes of fixed and variable rate tenders crucially depend on the symmetry or asymmetry of the loss function of the central bank. In this Section we use data for the periods January

[14] Notice that if the bank offered a lower rate $\tilde{r} < r_\gamma$ its payoff would be zero (since $l = 0$), while if it offered a higher rate $\tilde{r} > r_\gamma$ its payoff would be negative (since $\text{E}[l(r - \tilde{r})] = b(r_\gamma - \tilde{r}) < 0$), so these deviations are not profitable.

[15] However, the analysis in Back and Zender (1993) implies that for the case of the Dutch auction where the central bank preannounces $s_\gamma(\eta)$ there may be alternative equilibia in which the marginal tender rate r_m is below r_γ. In these equilibria the banks submit high inframarginal bids at very high rates (a costless strategy in a uniform price auction), so deviations by any bank are not profitable. But as noted by Back and Zender (1993, p.755) the presence of a potential pool of bidders (a feature of the main refinancing operations of the ECB) makes it difficult to sustain such equilibria.

1999–June 2000 and June 2000–September 2001 in which the ECB conducted 76 fixed rate and 63 variable rate tenders, respectively, to test whether the parameter γ of its loss function is significantly different from zero.[16] In addition, we use the switch to variable rate tenders to test some of the predictions of our model.

A symmetric loss function implies that, for both tenders, the differential between the interbank rate r and the target rate $\hat{r}$ (the tender rate in fixed rate tenders and the minimum bid rate in variable rate tenders) is on average zero. Hence an indirect and simple way of testing the null hypothesis $\gamma = 0$ is to test whether

$$\mu = \mathrm{E}(r) - \hat{r} = r_\gamma - \hat{r} = 0.$$

In our empirical analysis we consider two alternative measures of the interbank rate r, namely the 1-week euro interbank offered rate (Euribor) and the euro overnight interest rate (Eonia).[17] In both cases we choose the rate corresponding to the day of settlement of the tender.

It is worth noting that when comparing the interest rates r on interbank deposits with the target rate $\hat{r}$ there are two potential biases that can affect the spread $r - \hat{r}$. First, differences in credit risk: the main refinancing operations are collateralised while interbank deposits are unsecured, which may bias the spread upwards. Second, differences in maturity: the interest rate on the main refinancing operations may have a term premium when compared to rates on less-than-two-week deposits, which may bias the spread downwards.[18] In the case of 1-week Euribor, the difference in maturity is only one week and credit risk is likely to be very small (since it is a rate offered to prime banks), so the two biases are probably negligible. On the other hand, Eonia might be subject to higher biases pointing in opposite directions, so their net effect is difficult to evaluate, but it is the interest rate corresponding to the most active segment of the interbank market.

The results of the test of the null hypothesis $\mu = 0$ for both proxies of the interbank rate are shown in Table 1. For Euribor the average spread $\hat{\mu}$ was 13 basis points in the fixed rate tender period and 10 basis points in the variable rate tender period, with a standard deviation of only 1 basis point. For Eonia the average spread $\hat{\mu}$ was 8 basis points in the fixed rate tender period and 9 basis points in the variable rate tender period, with a standard deviation of also 1 basis point. In both cases the null hypothesis of a symmetric loss function for the ECB can be rejected, even at a confidence level of 1%.

It is interesting to note that we cannot reject the hypothesis that the estimated value of μ is the same for the fixed rate and the variable rate tender periods. In

[16] The sample ends in the first week of September 2001 in order to prevent our results from being biased by the unique situation in the aftermath of the September 11 events (exceptional liquidity providing operations, co-ordinated interest rate cuts, tremendous uncertainty in the markets etc.). Nothing really changes after this period.

[17] *Euribor* is the rate at which a prime bank is willing to lend funds in euro to another prime bank, and is computed as the average of the offer rates of a representative panel of prime banks. *Eonia* is an effective overnight rate computed as a weighted average of the interest rates on unsecured overnight contracts on deposits denominated in euro reported by a panel of contributing banks.

[18] Unfortunately, 2-week Euribor rates were not available until 15 October 2001, which is outside our sample period.

Table 1

Estimation of $\mu = \mathrm{E}(r) - \hat{r}$

	r = 1-week Euribor			r = Eonia		
	FRT	VRT	F + V	FRT	VRT	F + V
$\hat{\mu}$	0.13	0.10	0.12	0.08	0.09	0.08
(*s.e.*)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)
[p-value]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
n	76	63	139	76	63	139

The interest rate data in the first and the second block correspond, respectively, to 1-week Euribor and Eonia for the days of settlement of the tenders. The columns FRT, VRT, and F+V use, respectively, fixed rate, variable rate, and both types of tender data. Each column reports the sample mean $\hat{\mu}$, its standard error, the p-value of of the one-sided test of the null hypothesis $\mu = 0$ (against the alternative $\mu > 0$), and the sample size n.

particular, the p-value of the corresponding test is 0.17 for the 1-week Euribor sample, and 0.66 for the Eonia sample. Hence we conclude that the change in the tender procedure that took place in June 2000 did not alter the underlying loss function of the ECB.

To check the robustness of our results we considered two additional samples for Eonia: one including all days in the sample period except those corresponding to the end of the monthly maintenance periods of the reserve requirement (with $n = 669$), and another one including all days in the sample period (with $n = 700$). The null hypothesis of a symmetric loss function for the ECB is also rejected at a confidence level of 1%.

One criticism that can be made about these results is that they do not take into account the fact from November 1999 until November 2000 the ECB raised the interest rate of the main refinancing operations on seven consecutive occasions.[19] To the extent that these decisions were anticipated by the banks, they would have had an incentive to front-load their demands for liquidity, thereby putting an upward pressure on interbank rates.

To check whether our estimate of μ may be biased by this effect, we propose a procedure to correct the interest rate series for the effect of expectations of interest rate changes. This procedure, which is explained in detail in Appendix C, assumes that banks do not expect the ECB to modify its target rate except during a meeting of the Governing Council and that they correctly anticipate interest rate changes on the day they are announced. The first assumption allows us to set the expectations term equal to zero at the end of the maintenance periods of the reserve requirement, while the second sets it equal to the actual change in the target rate on the days when a change is announced. The expectations term for all the other days is obtained by linearly interpolating between the closest available estimates. Figure 2 shows the results of applying this procedure to Eonia rates for

[19] It also reduced rates in April 1999 and in May and August 2001. Expectations of interest rate cuts led in April 1999 and in February and April 2001 to underbidding by the banks, i.e. bidding a total amount below the one required to smoothly fulfil reserve requirements.

the days of settlement of the tenders. Notice that the corrected series tends to be below (above) the original one before interest rate hikes (cuts).

The results of the test of the null hypothesis $\mu = 0$ for the corrected interest rate series are shown in Table 2. For Euribor the average spread $\hat{\mu}$ for the whole sample period goes down from 12 to 10 basis points but it is still significantly different from zero at a confidence level of 1%. For Eonia the average spread $\hat{\mu}$ also goes down from 8 to 7 basis points, which is also statistically different from zero at a confidence level of 1%. Hence we conclude that the positive spread between the interbank rate r and the target rate $\hat{r}$, which according to our theoretical model explains the overbidding during the fixed rate tender period, cannot be accounted for by expectations of interest rate increases.[20]

To further check the robustness of our results we tried a different approach to correct the effect of expectations, namely to exclude from the original samples the data corresponding to two, three and four weeks prior to an interest rate change. The results were almost identical.[21] Hence the indirect test allows us to safely reject the null hypothesis of a symmetric loss function for the ECB.

A more direct test of the null hypothesis $\gamma = 0$ can be performed by exploiting the first order condition that characterises the optimal decision of the central bank (see the proof of Lemma 1):

$$\mathrm{E}[(r - \hat{r}) + \gamma 1_{[r<\hat{r}]}(r - \hat{r}) \mid \eta] = 0.$$

Since according to our model the liquidity provided by the central bank in each tender is a function of the signal η, we can estimate γ by the Generalised Method of

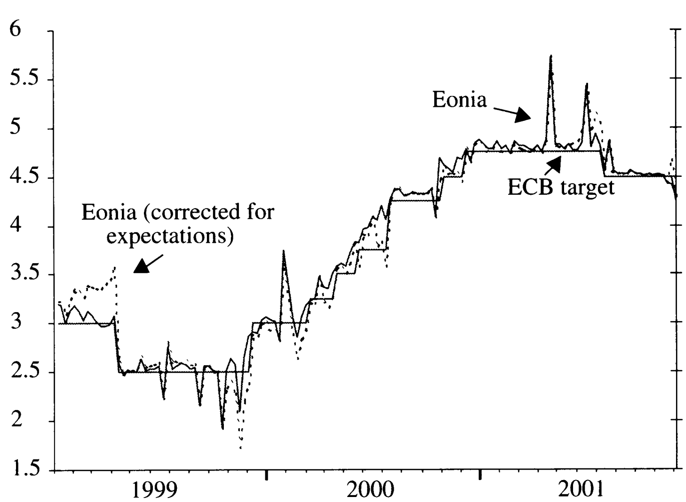

Fig. 2. *Interest Rates* (January 1999–September 2001)

[20] See Ayuso and Repullo (2001) for a further analysis of this issue.
[21] All the results not reported in the text are available from the authors upon request.

Table 2

Estimation of $\mu = E(r) - \hat{r}$ Using Interest Rates Corrected for Expectations

	$r =$ 1-week Euribor			$r =$ Eonia		
	FRT	VRT	F + V	FRT	VRT	F + V
$\hat{\mu}$	0.11	0.10	0.10	0.05	0.09	0.07
(*s.e.*)	(0.02)	(0.01)	(0.01)	(0.03)	(0.02)	(0.02)
[p-value]	[0.00]	[0.00]	[0.00]	[0.03]	[0.00]	[0.00]
n	76	63	139	76	63	139

The interest rate data in the first and the second block correspond, respectively, to 1-week Euribor and Eonia for the days of settlement of the tenders. Both series are corrected for expectations of interest rate changes following the procedure explained in Appendix C. The columns FRT, VRT, and F+V use, respectively, fixed rate, variable rate, and both types of tender data. Each column reports the sample mean $\hat{\mu}$, its standard error, the p-value of of the one-sided test of the null hypothesis $\mu = 0$ (against the alternative $\mu > 0$), and the sample size n.

Moments (GMM) using as instruments a constant and the total liquidity provided by the ECB through its main refinancing operations.[22] The results of the test of the null hypothesis $\gamma = 0$ for the original and the corrected-for-expectations interest rate series are shown in Table 3.

The four columns of Table 3 give the same qualitative result: the null hypothesis of a symmetric loss function for the ECB can be rejected, at a confidence level of 2%, and the instruments chosen pass the Sargan test without difficulty. The important quantitative difference in the estimated value of γ in the first column is due to the fact that, as reported in Table 1, the average spread between 1-week Euribor and the target rate is 12 basis points, while the spread in the other cases is

Table 3

GMM Estimation of the ECB's Loss Function Parameter γ

	$r =$ 1-week Euribor		$r =$ Eonia	
	Original r	Corrected r	Original r	Corrected r
$\hat{\gamma}$	69.50	7.18	3.69	1.71
(*s.e.*)	(33.25)	(2.53)	(1.73)	(0.80)
[p-value]	[0.02]	[0.00]	[0.02]	[0.02]
Sargan [p-value]	[0.18]	[0.11]	[0.16]	[0.19]
n	139	139	139	139

The interest rate data in the first and the second block correspond, respectively, to 1-week Euribor and Eonia for the days of settlement of the tenders, and comprise both fixed and variable rate tenders. Within each block, the second set of results use the series corrected for expectations of interest rate changes following the procedure explained in Appendix C. Each column reports the point estimate $\hat{\gamma}$, its standard error (robust to both heteroscedasticity and autocorrelation), the p-value of the one-sided test of the null hypothesis $\gamma = 0$ (against the alternative $\gamma > 0$), the p-value of the Sargan test, and the sample size n.

[22] Note that at each point in time there are two main refinancing operations outstanding, so we have taken as instrument the sum of amounts injected in them.

between 10 and 7 basis points. In order to rationalise this difference within our model, we require a much higher value of γ.

All in all, the empirical evidence is consistent with an explanation of the overbidding by the banks in the fixed rate tenders conducted by the ECB until June 2000 based on its aversion to seeing interbank rates fall below the tender rate. The ECB then supplied less liquidity than that required to keep the average interbank rate at the level of the tender rate, and the banks had an incentive to overbid in order to capture the rents associated with the differential between these two rates.

The switch to variable rate (American) tenders in June 2000 provides an ideal setting to test some of the predictions of our theoretical model. In particular, we look at the evidence on three specific implications of our analysis of variable rate tenders: (i) the average tender rate r_a (the weighted average rate of successful bids in the tender) should be equal to the marginal tender rate r_m, (ii) the interbank rate r should be, on average, equal to the average tender rate r_a, and (iii) the degree of overbidding should be smaller than under fixed rate tenders.

The evidence on these implications for the 63 variable rate tenders conducted by the ECB from June 2000 to September 2001 is as follows. First, the mean difference between the average and the marginal tender rates, $r_a - r_m$, was only 1.7 basis points, which is strikingly small. Second, the mean spread between the interbank rate and the average tender rate, $r - r_a$, was 4 basis points for 1-week Euribor and 3 basis points for Eonia.[23] Finally, the median allotment ratio was 61.5% which is 10 times higher than the corresponding figure for the fixed rate tender period. Hence we conclude that the evidence from the switch to variable rate tenders is consistent with the predictions of our model.

5. Concluding Remarks

We have developed a model of the tender procedures used by the ECB in its open market operations. The analysis shows that when the central bank is more concerned about interbank rates below the target than about interbank rates above the target (i.e. when its loss function is asymmetric), fixed rate tenders have a unique equilibrium characterised by high overbidding. The reason for this result is simple: the central bank tries to avoid low interbank rates by restricting the supply of liquidity and this opens a differential between the expected interbank rate and the tender rate, which the banks try to exploit by increasing the size of their bid until the marginal benefit of bidding one additional euro equals the marginal expected penalty cost. In contrast, variable rate tenders allow the banks to compete away this differential by offering higher rates, so in equilibrium they will be indifferent as to the amount bid as long as it does not exceed their collateral.

Our empirical analysis, based on the tenders conducted by the ECB from January 1999 to September 2001, is consistent with the predictions of our model, and supports the hypothesis of an asymmetric loss function for the ECB. Under these circumstances, and taking into account that penalties for excessive bidding

[23] While the Euribor spread is statistically different from zero, the Eonia spread is not (with a p-value of 0.12).

have been formally ruled out since November 2000, it would be unwise for the ECB to go back to fixed rate tenders, since they would lead to highly unstable bidding.

The framework put forward in this paper is useful for addressing a number of issues in variable rate tenders like the difference in the equilibrium outcomes of Dutch and American auctions (there is none), the advantage of announcing the desired liquidity injection prior to the tender (there is an equilibrium without overbidding) and the effect of introducing a minimum bid rate that signals the monetary policy stance (there is none as long as the central bank has an effective way of signalling this stance without it). Also, the framework may be useful for analysing alternative tender procedures. For example, for the full allotment fixed rate tender (in which the central bank commits to satisfy 100% of the bids at the target rate $\hat{r}$), one can show that there is a unique symmetric equilibrium in which the representative bank bids an amount $b = (\alpha - \hat{r})/\beta$ such that the expected equilibrium interbank rate r is equal to the target rate $\hat{r}$. Although there is no overbidding, the volatility of the interbank rate increases since now the central bank passively responds to the liquidity demands of the banks without taking into account its information on the autonomous liquidity creation and absorption factors.

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References

Ayuso, J. and Repullo, R. (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*, vol. 20, pp. 857–70.

Back, K. and Zender, J. F. (1993). 'Auctions of divisible goods: on the rationale for the Treasury experiment', *Review of Financial Studies*, vol. 6, pp. 733–64.

Backus, D. and Driffill, J. (1985). 'Inflation and reputation', *American Economic Review*, vol. 75, pp. 530–8.

Bank for International Settlements (2001). 'Comparing monetary policy operating procedures across the United States, Japan and the euro area', BIS Paper No. 9.

Bank of England (2002). 'The Bank of England's operations in the sterling money markets', *Quarterly Bulletin*, Summer, pp. 153–61.

Barro, R. J. (1986). 'Reputation in a model of monetary policy with incomplete information', *Journal of Monetary Economics*, vol. 17, pp. 3–20.

Bikhchandani, S. and Huang, C. (1993). 'The economics of Treasury securities markets', *Journal of Economic Perspectives*, vol. 7, pp. 117–34.

Bindseil, U. (2001). 'Central bank forecasts of autonomous factors: quality, publication, and the control of the overnight rate', ECB Working Paper No. 70.

Bindseil, U. (2002). 'Equilibrium bidding in the Eurosystem's open market operations', ECB Working Paper No. 137.

Breitung, J. and Nautz, D. (2001). 'The empirical performance of the ECB's repo auctions: evidence from aggregated and individual bidding data', *Journal of International Money and Finance*, vol. 20, pp. 839–56.

Campbell, J. Y. (1987). 'Money announcements, the demand for bank reserves, and the behavior of the federal fund rate within the statement week', *Journal of Money, Credit, and Banking*, vol. 19, pp. 56–67.

Catalão Lopes, M. (2000). 'Financing in the Eurosystem: fixed versus variable rate tenders', mimeo.

Ehrhart, K.-M. (2001). 'European Central Bank operations: experimental investigation of the fixed rate tender', *Journal of International Money and Finance*, vol. 20, pp. 871–93.

European Central Bank (1998). *The Single Monetary Policy in Stage Three. General Documentation on ESCB Monetary Policy Instruments and Procedures*. Frankfurt am Main.

European Central Bank (2000*a*). *Annual Report 1999*, Frankfurt am Main.

European Central Bank (2000*b*). *The Single Monetary Policy in Stage Three. General Documentation on Eurosystem Monetary Policy Instruments and Procedures*. Frankfurt am Main.

Favero, C. *et al.* (2000). *One Money, Many Countries. Monitoring the European Central Bank 2.* London: Centre for Economic Policy Research.

Hamilton, J. D. (1996). 'The daily market for federal funds', *Journal of Political Economy*, vol. 104, pp. 25–56.

International Monetary Fund (1999). *International Capital Markets. Developments, Prospects, and Key Policy Issues*. Washington DC.

Nautz, D. and Oechssler, J. (1999). 'The repo auctions of the European Central Bank and the vanishing quota puzzle', Discussion Paper No. 79, Humboldt-Universität Berlin.

Nyborg, K. G. and Strebulaev, I. A. (2001). 'Collateral and short squeezes of liquidity in fixed rate tenders', *Journal of International Money and Finance*, vol. 20, pp. 769–92.

Nyborg, K. G., Bindseil, U. and Strebulaev, I. A. (2002). 'Bidding and performance in repo auctions: evidence form ECB open market operations', ECB Working Paper No. 157.

Pérez-Quirós, G. and Rodríguez-Mendizábal, H. (2000). 'The daily market for funds in Europe: has something changed with EMU?', ECB Working Paper No. 67.

Välimäki, T. (2001). 'Fixed rate tenders and the overnight money market equilibrium', Bank of Finland Discussion Paper No. 8/2001.

Välimäki, T. (2002). 'Bidding in fixed rate tenders: theory and experience with the ECB tenders'. Bank of Finland Discussion Paper No. 1/2002.