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EMPIRICAL TESTING USING PANEL DATA[1]

Nuno Cassola[2]

In 2008 all ECB publications feature a motif taken from the €10 banknote.

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Abstract: The theory of liquidity management under uncertainty predicts that, under certain conditions, commercial banks will accumulate minimum reserve requirements linearly over the reserve maintenance period. This prediction is empirically tested using daily data (from March 2004 until February 2007) on the current accounts and minimum reserve requirements of a panel of 79 commercial banks from the euro area. The linear accumulation hypothesis is not rejected by the data with the exception of small banks which build-up excess reserves. The empirical analysis suggest that idiosyncratic liquidity uncertainty is much higher than aggregate liquidity uncertainty. Nevertheless, on the penultimate day in the reserve maintenance period, the inverse demand schedule of the representative bank is relatively flat around the middle of the interest rate corridor set by the standing facilities. This suggests that liquidity effects on the overnight inter-bank rate should be very muted on this day. Our calibration exercise suggests that the probability of an individual bank's daily overdraft in the euro area is very low (less than 1.0%). This is confirmed by the analysis of the daily recourses to the marginal lending facility by the panel banks.

JEL classification: C23; E4; E5; G2.

Keywords: Monetary policy implementation; Reserve requirements; Rate corridor; Liquidity management; Panel data.

Executive Summary

We consider an environment where monetary policy is implemented by steering an overnight interest rate within a corridor and banks have to comply with minimum reserve requirements on average over a maintenance period. The theory of liquidity management under uncertainty predicts that under the joint hypothesis of symmetry of the interest rate corridor set by the standing facilities around the target rate, and unbiased supply of liquidity by the central bank, commercial banks will accumulate minimum reserve requirements linearly over the reserve maintenance period. This prediction is empirically tested using daily data (from March 2004 until February 2007) on the current accounts and minimum reserve requirements of a panel of 79 commercial banks from the euro area. The linear accumulation hypothesis is not rejected by the data with the exception of small banks which build-up excess reserves. In addition, we calculate for the representative commercial bank in the euro area two liquidity uncertainty ratios: first, the ratio of idiosyncratic liquidity uncertainty over the individual minimum reserve requirement, and second, the ratio of idiosyncratic liquidity uncertainty over the aggregate liquidity uncertainty. Using these ratios we calibrate the theoretical model and make predictions about the frequency of recourses to the marginal lending facility by commercial banks. The latter are cross-checked against direct data on daily recourses to the marginal lending facility by the banks in the panel. Both exercises suggest that the probability of an individual bank's daily overdraft in the euro area is very low throughout the reserve maintenance period (about 0.5%). The empirical analysis suggests that idiosyncratic liquidity uncertainty is much higher than aggregate liquidity uncertainty. On the penultimate day in the reserve maintenance period, the inverse demand schedule of the representative bank is relatively flat around the middle of the interest rate corridor set by the standing facilities. This suggests that liquidity effects on the overnight inter-bank rate should be very muted on this day. Thus, the martingale hypothesis should be verified as a good approximation.

1. Introduction

Since the start of European Monetary Union, in January 1999, the European Central Bank (ECB) has been providing its weekly refinancing to the euro area banking system based on the concept of benchmark allotment.[1] The benchmark allotment is defined by the ECB as the allotment amount which allows counterparties to smoothly fulfil their reserve requirements until the day before the settlement of the next main refinancing operation (MRO), when taking into account the aggregate liquidity need of the banking system.[2] In practice, this means that the ECB has been following very closely a *linear liquidity supply* policy, which has the benefit of transparency and simplicity. One open question is whether this policy matches the intertemporal preferences of commercial banks in the euro area.[3] In fact, unless commercial banks prefer to accumulate reserve requirements linearly over time, there might be a mismatch between the demand and the supply of liquidity putting pressure on, and increasing the volatility of the overnight interest rate.

In order to shed some light into this question, we survey what the liquidity management theory predicts about the optimal reserve fulfilment path of a commercial bank and empirically test its main implication using panel data. To our best knowledge this is the first paper to tackle this issue empirically. The theoretical background is based on William Poole's model of commercial banks reserve management under uncertainty (Poole, 1968). In fact, the theory predicts linear accumulation of minimum reserve require-

[1] For information on the operational framework for monetary policy implementation of the Eurosystem see ECB (2006) downloadable from www.ecb.int.

[2] The aggregate liquidity need is calculated as the sum of: i) accumulated deviation from a smooth reserve fulfilment path that occurred previously in the same reserve maintenance period, either as a result of liquidity forecast errors, recourse to standing facilities or allotment amounts being different from the benchmark; ii) ECB's forecast of the autonomous factors; iii) ECB's forecast of excess reserves, which are assumed to be the same on each day of the reserve maintenance period; iv) the reserve requirement. The same concept has been used to calibrate the fine-tuning operations at the end of the maintenance periods (see ECB, 2002).

[3] As of 31 May 2007, 6150 credit institutions were subject to minimum reserve requirements in the euro area. On 14 May 2007, reserve requirements amounted to EUR 182.2 billion.

ments under the joint hypothesis of *symmetry of the interest rate corridor* set by the standing facilities of, and *unbiased supply of liquidity* by the ECB.[4]

This prediction of the model is tested using a panel of daily data (from March 2004 until February 2007) on the current accounts of 79 selected commercial banks from the euro area. The data was collected by National Central Banks (NCB) of the Eurosystem in the context of a Monetary Operations Committee (MOC) reporting exercise, which reviews the behaviour of Eurosystem's counterparties. This data set has high quality allowing us to test the linear reserve fulfilment path hypothesis, which is equivalent to testing the liquidity management model over a dimension so far not explored in the literature.

In addition, we calculate for the representative commercial bank in the euro area two *liquidity uncertainty ratios:* one is the ratio of idiosyncratic liquidity uncertainty over the individual minimum reserve requirement, and the other is the ratio of idiosyncratic liquidity uncertainty over the aggregate liquidity uncertainty. Using these ratios to calibrate the theoretical model predictions about the frequency of recourses to the marginal lending facility by commercial banks can be made. The latter are cross-checked against actual, direct data on daily recourses to the marginal lending facility made by the banks in the panel. Both exercises suggest that the probability of an individual bank's daily overdraft in the euro area is very low throughout the reserve maintenance period (less than 1.0%).

The remainder of the paper is organised as follows. Section 2 surveys the theory and its main empirical predictions. Section 3 explains the econometric methodology and Section 4 presents the data and the empirical results. The calibration of the model is presented and discussed in Section 5. Section 6 concludes.

2. Theoretical background

The daily problem faced by the liquidity manager of a commercial bank,

[4]This prediction is transparent when the dynamic version of William Poole's model is explicitly solved for a two-day maintenance period (see Välimäki (2003) and Whitesell (2006)) rather than simulated as in Gaspar, V. et. al. (2007) and Quirós and Mendizábal (2006).

taking into account the main features of the Eurosystem's operational framework for monetary policy implementation, has been formalized by Välimäki (2003), Quirós and Mendizábal (2006) and Gaspar et. al. (2007), using a dynamic version of the Poole (1968) model. Here we provide an outline of the model following the presentation in Whitesell (2006) in order to explicitly derive the testable implication of the theory (for a similar approach see also Välimäki, 2003). The standard and well-known implication of the model is that in an operational framework for monetary policy implementation based on an interest rate corridor with reserve requirements, higher volatility of the overnight interest rate should be observed towards the end of the reserve maintenance period. In this paper, instead, we focus on the conditions under which a linear reserve fulfilment path is optimal from the point of view of an individual commercial bank.

The commercial bank's liquidity manager has to monitor the bank's daily account at the central bank (a_t) complying with a no-overdraft constraint ($a_t \geq 0$). Borrowing in the interbank market is motivated with the view of offsetting end-of-day idiosyncratic liquidity shocks (after the interbank market is closed), and the need to fulfil a reserve requirement ($2R$) on average over a maintenance period of 2 days ($t = T-1, T$). The central bank provides the aggregate liquidity need which is R each day. The individual bank seeks to minimize the cost of funds. Two sources of funds are available: overnight interbank borrowing at rate i_t and central bank funding (marginal lending at rate $i^l = i^* + s$). Banks can accumulate reserves on a daily basis. However, given a no-overdraft constraint banks cannot de-cumulate reserves. If cumulated current accounts exceed the reserve requirement the bank fulfils its reserve requirement ahead of the end of the maintenance period and is said to be "locked-in". If the account at the central bank exceeds what is needed for the fulfilment of the reserve requirement (excess reserves) the surplus will be remunerated at the deposit facility rate ($i^d = i^* - s$). The central bank sets the interest rates on its standing facilities symmetrically ($\pm s$) around its target rate (i^*).

In the main text technical details are kept to a minimum. For further information on the formalization of the cost minimization problem, and proofs of the propositions the reader is referred to the Annex.

Last day of the reserve maintenance period

The model must be solved in a recursive way starting from the last day of the maintenance period (day T). The bank chooses its target account balance at the central bank (a_T) with the following information set: $I_T = \{i^*$, s, i_T, the distribution of the account balance shock, $G(\varepsilon)$, and $E(\varepsilon) = 0\}$. The first order condition for optimality is:

$$G(d_T - a_T^*) = \frac{i_T - i^d}{i^l - i^d} \tag{1}$$

or,

$$a_T^* = d_T - G^{-1}\left(\frac{i_T - i^d}{i^l - i^d}\right). \tag{2}$$

Equation (2) formalises the intuitive result that an individual bank's borrowing in the interbank market is declining in the level of the market interest rate (i_T), and increasing with the level of its reserve deficiency (d_T). Note that $a_T^* = b_T^* + a_{T-1}$, where b_T^* is optimal inter-bank borrowing by the bank.

Proposition I. *If the overnight interest rate is expected to be in the middle of the corridor set by the rates of the standing facilities; and if the distribution of the liquidity shock is symmetric,* ***the commercial bank will not target excess reserves****.*

$$a_T^* = d_T \tag{3}$$

The bank will borrow/target on the last day of the maintenance period exactly what it needs to satisfy the remaining part of the reserve requirement.

For further reference note that the first order condition can be re-written as follows:

$$i_T = i^l.G(d_T - a_T^*) + i^d.\left[1 - G(d_T - a_T^*)\right] \tag{4}$$

Penultimate day of the reserve maintenance period

On the penultimate day of the reserve maintenance period $(T-1)$, the commercial bank chooses its target account balance at the central bank (a_{T-1}) with the following information set: $I_{T-1} = \{i^*,\ s,\ i_{T-1}$, the distribution of the account balance shocks on the penultimate and last days, $F(\xi)$, and $G(\varepsilon)$, respectively, with $E(\xi) = E(\varepsilon) = 0\}$. The bank does not have information on i_T and d_T. With a daily average requirement of R and end-of-day account balance on the penultimate day, $a_{T-1} + \xi$, the value of d_T is:

$$d_T = \begin{cases} 2R & \textit{for } a_{T-1} + \xi \leq 0 \\ 2R - a_{T-1} - \xi & \textit{for } 0 < a_{T-1} + \xi < 2R \\ 0 & \textit{for } a_{T-1} + \xi \geq 2R \end{cases} \tag{5}$$

In this case the optimal behaviour of the bank is slightly more complicated. The first order condition is:

$$\begin{aligned} i_{T-1} = i^l.F(-a^*_{T-1}) + i^d.\left[1 - F(2R - a^*_{T-1})\right] + \\ + \left[F(2R - a^*_{T-1}) - F(-a^*_{T-1})\right].E_{T-1}(i_T) \end{aligned} \tag{6}$$

where, $E_{T-1}(i_T)$ denotes the expectation of the overnight rate level for day T with information available on the penultimate day in the maintenance period. Compared to equation (4) there are two new terms in equation (6), the first and the third. Apart from the (potential) difference between the distribution of shocks in the two days, the difference between the first term in equation (6) and the first term in equation (4) is the exclusion of the reserve deficiency from the argument in the probability of taking recourse to marginal lending; this is due to the fact that on the penultimate day of the maintenance period the reserve requirement is not yet a binding constraint as fulfilment can be delayed by one day. The last term is the most important as it links the level of the market rate at $T-1$ to its expected level on the last day of the maintenance period (T).

Proposition II. *Suppose the interest rate is in the middle of the corridor on day $T-1$, and is expected to remain there on day T; if the distribution of the liquidity shocks,* $G(\varepsilon)$ and $F(\xi)$, *are symmetric,* ***the commercial bank***

will target the daily reserve requirement.

$$a^*_{T-1} = R. \tag{7}$$

Corollary. *The bank targets the average daily reserve requirement as reserve deficiency for the last day.*

$$d^*_T = R. \tag{8}$$

Equation (7), equation (8) and equation (3) lead to the prediction that the representative bank will optimally *target a linear path for the fulfilment of the reserve requirement.*

If the probability of an individual bank taking recourse to either standing facility on the penultimate day is low, equation (6) implies:

$$i_{T-1} \approx E_{T-1}(i_T). \tag{9}$$

Under these conditions, the overnight interest rate on the penultimate day of the reserve maintenance period will be approximately equal to the level expected for the last day, which is the martingale hypothesis.

In theory, and from the point of view of the individual bank, the martingale hypothesis hinges on whether, in equation (6), the term $[F(2R - a^*_{T-1}) - F(-a^*_{T-1})]$, is close to 1. This should be the case when the probability of a daily overdraft and the probability of a bank locking-in are both very low.

Aggregate demand and liquidity uncertainty ratios

Consider normally and independently distributed individual liquidity shocks. Aggregate demand can be obtained by summimg up equation (2) over (N) banks:

$$D = \sum_{j=1}^{N} b^*_{j,T} = N.\sigma_\varepsilon.\Phi^{-1}\left(\frac{i_T - i^d}{i^l - i^d}\right), \tag{10}$$

where $\Phi(.)$ is the standardized normal distribution and σ_ε is the standard error of the liquidity shock. Market clearing is obtained by setting aggregate demand equal to central bank supply of liquidity ($\overline{S}$):

$$\overline{S} = N.\sigma_\varepsilon.\Phi^{-1}\left(\frac{i_T - i^d}{i^l - i^d}\right), \tag{11}$$

which implies the following market clearing interest rate:

$$i_T = i^l.\Phi\left(\frac{\overline{S}/N}{\sigma_\varepsilon}\right) + i^d.\left[1 - \Phi\left(\frac{\overline{S}/N}{\sigma_\varepsilon}\right)\right]. \tag{12}$$

The interpretation of equation (12) is that the overnight interest rate on the last day of the maintenance period is equal to the probability weighted cost of using the standing facilities. If the central bank supplies the daily liquidity requirement without error, $\overline{S} = N.R$, the overnight interest rate will be on target on the last day of the maintenance period, $i_T = i^*$. In general, the central bank cannot supply liquidity with full certainty and an *aggregate liquidity shock* (error) will be observed ($\overline{S} + u_T$, $u_T \neq 0$; $E(u_T) = 0$). Thus, the volatility of the overnight interest rate will depend not only on the ratio of the standard deviation of the idiosyncratic shock over the reserve requirement (σ_ε/R) but also on its ratio over the standard deviation of the central bank liquidity supply error ($\sigma_\varepsilon/\sigma_u$). We denote these ratios as liquidity uncertainty ratios.

3. Econometric methodology

The theoretical model makes several empirical predictions two of which have been tested by Gaspar et al. (2007) and Quirós and Mendizábal (2006): firstly, that the volatility of the overnight interest rate increases towards the end of the maintenance period; and secondly, that individual recourses to standing facilities increase as the end of the maintenance period approaches. In fact, euro area data closely matches these predictions. Regarding the martingale hypothesis the evidence is mixed: whereas in Quirós and Mendizábal (2006) simulations suggest that a slight upward trend in the overnight rate within the maintenance period should be expected, more recently Gaspar et al. (2007) show that the martingale hypothesis is not rejected by euro area data after the implementation, in March 2004, of the reform of the Eurosystem's operational framework.[5]

Testing whether the panel is representative of the euro area commercial banks

With data on the daily current accounts of individual banks we can test for the linearity of the reserve fulfilment path at the individual bank level. The theoretical framework suggests a strategy for econometric modelling. Consider the last two days in the reserve maintenance period ($T-1$, T). The following relation is implied by the theory:

$$\frac{a_T}{R} = 1 - \left(\frac{a_{T-1}}{R} - 1\right) + \frac{\varepsilon_T}{R} \tag{13}$$

where $(\frac{a_{T-1}}{R} - 1) = \frac{\xi_{T-1}}{R}$ is the (scaled) deviation from target on the previous day. Thus, the theoretical framework suggests modelling the ratio of a bank's current account over its daily reserve requirement as a first order autorregressive process. In a regression, $a_T/R = \alpha^* + \beta^*.(a_{T-1}/R) + \varepsilon_T^*$, one should test the null hypothesis, $\widehat{\alpha}^* + \widehat{\beta}^* = 1$.

In practice, some adjustment costs might prevent the bank from fully correcting deviations of current accounts from target on a daily basis. Therefore, the first panel regression considered is a dynamic relation:

$$\left(\frac{a_{j,t}}{R_{j,t}}\right) = \alpha + \beta.\left(\frac{a_{j,t-1}}{R_{j,t-1}}\right) + \eta_{j,t}, \text{ with } j = 1, ..., N \text{ and } t = 1, ..., T, \tag{14}$$

or, most conveniently written in error correction form:

$$\Delta\left(\frac{a_{j,t}}{R_{j,t}}\right) = -(1-\beta).\left(\frac{a_{j,t-1}}{R_{j,t-1}} - \frac{\alpha}{1-\beta}\right) + \eta_{j,t}, \tag{15}$$

where: j is an index for the individual bank where N is the number of banks in the panel; t is an index for time and T is the number of time series observations in the sample; Δ is the first difference operator; $a_{j,t}$ is the current account of bank j held at the central bank at time t (end-of-day; after market trading); $R_{j,t}$ is the daily average reserve requirement of bank

[5] On the reform of the operational framework of the Eurosystem see ECB (2003) and ECB (2005).

j at time t; it is constant within each reserve maintenance period for each bank and time varying across maintenance periods and banks; $\alpha/(1-\beta)$ is the target daily current account at the central bank and $(1-\beta)$ is the adjustment coefficient.

Equation (15) states that if the current account is above the target the treasurer of the bank will let the bank's account at the central bank run down in proportion to the imbalance, measured by the second term in brackets on the r.h.s. of equation (15).

The error term, $\eta_{j,t} = \eta_j + \vartheta_{j,t}$, contains a *fixed effect* component (η_j) and a *stochastic component* ($\vartheta_{j,t}$). The fixed component groups banks by size (large, medium and small) the idea being that the size of bank may affect the ability and/or the resources invested in the management of liquidity. In this context the main hypothesis to be tested, are as follows:

$H1$ - The daily current account target of the banks in the panel is the average daily reserve requirement; panel banks do not build up excess reserves at the end of the maintenance period: $\frac{\alpha}{1-\beta} = 1$, or, equivalently, $\alpha + \beta = 1$.

$H2$ - Banks in the panel attempt to restore their target within every week (according to the regular refinancing by the ECB). With daily data this implies $0.14 \leq 1 - \beta \leq 1$.

A smaller adjustment coefficient can be interpreted as greater willingness to deviate from the linear path possibly (though not exclusively) for interest rate arbitrage motive or due to adjustment costs.

The caveat of the hypothesis testing described above and, indeed, of panel regressions like (14) and (15) is that they may not reveal anything about individual bank's behaviour. Indeed, it can be argued that if the panel is representative one should expect $H1$ and $H2$ not to be rejected, not because of a specific/optimal liquidity management style by commercial banks, but simply because that is what the liquidity supply policy of the ECB implies on average, over time, if a large cross section of banks is observed. In this vein one may wish to interpret regressions (14) and (15) as *pre-testing* whether the selected panel is representative.

Be that as it may, it should be emphasized that the total reserve requirement of the banks included in our sample represented, on 1 January

2007, 42% of the total minimum reserve requirements in the euro area; thus, the aggregate constraint implied by the linear liquidity supply of the ECB does not constrain the banks in the panel to fulfil their reserve requirement linearly over time.

Testing the individual linear fulfilment path hypothesis

A direct test on a bank's behaviour can be done by running the following static panel regressions

$$\left(\frac{d_{j,t}}{R_{j,t}}\right) = \delta + \nu_{j,t}, \text{ with } j = 1, ..., N \text{ and } t = T - 1 \text{ or } t = T, \tag{16}$$

where: j is an index for the individual bank (N banks in the panel); t is an index for time; it is either the penultimate day in the maintenance period, $T - 1$, or the last, T ; $d_{j,t}$ is the reserve deficiency of bank j on day t (beginning-of-day; before market trading); $R_{j,t}$ is the daily average reserve requirement of bank j at time t. The error term, $\nu_{j,t} = \nu_j + \upsilon_{j,t}$, contains a fixed effect component (ν_j) and a stochastic component ($\upsilon_{j,t}$). The fixed component groups banks by size (large, medium and small).

In this context the main hypotheses to be tested, are as follows:

$H3$ - On the penultimate day in the maintenance period, banks target twice the daily average minimum reserve requirement for their reserve deficiency: $\delta = 2$, in equation (16) when $t = T - 1$.

$H4$ - On the last day in the maintenance period, banks target the daily average minimum reserve requirement for their reserve deficiency: $\delta = 1$, in equation (16) when $t = T$.

Note that $H1$ and $H3 - H4$ are closely related. However, $H3 - H4$ constitute a direct and stringent test on the individual linear accumulation of reserves. In fact, the supply policy of the ECB implies neither $H3$ nor $H4$, as on the last two days of the reserve maintenance period banks are free to either *frontload* their reserve fulfilment path ($\delta < 1$ for last day and/or $\delta < 2$ for penultimate day); or *backload* it ($\delta > 1$ for last day and/or $\delta > 2$ for penultimate day).

More generally, the linear accumulation of reserves, in the absence of liquidity shocks, implies that the ratio of reserve deficiency over the daily reserve requirement on any day to be equal to the distance until the end of the maintenance period plus one:

$$d_{j,t}/R_{j,t} = (T - t) + 1. \tag{17}$$

Calculating the liquidity uncertainty ratios

Panel data allows us to extract information about the uncertainty facing individual institutions and estimate the ratio of aggregate versus idiosyncratic uncertainty. If the hypothesis $H1$ and $H2$ are not rejected by the data, the panel can be considered representative and the regression residuals contain useful information: (i) about the idiosyncratic uncertainty in relation to the individual bank's daily reserve requirement; and (ii) about the ratio of aggregate uncertainty over idiosyncratic uncertainty. The *liquidity uncertainty ratios* are key ingredients, necessary to realistically calibrate any theoretical model of the inter-bank market. In the following we set out a method for calculating these ratios.

The stochastic component in the error term of equation (14) has two components, $\vartheta_{j,t} = \vartheta^c_{j,t} + \vartheta^j_{j,t}$. The first component is an aggregate shock, $\vartheta^c_{j,t}$, resulting from errors in the supply of (aggregate) liquidity by the central bank. The other component is an idiosyncratic shock, $\vartheta^j_{j,t}$, which stems from uncertainty about inter bank flows of funds.

To identify the components we make two additional assumptions. The first assumption is that the average of the aggregate shock across banks, at each point in time, is different from zero:

$$\frac{1}{N}\sum_{j=1}^{N}\vartheta^c_{j,t} \neq 0. \tag{18}$$

However, over time, it should be equal to zero if the ECB has an unbiased supply of liquidity:

$$\frac{1}{N.T}\sum_{t=1}^{T}\sum_{j=1}^{N}\vartheta^c_{j,t} = 0. \tag{19}$$

The second assumption is that the average of idiosyncratic shocks across banks, at each point in time, is zero (by the law of large numbers):

$$\frac{1}{N}\sum_{j=1}^{N}\vartheta_{j,t}^{j} = 0. \tag{20}$$

Both error processes are assumed to be normally distributed. The aggregate shock is assumed to be orthogonal to the idiosyncratic shocks and uncorrelated over time. The idiosyncratic components are also assumed to be orthogonal and uncorrelated over time. Similar assumptions are also taken for the residuals $\upsilon_{j,t}$.

To compute σ_{ϑ^j} (standard deviation of the idiosyncratic liquidity shock) we procede in three steps: first, we generate series of idiosincratic liquidity shocks for each bank (j) and each day (t), $\vartheta_{j,t}^{j} = \vartheta_{j,t} - (1/N)\sum_{j=1}^{N}\vartheta_{j,t}^{c}$; second, we compute the standard deviations of the idiosyncratic shocks for each bank $(\sigma_{\vartheta^j}^{j})$, and third, we calculate the average of $(\sigma_{\vartheta^j}^{j})$ across banks. To compute σ_{ϑ^c} (standard deviation of the aggregate liquidity shock) we generate the series of aggregate liquidity shock for each day (t), $\vartheta_t^c = (1/N)\sum\limits_{j=1}^{N}\vartheta_{j,t}$ and compute the sample standard deviation.

4. Data and empirical results

The data set used in this study was collected by NCB in the context of the preparation a Market Operations Committee (MOC) reporting exercise, which regularly reviews the behaviour of Eurosystem's counterparties. The choice of the institutions was at the discretion of NCB under the general guidance that it should cover a sample of representative euro area commercial banks (large, medium and small; EONIA panel banks and non EONIA panel banks; eligible for fine-tuning operations (FTO) and not eligible for FTO). The original data set includes 85 commercial banks and covers the period from January 2003 until 28 February 2007. It comprises daily information about individual bank's current accounts recourses to standing facilities, excess reserves and reserve requirements. On 1 January 2007 the total reserve requirement of the panel banks represented 42% of the total euro area reserve requirements.

In order to work with a balanced panel and given the changes to the operation framework for the implementation of monetary policy of the Eurosystem, implemented in March 2004, the study covers only 79 banks and the period from 10 March 2004 until 16 January 2007. Of the 6 banks excluded 3 are from Slovenia which joined the euro area only in January 2007, and therefore could not be included in the econometric study. The panel has a cross section dimension $N = 79$ much smaller than the time series dimension $T = 1043$ with a total of $N\text{x}T = 82,397$ observations for the estimation of equation (14). However, given that the sample includes only 34 reserve maintenance periods, the time series dimension is shorter than the cross sectional dimension for the estimation of equations (16) ($N\text{x}T = 2686$).

Over the period from 10 March 2004 until 16 January 2007 the panel euro area banks complied with a minimum reserve requirement of about EUR 770 million (daily average reserve requirement per bank). The average reserve requirement increased smoothly over time from EUR 668 million to just over EUR 900 million. The population of banks in the sample is very heterogeneous from the perspective of the size of their minimum reserve requirement (see Figure 1): 5 banks had daily average minimum reserve requirement, on average, below EUR 5.5 million; 18 banks had daily average minimum reserve requirement, on average, between EUR 5.5 million and EUR 60 million; 26 banks between 60 million and 700 million; and 30 banks between 700 million and 5 billion. The classification of banks into large, medium, and small was at the discretion of the NCB; the resulting classification turned out as follows: large banks are considered those with a daily average reserve requirement above EUR 200 million (average in the sample); and small banks are considered those with a daily average reserve requirement below EUR 20 million (average in the sample); medium banks are in between (see Figure 1).

In the econometric testing, besides using the full sample, three sub-samples are considered broadly coinciding with the three years covered by the sample: the first sub-sample runs from 10 March 2004 until 18 January 2005; the second sub-sample from 19 January 2005 until 17 January 2006, and the third sub-sample from 18 January 2006 until 16 January 2007. The three sub-samples roughly coincide with the timing of *three different liquidity management policies* by the ECB during the sample period: the first sub-sample covers the period when the ECB did not systematically fine-tune on the last day of the reserve maintenance period; the second sub-sample covers the period when the ECB did so with higher frequency; and the third sub-sample includes the period when the ECB targeted a liquidity draining operation at the end of the reserve maintenance period. Moreover, in the three sub-samples, the ECB supplied liquidity either following the benchmark rule (first sub-sample) or provided slightly above benchmark at all but the last MRO (second sub-sample); or provided slightly above benchmark at all MRO (third sub-sample). In the latter case, the FTO on the last day of the reserve maintenance period aimed at zero net recourse to standing facilities. Splitting the econometric testing of hypothesis in three sub-samples allows checking whether evidence of structural change is emerging linked to the potential commercial bank's reaction to the slightly different liquidity management policies followed by the ECB.

Is the panel representative?

An overall perspective of the econometric results can be gauged by looking at the cross-plot of the day in the maintenance period against the average, over banks, of the individual cumulated ratio of current account over the reserve requirement, up to that day. In fact, linear fulfilment path by bank j implies:

$$\sum_{s=1}^{t} \frac{a_{j,s}}{R_{j,s}} = t, \quad \text{for } j = 1, ..., N. \tag{21}$$

Figure 2 shows for each day in the reserve maintenance period the cross sectional average of the cumulated ratio of current account over minimum reserve requirement in each day of the reserve maintenance period (equation (21)). Figure 3 shows the same variable calculated on the last day of each reserve maintenance period. All data points are very close to the 45° line. Figure 4 shows the daily cross section average of the ratio of the current account over minimum reserve requirement. This variable moves around one.

Statistical testing is reported in Table 1 (full sample) and Table 2 (sub-samples). The dynamic panel was estimated using the Anderson and Hsiao (1981) estimator as, given the large time dimension of the panel, the Arellano and Bond (1991) GMM estimator is not feasible. The results are striking. For the full sample, $\widehat{\alpha} + \widehat{\beta} = 1$, and there does not seem to be any major difference between large euro area banks (reference group) and medium or small banks. The adjustment coefficient is large, $1 - \widehat{\beta} \approx 0.7$, suggesting a quick return to target current accounts (70% of deviation corrected within one day). For the sub-samples, $\widehat{\alpha} + \widehat{\beta} = 1$, but small banks seem to have a somewhat higher target ratio than the other groups suggesting excess reserves build-up by this group. The adjustment coefficient is still large, $1 - \widehat{\beta} \approx 0.7$, but it seems to have declined slightly after the ECB enacted the policy of more frequent fine-tuning at the end of the reserve maintenance period (2005-2007). The decline in the speed of adjustment to target current accounts could have been the result of the fine-tuning (or liquidity) policy as it might have directly encouraged liquidity smoothing by commercial banks or indirectly by reducing the average size of the liquidity imbalances. Therefore, the econometric and graphical evidence strongly supports the view that the panel is representative of euro area commercial banks and that banks accumulate reserves linearly over time.

Do banks follow a linear fulfilment path?

Figure 5 shows the cross sectional average (and the one-standard deviation band) of the ratio of the reserve deficiency over the minimum reserve requirement on the penultimate day of each reserve maintenance period. Figure 6 shows the same variable calculated on the last day of each reserve maintenance period. Data points are close to 2 and 1 respectively therefore suggesting that the panel banks fulfil their reserve requirement linearly over time. Nevertheless, the linear reserve accumulation path seems to have been followed more closely by banks after the ECB started the policy of frequent fine-tuning (2005-2007).

Statistical testing is reported in Table 3 (full sample) and Table 4 (sub-samples), for the last day in the maintenance period, and in Table 5 (full sample) and Table 6 (sub-samples) for the penultimate day. The static panels were estimated using the Least Squares Dummy Variable (LSDV) method. The results are striking. Large euro area banks target the daily average reserve requirement as deficiency for the last day of the maintenance period a result that strongly supports the linear fulfilment path prediction. The behaviour of medium size banks is not statistically different from the behaviour of large banks. However, small banks seem to frontload the reserve fulfilment path as they enter the last day of the maintenance period with a reserve deficiency of just over 10% of the daily minimum reserve requirement ($d_T^{small} = 0.11.R$). This is consistent with small banks building-up excess reserves. These results are confirmed for each of the sub-samples considered. However, the small banks included in the sample reveal some convergence towards the behaviour of the other groups as the specific effect attached to this group against the reference group (large banks) increased from -2.58 to -0.83 (thus being closer to ratio 1).

Large euro area banks target twice the daily average reserve requirement as deficiency for the penultimate day of the maintenance period a result that again strongly supports the linear fulfilment path prediction. Also in this case the behaviour of medium size banks is not statistically different from the behaviour of large banks. Small banks frontload the reserve fulfilment path as they enter the penultimate day of the maintenance period with a reserve deficiency of about 50% of the daily minimum reserve requirement ($d_T^{small} = 0.50.R$). This is again consistent with small banks building-up excess reserves. These results are confirmed for each of the sub-samples considered with the small banks included in the sample revealing some convergence towards the behaviour of the other groups as the specific effect attached to this group against the reference group (large banks) increased from -2.55 to -0.86 (closer to ratio 2).

All in all, most euro area commercial banks included in the panel seem to fulfil their reserve requirements in a linear way therefore neither back- nor frontloading the fulfilment path. This is indeed the optimal behaviour when the ECB is expected to supply liquidity without any bias and the interest rate corridor is perceived as symmetric. Nevertheless, some heterogeneity is noted with small banks in the sample revealing frontloading behaviour and/or the building up of excess reserves, consistent with the idea of less investment by these institutions in liquidity management technology or resources. This may well be the optimal choice when the requirement to be fulfilled is small, given the high costs of monitoring end-of-day current accounts at NCB and of non-compliance (see Bindseil et al. (2006)).

How important is the idiosyncratic liquidity shock?

The ratio of idiosyncratic over aggregate uncertainty ($\sigma_{\vartheta^j}/\sigma_{\vartheta^c}$) calculated as explained in Section 3, is about 6, suggesting that commercial banks in the euro area face idiosyncratic liquidity uncertainty several times higher than aggregate liquidity uncertainty. The standard deviations of the shocks are $\sigma_{\vartheta^c} = 0.1$, and $\sigma_{\vartheta^j} = 0.6$. These values are used as a basis for calibrating the theoretical model.

However, to calibrate the individual demand schedules, we can use additional information on the *daily recourses to marginal lending by the panel banks.* In the full sample, the probability that a bank takes recourse to marginal lending, on any day in the maintenance period is 0.5% (429 recourses in a total of 82,397 observations). Most of the recourses occur on the last day of the reserve maintenance period; but there is some heterogeneity, among the three groups of banks, on the frequency of daily recourses to marginal lending. In fact, the probability that a *large size bank* takes recourse to marginal lending *on the last day* of the maintenance period is small (0.20%); the probability that a large size bank takes recourse to marginal lending on the other days is even smaller (0.05%). The probability that a *medium size bank* takes recourse to marginal lending *on the last day* of the maintenance period is negligible (0.03%); and the probability that a medium size bank takes recourse to marginal lending on the other days is somewhat higher (0.22%). *Small size banks* in the panel never took recourse to marginal lending, which is coherent with this group building up excess reserves.[6]

Thus, in drawing the inverse demand schedules we used, $\sigma_{\vartheta j} = 0.43$, instead of $\sigma_{\vartheta j} = 0.60$, which is the standard deviation of the idiosyncratic shock that generates a 1% probability of individual recourse to marginal lending on the penultimate day of the maintenance period, when the commercial bank has a reserve requirement of EUR 1 billion and targets this value for its daily current account. With these values we obtain a ratio, $\sigma_{\vartheta j}/R < 0.5$, implying that the martingale hypothesis is likely to be verified in the simulation.

The standard deviation of the idiosyncratic shock obtained with information from individual marginal lending is lower than the standard deviation that is implied by the calculation of the liquidity uncertainty ratios. However, in the simulation exercise the difference is minor, as both standard deviations imply flat inverse demand curves on the penultimate day of the reserve maintenance period.

5. Calibration

Figure 7 shows the inverse demand schedules on the last two-days of the reserve maintenance period for the representative (large) commercial bank in the euro area assuming an individual daily reserve requirement of EUR 1 billion. The curves show optimal borrowing for a given level of the

[6] The probabilities were estimated using a panel Logit model. Detailed results are available from the author upon request.

overnight interest rate during the last two-days in the reserve maintenance period, assuming that the rate expected to prevail on the last day is exactly at the middle of the interest rate corridor (3% in Figure 7).

Two features of the (inverse) demand schedules are worth noting. Firstly, on the penultimate day of the maintenance period the inverse demand schedule is relatively flat - highly elastic - around the interest rate level expected to prevail on the last day. Secondly, on the last day, the inverse demand curve is much steeper.

For the simulation exercise we considered an interbank overnight market composed of 150 homogeneous banks each having a reserve requirement of EUR 1 billion. The probability of a daily overdraft with an aggregate reserve requirement of EUR 150 billion is about 1%. We can assume that this probability remains constant over the whole maintenance period. The probability of locking-in should be zero at the beginning of the maintenance period, staying low most of the time and increasing quickly as the last day of the maintenance period approaches. Taking equation (6) as a rough guide for the determination of the overnight interest rate on the first day of a longer maintenance period, we should expect the overnight rate to start the maintenance period at most 1 basis points above the minimum bid rate, if it is expected to be at exactly the middle of the corridor on the last day (0.01x4+0.99x3=3.01).

Figure 8 shows the empirical density of the deviation of EONIA from the minimum bid rate on the penultimate day of the reserve maintenance period for the full sample and for a sub-sample (after more frequent fine-tuning by the ECB). Figure 10 shows the empirical density of the deviation of EONIA from minimum bid rate on the last day of the reserve maintenance period for the full sample and for the sub-sample. Table 7 and Table 8 report the respective normality tests.

We concentrate on the statistics for the sub-sample given that without a fine-tuning operation on the last day of the maintenance period, one of the basic assumptions of the model is violated. Statistics for the penultimate day of the reserve maintenance period, in the sub-sample, show a positive average deviation from the minimum bid rate of about 4 basis points; with a standard deviation of 9 basis points the sample mean is statistically different from zero at the 5% confidence level (25 degrees of freedom). The empirical distribution is close to normal. The results of the simulation are illustrated in Figure 9. The simulated standard deviation of the overnight interest rate is 10 times smaller than the sample standard deviation. This suggests that the liquidity uncertainty ratio on the penultimate day is smaller than 6, the value used in the simulation. This may be due to higher aggregate uncertainty. Commercial banks have to wait until the morning of the last day of the maintenance period to learn whether the ECB will launch a fine-tuning operation and whether the operation will be liquidity absorbing or liquidity providing. To some extent, this could explain the higher than calibrated aggregate uncertainty on the penultimate day of the maintenance period.

The standard deviation of the aggregate shock chosen for the simulation of the last day is 6 times smaller than the standard deviation of the idiosyncratic shock. The latter was fixed at 0.43 as explained. It is interesting to note that the statistics for the last day of the maintenance period show a deviation from the minimum bid rate at zero (in the sub-sample) with standard deviation 0.13. These moment values are matched exactly by averaging over 1,000 simulations of the theoretical model (see simulations in Figure 11). The calibrated model can be used to simulate the effects of changes to the operational framework, like a reduction in the reserve ratio or a change in the width of the interest rate corridor set by the standing facilities. This however is outside the scope of this paper and is left for future work.

6. Conclusions

In this paper we inquired into the reserve fulfilment path of a representative panel of euro area commercial banks. The empirical analysis confirms the theoretical prediction that banks optimally target their daily current account with the central bank at around their respective minimum reserve requirement. The exception seems to be small banks which build-up excess reserves.

The empirical analysis suggests that idiosyncratic liquidity uncertainty is much higher than aggregate uncertainty. Nevertheless, the inverse demand schedule of the representative bank, on the penultimate day of the reserve maintenance period is relatively flat around the middle of the interest rate corridor set by the rates on the standing facilities. This suggests that, except on the last day, liquidity effects should be very muted within the maintenance period in the euro area. Indeed, the probability of an individual bank's daily overdraft in the euro area seems to be very low (below 1%).

Our results have several policy implications. Firstly, the *benchmark allotment policy* followed by the ECB is fully consistent with individual commercial bank's optimality in a model where the ECB is expected to supply liquidity without any bias and steer very-short term money market rates whithin a symmetric interest rate corridor. Secondly, one component of the benchmark allotment is the forecast of *excess reserves*. According to the theoretical model presented in this paper, there is no rationale for banks to systematically take recourse to the deposit facility (or build up excess reserves) on the last day of the maintenance period. Nevertheless, the empirical evidence shows that small banks build-up excess reserves; this heterogeneity in market behaviour complicates, somewhat, the ECB's task of calibrating the aggregate liquidity supply.

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Annex

1. Cost minimization problem on the last day of the maintenance period

On the last day of the reserve maintenance period the cost minimization problem of a representative bank can be formalized as follows (see Whitesell, 2006):

$$\begin{aligned}
&\min_{a_T} \{i_T.d_T+ \\
&+\int_{d_T-a_T}^{\infty}\left(i_T-i^d\right).(a_T-d_T+\varepsilon).dG(\varepsilon)+ \\
&+\int_{-\infty}^{d_T-a_T}\left(i^l-i_T\right).(d_T-a_T-\varepsilon).dG(\varepsilon)\}
\end{aligned} \tag{22}$$

The first term is the cost of borrowing from the market to meet the remaining reserve requirement, named *reserve deficiency* (d_T). The first integral is the opportunity cost of holding excess balances (for $a_T - d_T + \varepsilon > 0$); the second integral is the cost of borrowing from the central bank rather than from the market, to meet the reserve requirement (for $a_T - d_T + \varepsilon < 0$).

2. Proof of Proposition I:

By setting $i_T = i^l - (i^l - i^d)/2$ in equation (2) we get $G^{-1}(0.5)$; with symmetric probability distribution, $G(\varepsilon)$, and $E(\varepsilon) = 0$, $G^{-1}(0.5) = 0$. The result follows immediately.

3. Cost minimization problem on the penultimate day of the maintenance period

To derive the first order conditions of optimality note that, $d_T - a_T^*$, is independent of d_T (see Whitesell, 2006).

$$d_T - a_T^* = G\left(\frac{i_T - i^d}{i^l - i^d}\right) = k(i_T, i^*, s, G). \tag{23}$$

Using the optimality condition(2) to replace a_T^* in equation (22) we obtain the expected cost function, $V(a_T^*|I_T)$, on day $T-1$:

$$V(a_T^*|I_T) = i_T.d_T + K(i_T, i^*, s, G) \tag{24}$$

with

$$K(i_T, i^*, s, G) = \{\left(i_T - i^d\right). \int_{k(i_T,i^*,s,G)}^{\infty} \varepsilon.dG(\varepsilon) \tag{25}$$

$$- \left(i^l - i_T\right). \int_{-\infty}^{k(i_T,i^*,s,G)} \varepsilon.dG(\varepsilon)\}$$

The cost minimization problem of the representative bank on the penultimate day of the reserve maintenance period can be formalized as follows:

$$\min_{a_{T-1}} \int_{-a_{T-1}}^{\infty} \left(i_{T-1} - i^d\right).(a_{T-1} + \xi).dF(\xi) + \tag{26}$$

$$- \int_{-\infty}^{-a_{T-1}} \left(i^l - i_{T-1}\right).(a_{T-1} + \xi).dF(\xi)\}$$

$$+ E_{T-1}\left[V\left(a_T^*\right)\right].$$

4. Proof of Propostion II:

In (6) set, $i_{T-1} = E_{T-1}(i_T) = i^l - (i^l - i^d)/2$; we obtain

$$\frac{i^l + i^d}{2} = i^l.F(-a_{T-1}^*) + i^d.\left[1 - F(2R - a_{T-1}^*)\right] + \tag{27}$$

$$+ [F(2R - a_{T-1}^*) - F(-a_{T-1}^*)].\left(\frac{i^l + i^d}{2}\right).$$

If $F(\xi)$ is symmetric and $E(\xi) = 0$ then (27) simplifies to:

$$1 - F(-a_{T-1}^*) = F(2R - a_{T-1}^*) \tag{28}$$

which implies the statement in the proposition.

5. Proof of Corollary:

It follows directly from Proposition I and the definition of deficiency $d_T = 2R - a_{T-1}$.

Tables:

Table 1: Testing whether the panel is representative (full sample)

RATIO OF DAILY CURRENT ACCOUNT OVER DAILY AVERAGE MINIMUM RESERVE REQUIREMENT (FULL SAMPLE)		
	Model I	Model II (With SIZE)
$\hat{\alpha}$	0.7310107 *** (12.790172)	0.6530354*** (13.165791)
$\hat{\beta}$	0.2692778 *** (4.9221181)	0.3473692*** (7.0064211)
$1-\hat{\beta}$	0.73	0.65
$\hat{\alpha}+\hat{\beta}$	1	1
$MEDIUM_i$		0.0113581 (0.3625417)
$SMALL_i$		0.0139939 (0.8207584)
t – Statistics are in parentheses. ***** Statistically significant at 10% level ****** Statistically significant at 5% level ******* Statistically significant at 1% level		

Table 2: Testing whether the panel is representative (sub-samples)

RATIO OF DAILY CURRENT ACCOUNT OVER DAILY AVERAGE MINIMUM RESERVE REQUIREMENT (FOR THREE SUB – SAMPLES)			
	Sub-sample I (Mar.10 04 – Jan. 18 05)	Sub-sample II (Jan. 19 05 - Jan. 17 06)	Sub-sample III (Jan. 18 06 - Jan. 16 07)
$\hat{\alpha}$	0.7387804 *** (13.767032)	0.6657488 *** (12.32865)	0.6526055 *** (12.280029)
$\hat{\beta}$	0.2616836 *** (4.876006)	0.3341681 *** (6.1907626)	0.3479071 *** (6.5480525)
$1-\hat{\beta}$	0.74	0.67	0.65
$\hat{\alpha}+\hat{\beta}$	1	1	1
$MEDIUM_i$	0.0092891 (0.2603782)	0.0044758 (0.1320761)	-0.01159 (-0.441422)
$SMALL_i$	-0.033182 (-0.9034)	0.0234595 * (1.9150614)	0.014099 * (1.7343155)

t – Statistics are in parentheses.
***** Statistically significant at 10% level
****** Statistically significant at 5% level
******* Statistically significant at 1% level

Table 3: Testing the linear fulfilment path hypothesis on last day of reserve maintenance period (full sample)

RATIO OF RESERVE DEFICIENCY OVER AVERAGE DAILY MINIMUM RESERVE REQUIREMENT ON LAST DAY FOR EACH RESERVE MAINTENANCE PERIOD (FULL SAMPLE)			
	Coefficient	Standard Error	t-statistics
$\widehat{\lambda}$	1.03990 ***	0.08949	19.62
$MEDIUM_i$	-0.18595	0.16166	-1.15
$SMALL_i$	-1.153123***	0.16813	-9.11

* Statistically significant at 10% level
** Statistically significant at 5% level
*** Statistically significant at 1% level

Table 4: Testing the linear fulfilment path hypothesis on last day of reserve maintenance period (sub-samples)

RATIO OF RESERVE DEFICIENCY OVER AVERAGE DAILY MINIMUM RESERVE REQUIREMENT ON LAST DAY FOR EACH RESERVE MAINTENANCE PERIOD (THREE SUB – SAMPLES)			
	Sub-sample I (Mar.10 04 – Jan. 18 05)	Sub-sample II (Jan. 19 05 - Jan. 17 06)	Sub-sample III (Jan. 18 06 - Jan. 16 07)
$\widehat{\lambda}$	1.05253 *** (3.93)	1.03232 *** (10.82)	1.03696 *** (14.78)
$MEDIUM_i$	-0.36261 (-0.75)	-0.30329 * (-1.76)	0.07945 (0.63)
$SMALL_i$	-2.57665 *** (-5.12)	-1.35790 *** (-7.57)	-0.83337 *** (-6.32)

t – Statistics are in parentheses.
* Statistically significant at 10% level
** Statistically significant at 5% level
*** Statistically significant at 1% level
For the three sub-samples, we accept $H0: \quad Intercept = 1$ with p-values 0.8445, 0.7350 and 0.5985 respectively

Table 5: Testing the linear fulfilment path hypothesis on penultimate day of reserve maintenance period (full sample)

RATIO OF RESERVE DEFICIENCY OVER AVERAGE DAILY MINIMUM RESERVE REQUIREMENT ON THE PENULTIMATE DAY OF RESERVE MAINTENANCE PERIOD (FULL SAMPLE)			
	Coefficient	Standard Error	t-statistics
$\hat{\lambda}$	2.03695 ***	0.09559	21.31
$MEDIUM_i$	-0.07775	0.17268	-0.45
$SMALL_i$	-1.50820 ***	0.17959	-8.40
* Statistically significant at 10% level ** Statistically significant at 5% level *** Statistically significant at 1% level			

Table 6: Testing the linear fulfilment path hypothesis on penultimate day of reserve maintenance period (sub-samples)

RATIO OF RESERVE DEFICIENCY OVER AVERAGE DAILY MINIMUM RESERVE REQUIREMENT ON THE PENULTIMATE DAY OF RESERVE MAINTENANCE PERIOD (THREE SUB-SAMPLES)			
	Sub-sample I (Mar.10 04 – Jan. 18 05)	Sub-sample II (Jan. 19 05 - Jan. 17 06)	Sub-sample III (Jan. 18 06 - Jan. 16 07)
$\hat{\lambda}$	2.03466 *** (7.45)	2.03865 *** (18.84)	2.03715 *** (21.13)
$MEDIUM_i$	-0.35452 (-0.72)	-0.21886 (-1.12)	0.29401 * (1.69)
$SMALL_i$	-2.54730 *** (-4.96)	-1.28672 *** (-6.33)	-0.86378 *** (-4.77)
t – Statistics are in parentheses. * Statistically significant at 10% level ** Statistically significant at 5% level *** Statistically significant at 1% level For the three sub-sample, we accept $H0: \quad Intercept = 2$ with p-values 0.8991, 0.7211 and 0.7001 respectively			

Table 7: Normality tests for the penultimate day of the maintenance period

Normality test for EONIA-MBR over the full sample 06/04/2004 – 16/01/2007	**Normality test for EONIA-MBR over the sub-sample 18/01/2005 – 16/01/2007**
Observations 34 **Mean 0.048** Std.Devn. 0.114 Skewness 0.066 Excess Kurtosis 0.246 Minimum -0.200 Maximum 0.330 Asymptotic test: Chi^2(2) = 0.11033 [0.9463] Normality test: Chi^2(2) = 1.6833 [0.4310]	Observations 25 **Mean 0.040** Std.Devn. 0.088 Skewness -0.371 Excess Kurtosis 0.614 Minimum -0.200 Maximum 0.210 Asymptotic test: Chi^2(2) = 0.96555 [0.6171] Normality test: Chi^2(2) = 3.3275 [0.1894]

Table 8: Normality tests for the last day of the maintenance period

Normality test for EONIA-MBR over the full sample 06/04/2004 – 16/01/2007	**Normality test for EONIA-MBR over the sub-sample 18/01/2005 – 16/01/2007**
Observations 34 **Mean 0.066** Std.Devn. 0.232 Skewness 1.393 Excess Kurtosis 2.850 Minimum -0.370 Maximum 0.770 Asymptotic test: Chi^2(2) = 22.497 [0.0000]** Normality test: Chi^2(2) = 10.201 [0.0061]**	Observations 25 **Mean 0.0028** Std.Devn. 0.127 Skewness -1.084 Excess Kurtosis 1.079 Minimum -0.370 Maximum 0.180 Asymptotic test: Chi^2(2) = 6.1038 [0.0473]* Normality test: Chi^2(2) = 5.7633 [0.0560]

Figures:

Figure 1: Histogram of the panel of euro area banks

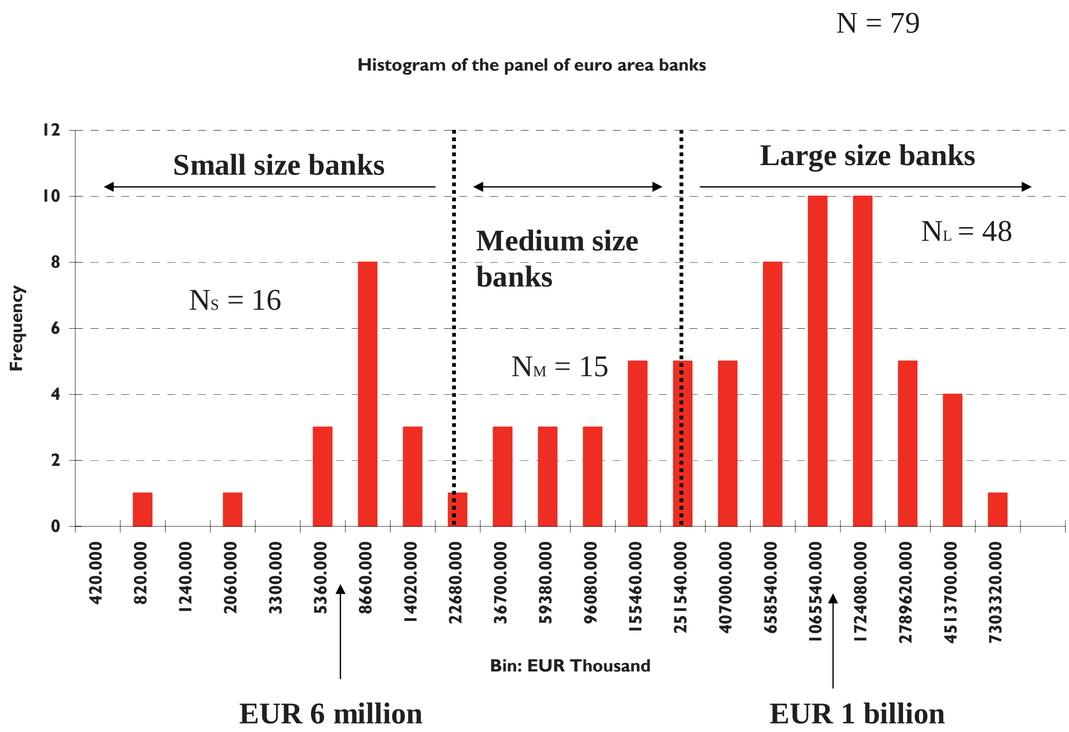


Figure 2: Cumulated ratio of current account over minimum reserve requirement: average across banks in each day of the reserve maintenance period

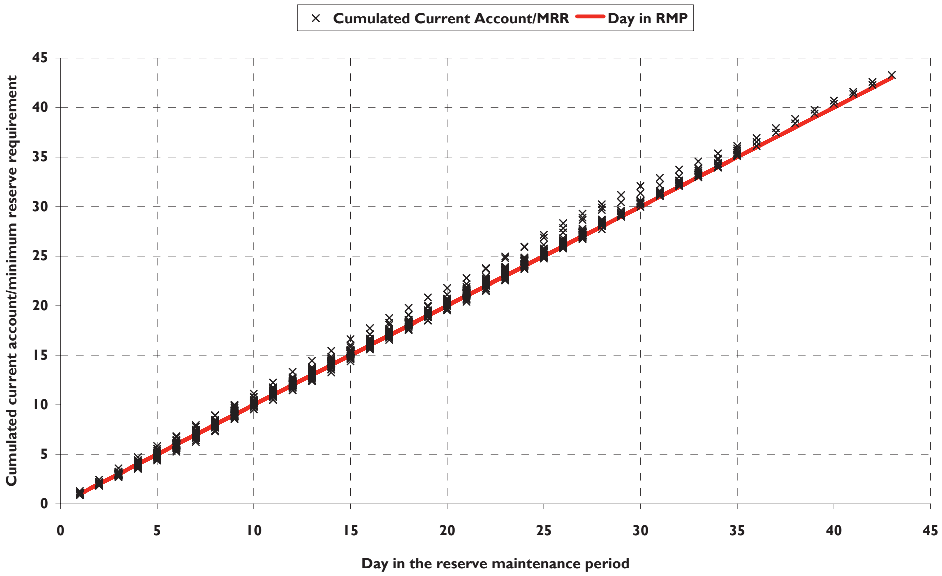


Figure 3: Cumulated ratio of current account over minimum reserve requirement: average across banks on last day of the reserve maintenance period

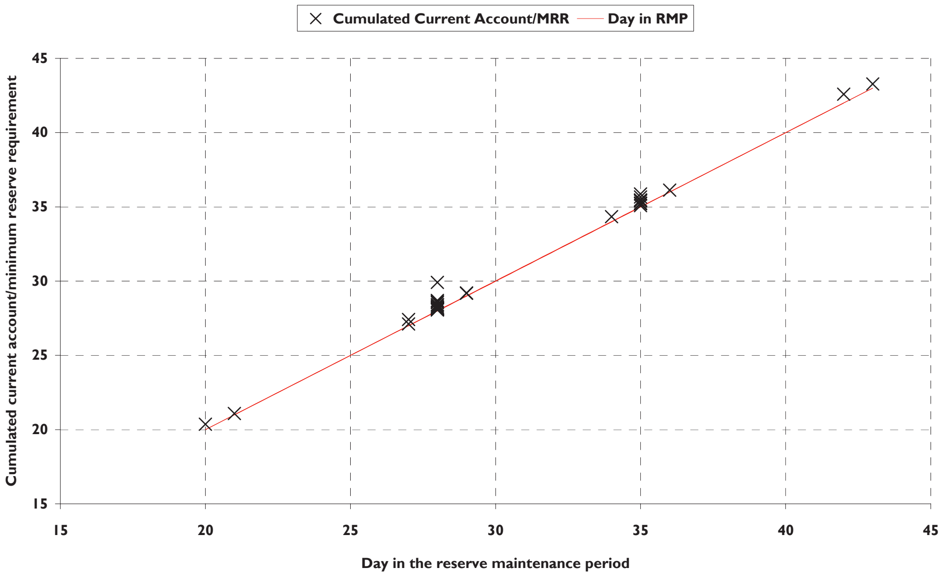


Figure 4: Ratio of current account over minimum reserve requirement: daily average across banks

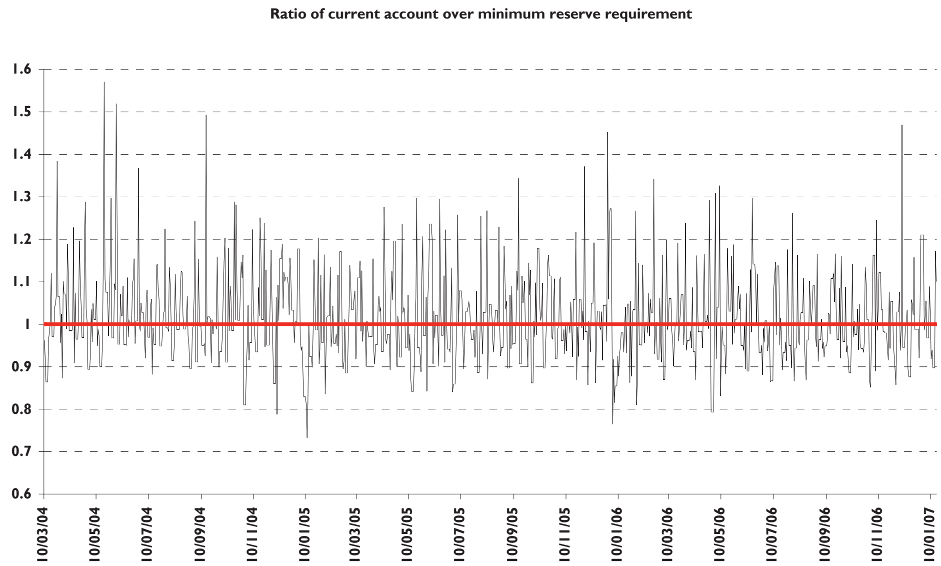


Figure 5: Ratio of reserve deficiency over minimum reserve requirement on the penultimate day of the reserve maintenance period

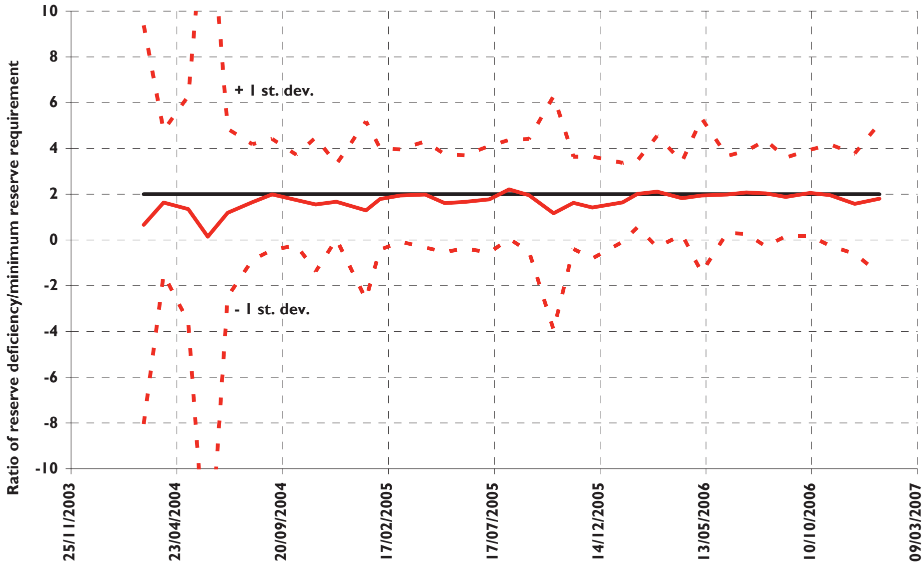


Figure 6: Ratio of reserve deficiency over minimum reserve requirement on the last day of the reserve maintenance period

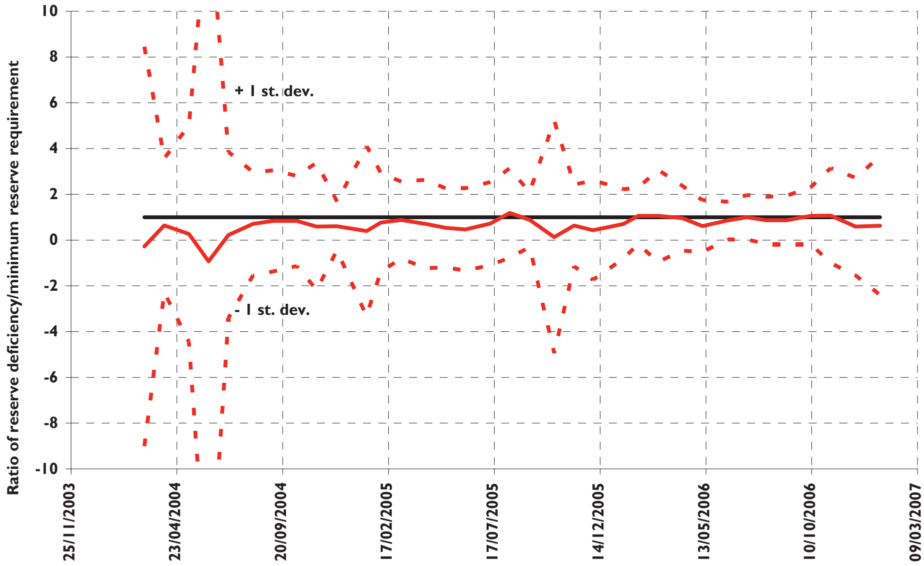


Figure 7: Demand schedules on the last 2-days of the maintenance period calibrated for the representative bank in the euro area

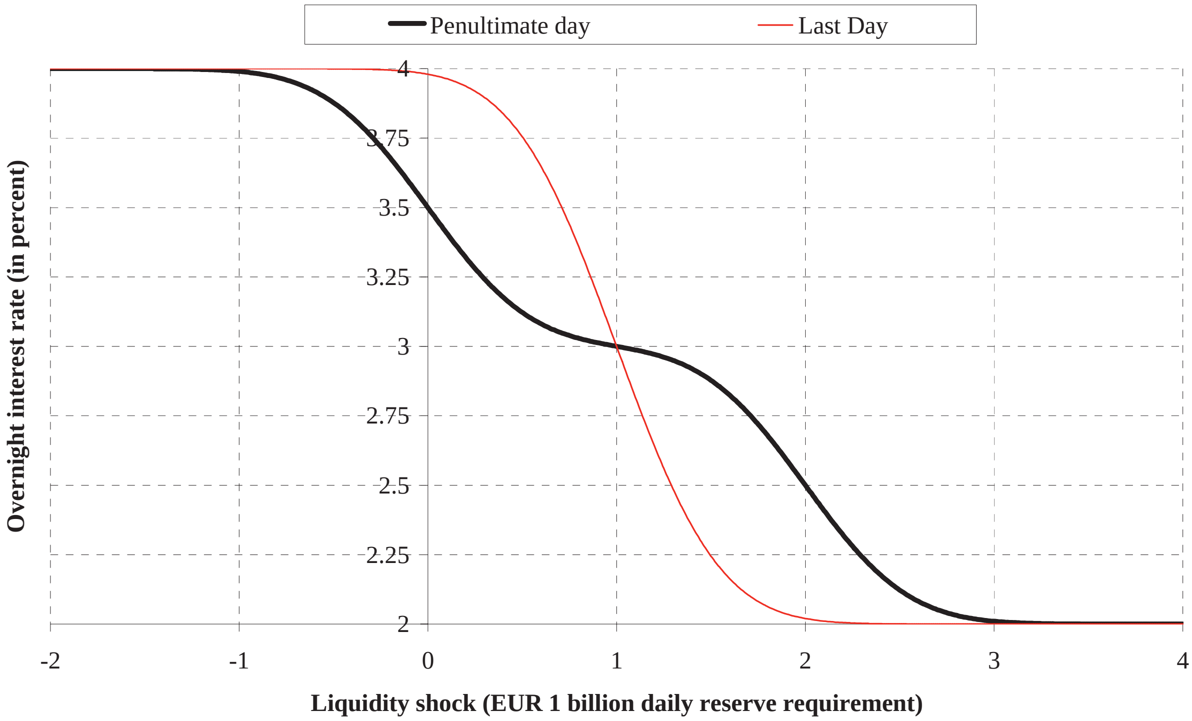


Figure 8: Deviation of EONIA from minimum bid rate on penultimate day of reserve maintenance period

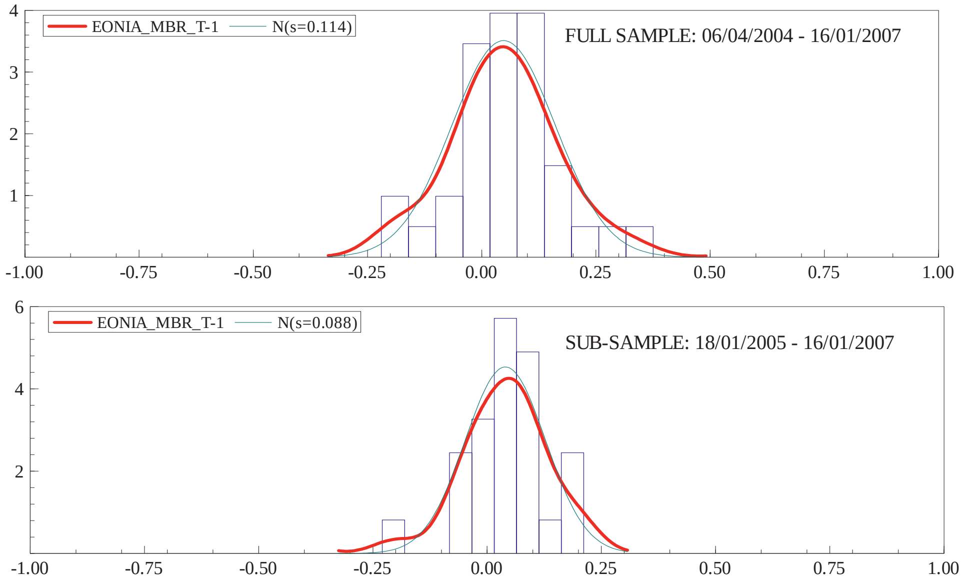
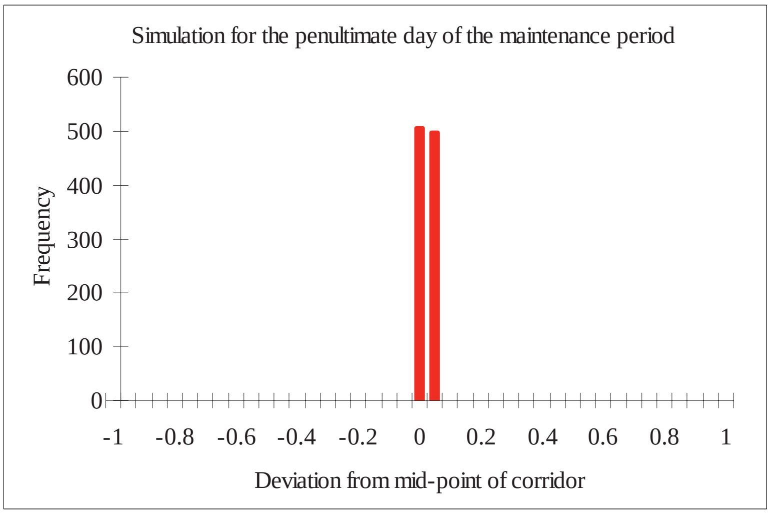


Figure 9: Simulated deviation of the overnight rate from the minimum bid rate (middle of the corridor set by standing facilities) on the penultimate day in the reserve maintenance period



Mean	**0.000**
St.dev.	**0.009**
Median	**0.000**
Kurtosis	**-0.128**
Skewness	**-0.069**
Max	**3.03**
Min	**2.97**

Figure 10: Deviation of EONIA from minimum bid rate on last day of reserve maintenance period

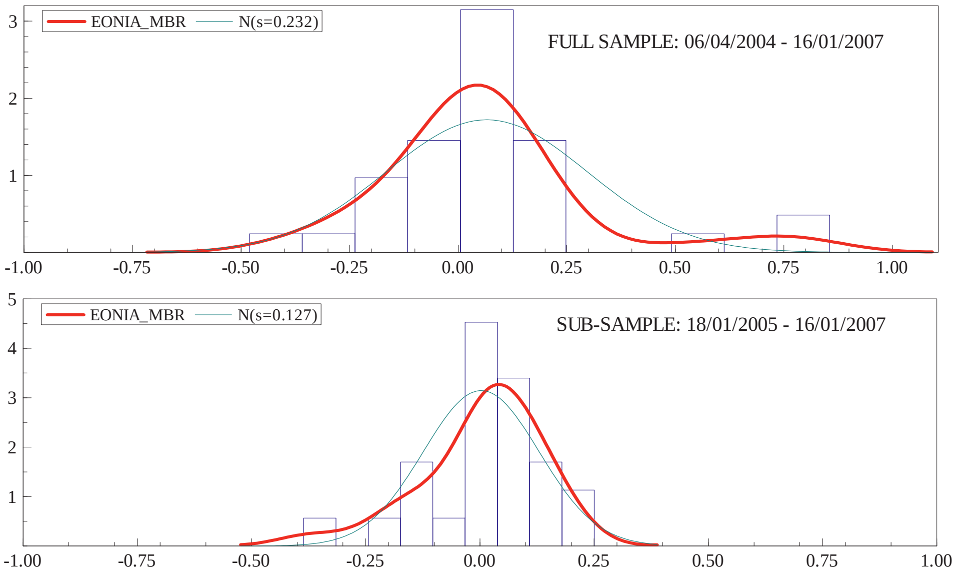
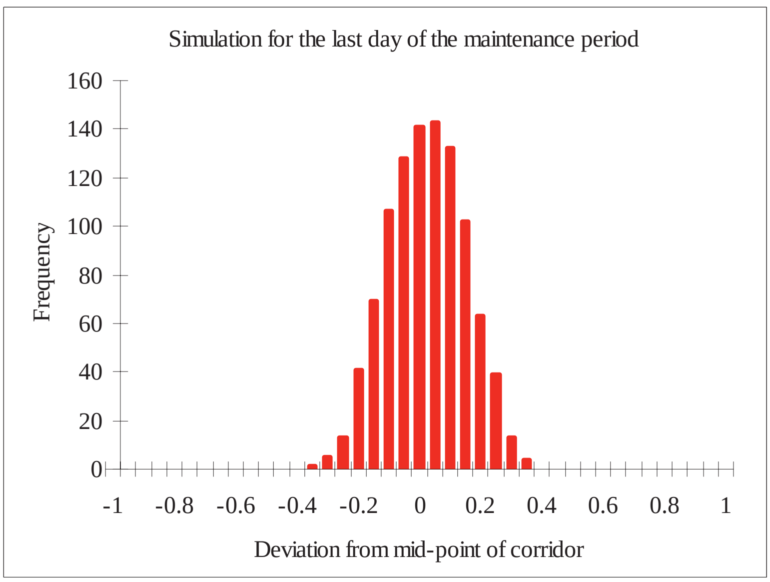


Figure 11: Simulated deviation of the overnight rate from the minimum bid rate (middle of the corridor set by standing facilities) on the last day in the reserve maintenance period



Mean	**-0.003**
St.dev.	**0.125**
Median	**-0.002**
Kurtosis	**-0.443**
Skewness	**-0.044**
Max	**3.33**
Min	**2.64**

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