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In 2004 all publications will carry a motif taken from the €100 banknote.

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Abstract

This paper explains to what extent excess reserves are and should be relevant today in the implementation of monetary policy, focusing on the specific case of the operational framework of the Eurosystem. In particular, this paper studies the impact that changes to the operational framework for monetary policy implementation have on the level and volatility of excess reserves. A 'transaction costs' model that replicates the rather specific intra-reserve maintenance period pattern of excess reserves in the euro area is developed. Simulation results presented not only show that excess reserves may increase considerably under some changes to the operational framework, but also that their volatility and hence unpredictability could.

Key words: excess reserves, monetary policy implementation, liquidity management.

JEL-classification: E52, E58.

Non-technical summary

Excess reserves refer to the current account holdings of banks with their central bank beyond required reserves. In the past, excess reserves were regarded as playing the key role in the transmission of monetary policy. Banks were perceived as being more inclined to provide loans when the volumes of excess reserves were high, and less inclined when low. Open market operations were therefore - at least in theory - conducted with the main objective of steering the level of excess reserves. This view on monetary policy implementation was referred to as 'reserve position doctrine' (RPD). This situation has been reversed when central banks returned to more explicit interest rate targeting at the beginning of the 1990s.

In the case of the US, no deposit facility limits the possible amount of excess reserves, and thus the Fed can set excess reserves at any positive level by injecting sufficient funds through open market operations. However, it does not make sense, at least under normal circumstances, for the Fed to trigger an expansionary impulse by injecting through open market operations excess reserves in order to trigger additional loans. Small aggregate surpluses or deficits in the money market relative to needs over the reserve maintenance period, if recognized by market participants, lead to large and immediate changes of short term interest rates. In particular, engineering through open market operations excess reserves on an *aggregate level* simply means driving short-term interest rates to zero (or to the deposit facility rate, if any). The problem with this channel is that (1) it is too radical for normal times; (2) if not deemed to persist over some time, it provides little guidance on the future evolution of short term rates, and therefore fundamentally destabilizes the yield curve and therefore inter-temporal economic decisions by economic agents; (3) it is normally more relevant to describe such a policy measure as the setting of a zero interest rate target, than to define it as an excess reserves target.

Although excess reserves should not play a particular role in monetary macroeconomics, it should not be forgotten that they represent a challenge in the day-to-day implementation of monetary policy, since they constitute an only partially predictable reserve market factor, similarly to other so-called autonomous liquidity factors like for instance the deposits of the Government with the central bank or the volume of banknotes in circulation. This paper hence focuses on explaining to what extent excess reserves are and should be relevant today in the implementation of monetary policy, focusing on the specific case of the operational framework of the Eurosystem. In particular, we study the impact that changes to the operational framework for monetary policy implementation have on the level and volatility of excess reserves.

A simple 'transaction costs' model of excess reserves in the euro area is developed to address these issues. Starting from the observation that in the euro area, excess reserves can in principle always be avoided by recourse to the remunerated deposit facility, transaction costs are modelled as the (low) costs to remain in the office until 18:30, which is the time when the last payments have been settled, and around 90 minutes after the interbank market, in which transactions are initiated, has closed. This model is used to simulate the following policy scenarios: 1) Changing all key ECB interest rates; 2) Modifying the width of the corridor of the standing facility rates; 3) Ending the deposit facility; 4) Changing the penalty rate; 5) Changing banks' reserves requirements; 6) Changing the volatility of payment shocks. Changes in the volatility of payment shocks can be interpreted as: a) changes in the efficiency of payment systems, b) changes in the volume of payment activities, or c) changes in the smoothness of the functioning of money markets.

The simulation of the model shows not only that excess reserves may increase considerably under some changes of the framework for monetary policy implementation, but also that their volatility and hence unpredictability could. This may cause an increase of the volatility of the overnight rate at the very end of the reserve maintenance period.

1 Introduction

Excess reserves refer to the current account holdings of banks with their central bank beyond required reserves. In the past, excess reserves were regarded as playing the key role in the transmission of monetary policy. Banks were perceived as being more inclined to provide loans when the volumes of excess reserves were high, and less inclined when low. Open market operations were therefore - at least in theory - conducted with the main objective of steering the level of excess reserves. This view on monetary policy implementation was referred to as 'reserve position doctrine' (RPD).[1] This situation has been reversed when central banks returned to more explicit interest rate targeting at the beginning of the 1990s. Although it has thus been confirmed that excess reserves should not play a particular role in monetary macroeconomics, it should not be forgotten that they represent a challenge in the day-to-day implementation of monetary policy. A central bank's objective of steering interest rates is achieved by managing the conditions that equilibrate supply and demand in the market for bank reserves. When assessing the liquidity needs of the banking system, it is necessary to take into account the expected value of excess reserves in a similar way as is done for the so-called 'autonomous liquidity factors', e.g. the deposits of the Government with the central bank or the volume of banknotes in circulation.

This paper explains to what extent excess reserves are and should be relevant today in the implementation of monetary policy, focusing on the specific case of the operational framework of the Eurosystem. In particular, we studies the impact that changes to the operational framework for monetary policy implementation have on the level and volatility of excess reserves. A simple 'transaction costs' model of excess reserves in the euro area is developed to address these issues. Starting from the observation that in the euro area, excess reserves can in principle always be avoided by recourse to the remunerated deposit facility, transaction costs are modelled as the (low) costs to remain in the office until 18:30, which is the time when the last payments have been settled, and around 90 minutes after the interbank market, in which transactions are initiated, has closed.

The results show not only that excess reserves may increase considerably under some changes of the framework for monetary policy implementation, but also that their volatility and hence unpredictability could. This would cause an increase of the volatility of the overnight rate at the very end of the reserve maintenance period. The model developed in this paper follows the precautionary demand models of Orr and Mellon (1961) and Poole (1968) that suggested that the demand for excess reserves should decrease with interest rates and increase with the magnitude of payment shocks. This same result was also found for the US by Dow (2001).

[1]The term 'reserve position doctrine' is due to Meigs (1962, pp. 7-22).

Section 2 provides a general short review of the role of excess reserves in Monetary Policy. Section 3 presents the relevant aspects of the operational framework of the Eurosystem and explains the *raison d'être* of excess reserves in the euro area. Section 4 describes the patterns displayed by the series of excess reserves in the euro area, as well as some other complementary data relevant for the calibration of the model. Section 5 develops the simple economic model of the daily pattern of excess reserves within the maintenance period in the euro area. Section 6 estimates and simulates this model and reports the results of a number of experiments which investigate how changes in the operational framework and in the level of short term interest rates could potentially impact on excess reserves and in the implementation of monetary policy. Section 7 concludes.

2 The role of excess reserves in monetary policy

In the 19th century and until around 1920, central bank policy implementation was perceived as short-term interest rate policy in the form of 'Bank rate' (i.e. discount rate) policy. This perception was not only limited to the case of a commodity standard, but authors like Thornton, Bagehot, Wicksell and in the earlier 20th century, Cassel, also viewed interest rate policy as the natural approach to monetary policy implementation under a paper standard. This view was mainly abandoned for around 60 years in preference for RPD as a result of the: *i*) revival of the quantity theory of money by Irving Fisher among others, *ii*) introduction of the money multiplier by C.A. Phillips in 1920, and *iii*) difficulties and misunderstandings in the implementation of monetary policy experienced by the Fed in its first decade (See e.g. Meltzer (2003)).

RPD downplayed the role of short-term interest rates in the implementation of monetary policy. Instead, excess reserves were regarded as playing the key role as starting point of monetary policy transmission. Banks were perceived as being more inclined to provide loans when the volumes of excess reserves were high, and less inclined when low. Open market operations were therefore conducted with the main objective of steering the level of excess reserves. Keynes (1930, p. 226) explained the basic idea of RPD as follows.

> "*The first and direct effect of an increase in the Bank of England's investments is to cause an increase in the reserves of the joint stock banks and a corresponding increase in their loans and advances on the basis of this. This may react on market rates of discount and bring the latter a little lower than they would otherwise have been. But it will often, though not always, be possible for the joint stock banks to increase their loans and advances without a material weakening in the rates of interest charged.* "

In line with Keynes, a largely accepted view in monetary economics until the mid 1980s was that excess reserves are an indicator of the degree of ease or tightness of monetary policy. When excess reserves are large, banks supposedly are eager to provide loans. When they are small, banks are supposedly under pressure to pay off their indebtedness and will restrict credit. The popularity of this view is reflected in the literature surveyed by Meigs (1962) or in the interpretation of the Great Depression by Friedman and Schwartz (1963). Generally, monetarists, which liked quantities, but tended to dislike the idea of central bank control of (short term) interest rates, broadly supported RPD. However, they were less keen on being bothered with a need to split up their most cherished concept for monetary policy implementation, the monetary base, into petty-minded technical concepts like excess reserves, free reserves, borrowed reserves, etc. The 1979-82 Fed experiment with short term monetary control was probably the most ambitious attempt to put some sort of RPD into practice.

This situation was reversed at the beginning of the 1990s when central banks returned to more explicit interest rate targeting.[2] A notable exception to this general trend is of course the move of the Bank of Japan (BOJ) of 19 March 2001 in which it first announced some form of target for reserves (and hence excess reserves), which was subsequently increased on several occasions. The move seemed to be at least not inconsistent with Friedman and Schwartz (1963). However, the BOJ acknowledged that it is "as drastic as is unlikely to be taken under ordinary circumstances."

In the case of the US, no deposit facility limits the possible amount of excess reserves, and thus the Fed can set excess reserves at any positive level by injecting sufficient funds through open market operations. Why thus doesn't it make sense, at least under normal circumstances, for the Fed to trigger an expansionary impulse by injecting through open market operations excess reserves in order to trigger additional loans? An observation made 130 years ago by Bagehot (1873, pp. 58) in his book *Lombard Street* explains the problem with this idea:

> *"[Money] is a commodity subject to great fluctuations of value and those fluctuations are easily produced by a slight excess or a slight deficiency of quantity. Up to a certain point money is a necessity. If a merchant has acceptances to meet tomorrow, money he must and will find today at some price or other. And it is this urgent need of the whole body of merchants which runs up the value of money so wildly and to such a height in a great panic. On the other hand, money easily becomes a drug, as the phrase is, and there is soon too much of it. "*

[2] See ECB (2002) and Beek (1981) for the Fed.

Bagehot's description of the money market is exactly opposite to the indeed counter-intuitive idea of Keynes, according to which credit quantities could adapt faster than money market rates.[3] Anyone knowing central bank operations will tend to confirm Bagehot's position: small aggregate surpluses or deficits in the money market relative to needs over the reserve maintenance period, if recognized by market participants, lead to large and immediate changes of short term interest rates. In particular, engineering through open market operations excess reserves on an *aggregate level* simply means driving short-term interest rates to zero (or to the deposit facility rate, if any). This happened in the US during the 1930s and is today practiced in Japan, but even much smaller excess reserves than those engineered during these episodes are sufficient to drive interest rates to zero.

Leaving aside the fact that in both cases it does not seem to have helped by itself to create credit expansion, the problem with this channel is that (1) it is too radical for normal times; (2) if not deemed to persist over some time, it provides little guidance on the future evolution of short term rates, and therefore fundamentally destabilizes the yield curve and therefore inter-temporal economic decisions by economic agents; (3) it is normally more relevant to describe such a policy measure as the setting of a zero interest rate target, than to define it as an excess reserves target.

Although it has thus been confirmed that excess reserves should not play a particular role in monetary macroeconomics, it should not be forgotten that they represent a challenge in the day-to-day implementation of monetary policy, since they constitute an only partially predictable reserve market factor, similarly to other so-called autonomous liquidity factors like for instance the deposits of the Government with the central bank or the volume of banknotes in circulation.

3 Raison d'être of excess reserves in the euro area

Excess reserves cannot be understood without considering the environment in which they are generated. This environment is determined by the following factors:

A. *The operational framework of the ECB.* The operational framework of the Eurosystem is characterized by the following elements of key relevance to excess reserves:

   - Reserve requirement system with a one month averaging period. Credit institutions in the euro area are required to hold minimum reserves on accounts with the national central banks. Broadly speaking required reserves of individual banks are calculated by applying a reserve ratio of 2% to their short term liabilities. A

[3]Bagehot's description of the money market is not less valid in the 1920s, when Keynes developed his Treaties on Money, as the Macmillan Committee hearings of 1929 may suggest. Today's money markets are even more efficient, and thus prices react even faster to imbalances of quantities than at those times.

lump sum allowance of EUR 100,000 is applied to the requirement, and hence a substantial number of small banks ends with effectively zero reserve requirements. Compliance with reserve requirements is determined on the basis of the average reserve holdings over a maintenance period of one month. Reserve holdings not exceeding the minimum reserve requirements are remunerated at market rates, but excess reserves are not remunerated at all. It should be highlighted that in the present paper the term excess reserves strictly refers to the difference between *accumulated* reserve holdings, e.g. at day t of the maintenance period the sum of the reserve holdings of days 1 to t, and *total* reserve requirements, i.e. 2% of short term liabilities multiplied by the number of days in the maintenance period. This averaging system of the euro area implies that banks subject to reserve requirements are unlikely to generate excess reserves for most of the reserve maintenance period. Only towards the end of the reserve maintenance period, when the remaining accumulated reserve requirement to be fulfilled becomes small, the likelihood of generating excess reserves as a result of unanticipated liquidity providing payment shocks increases.

- Standing facilities. As many other central banks, the Eurosystem offers to banks an advance (or lombard) facility, called the marginal lending facility. Banks can thus always refinance overnight at a rate normally 100 basis points above market rates. In addition the Eurosystem offers a deposit facility, in which banks can always deposit excess reserves at end of day. Both standing facilities can be accessed after all inter-bank payments have been processed. The euro area payment system TARGET usually closes at 18:00 and the processing of all payments is normally completed by 18:30. The banks can make use of either of the standing facilities until 18:30. The existence of a deposit facility implies that there is in fact no a priori rationale for excess reserves since in the event of excess reserves after all intra-bank payments of the day have been processed, it always pays to deposit them at the deposit facility. Thus, in the euro area, the only reason for excess reserves can be that a bank does not care, or that the transaction costs associated with the recourse to the deposit facility are higher than the remuneration expected from placing those funds in the deposit facility. If the latter calculus is relevant, then the level of ECB rates, which includes the deposit facility rate, should also determine the amount of excess reserves.

B. *The reserves supply policy of the ECB.* The reserve supply policy through open market operations of the ECB is, according to ECB (2002), normally characterized by the aim to be neutral, i.e. to keep the likelihood of an aggregate recourse of the banking system to the marginal lending facility equal to the likelihood of an aggregate recourse to the deposit facility, such that short term market rates tend to remain in the middle of the 200 basis points corridor set by the two standing facility rates. To be able to keep money market conditions neutral in this sense, the weekly frequency of open market operations implies a need to forecast all factors impacting on the demand for reserves. These include the typical autonomous factors, i.e. Government deposits and banknotes, as well as excess reserves. A precise forecast is critical especially for setting the volume of the *last* main refinancing operation of the maintenance period because forecast errors can no longer be compensated through other open market operations within the reserve maintenance period. Large forecasting errors lead to corresponding liquidity imbalances at the end of the maintenance period, which can then also lead to a significant deviation in the overnight rate from the minimum rate of the main refinancing operation set by the ECB.

C. *The structure of the payment system and volume of payment activity.* The euro area interbank money market and payment system is characterized overall by a high degree of efficiency and reliability. The reliability of systems implies that it is normally not technical failure of payment systems which generate payment shocks and thus potentially excess reserves, but human mistake in the use of the systems or failure of banks' local IT systems connected to the payment system.

Excess reserves in the US and their treatment in monetary policy implementation were described in detail some time ago by Beek (1981). Although we will not revisit the patterns of excess reserves in the US, it is worth looking briefly at the main institutional differences to understand what is specific to the euro area. First, reserve requirements are today much lower in the US, where the averaging capacity is less than 10 per cent of the one in the euro area (see e.g. Blenck, Hasko, Hilton, and Masaki (2001)). This should imply that the maintenance period pattern of excess reserves is somewhat weaker in the US, and that excess reserves are overall somewhat higher. Second, there is no deposit facility in the US. Therefore, also aggregate surpluses of reserves have to end as excess reserves, and not like in the euro area to a large extent as a recourse to the deposit facility. Basically, one could say that the US excess reserves correspond to the sum of excess reserves and the recourse to the deposit facility in the euro area. Of course, the related incentives to banks are somewhat different in the two cases, and therefore, if everything else remained equal, a system with a deposit facility would not generate the same level of excess reserves plus recourse to the deposit facility as a system without a deposit facility would generate excess reserves. Finally, the Fed allows banks to *carry-over* some reserve deficits or reserve surpluses into the following reserve maintenance period. This specification will contribute to lowering excess reserves in the US as compared to the euro area. The net effect of the mentioned three key differences on the total level of excess reserves can be in either direction, since the first two suggest that excess reserves in the US would be lower, while the last one suggests the opposite.

4 Excess reserves and complementary euro area data

Excess reserves can be split into two main categories: excess reserves generated by banks that are not obliged to fulfil minimum reserve requirements (X1), and excess reserves generated by banks obliged to fulfil reserve requirements (X2). Figure 2 shows the evolution of average excess reserves per maintenance period in the euro area for the period January 2000 to March 2003. The daily average level of excess reserves was EUR 743 million over this sample, with a standard deviation of EUR 176 million. The minimum was EUR 589 million in March 2001 and the maximum EUR 1644 million in January 2002. This exceptionally high figure was due to the euro cash changeover which resulted in extraordinarily high payment uncertainties because of the high volatility of the level of banknotes in circulation. Overall, X1 averaged EUR 161 million with a standard deviation of EUR 39 million. X2 constitutes most of the total of excess reserves. The daily average of X2 has been EUR 582 million with a standard deviation of EUR 162 million.

The level of excess reserves during a maintenance period displays a fairly regular and predictable pattern, see figure 3. It remains low during most of the maintenance period, and builds up rapidly over the last few days. The slightly increasing trend throughout the maintenance period obviously stems from the fact that the number of banks which have already fulfilled their required reserves, and which may hence accumulate excess reserves if they are exposed to a positive liquidity shock at the end of the day (if they do not make recourse to the deposit facility), increases monotonously. The steep increase in excess reserves on the last days of the maintenance period confirms that banks which actually have to fulfil relevant reserve requirements play an important role in generating excess reserves (X2), since banks which do have not to fulfil any effective reserve requirements (X1) should, *ceteris paribus*, accumulate excess reserves in a proportional manner over the reserve maintenance period.

In addition to the data on daily excess reserves, the ECB has also collected data on the monthly reserve requirements of 3522 individual banks for the period from January 1999 to August 2001. These banks' reserve requirements account for most of the euro area reserve requirements. In August 2001, for example, the combined reserve requirement of these banks was EUR 106.5 billion which is 84% of the total euro area reserve requirement of EUR 127.2 billion. The distribution of reserve requirements is skewed heavily towards zero, see table 1. Indeed, in August 2001, 551 banks out of those for which data is available have effective reserve requirements of exactly zero (due to the lump sum allowance of EUR 100,000). The average for this sample of 3522 banks is EUR 30 million, ranging from EUR 0 million to EUR 3694 million. This compares with the average for the Eurosystem as a whole which is EUR 17 million. In the simulation exercises conducted below, the reserve requirements of the remaining banks not included in this sample (which accounted for 16% of aggregate reserve requirements) were assumed to have a similar distribution with the values scaled downwards proportionately. Since the data was only available up to August 2001, it was further assumed that each bank's reserve requirement as a proportion of the total euro area reserve requirement remained the same when the simulations were carried out for subsequent maintenance periods.

Finally, data on the recourse to standing facilities has been collected for the sample period. In the period May 2001 to February 2003, the average total daily recourse by euro area banks to the marginal lending facility amounted to EUR 263 million, while the recourse to the deposit facility amounted to EUR 231 million. As figure 4 reveals, these figures vary to some extent from one reserve maintenance period to the next, with a few outliers. No data was available to the authors on how widespread these recourses were across banks.

5 A transaction costs model of excess reserves

There are two calendar related features that render the formulation of our model cumbersome. Namely, i) money markets are closed over the weekend, and ii) the last day of the maintenace period may occur over the weekend. For the sake of clarity we formulate the model ignoring these complications, and leave for the appendix its more complicated 'full' algebraic formulation.

5.1 Variable definition

We define T as the total number of days in a maintenance period, and the subindex $t = 1, \ldots, T$ will be used to denote a particular day of the maintenance period. For a given bank at time t we further define:

- q reserve requirements.
- ε_t end of day payment shock (liquidity shock).
- r_t^I reserve holdings before the occurrence of ε_t.
- d_t recourse to the deposit facility.

m_t	recourse to the marginal lending facility.
r_t^{II}	reserve holdings after the occurrence of ε_t but before recourse to d_t and m_t.
r_t^{III}	reserve holdings at the very end of the day.
h_t	'stay or go' dummy variable of value either 0 (leave) or 1 (stay).
s_t	cumulative 'gross' excess reserves after recourse to standing facilities (see below).
δ	the cost of 'staying in the office'.

The key ECB interest rates are defined as:

i_t^d	rate of the deposit facility.
i_t^m	rate of the marginal lending facility.
i_t^r	remuneration rate of reserve requirements.
i_t^p	penalty rate applied to the part of reserve requirements not fulfilled.

Figure 1 helps to understand the definitions above by showing the daily time schedule for reserve management faced by treasurers. After the interbank money market has effectively closed in the late afternoon between 17:30 and 18:00, each bank's treasurer knows fairly precisely his position in the interbank market, and by how much he still has to fulfil his reserve requirements. However, the treasurer still faces the possibility of a late payment shock, which may be due to: some erroneous handling of a payment by himself or by another bank, a technical problem with the payment system connection of a bank, or any other unexpected event implying that payments do not go out or come in as expected. In the euro area, it is always possible for banks to deposit excess funds at the deposit facility at 18:30 (when no further payment shock can take place because payment systems are closed), and thus excess reserves could be eliminated. The variable h_t takes the value of 0 if the treasurer decides to leave the office at 17:30 , and the value 1 if he decides to stay until 18:30. The opportunity cost of holding excess reserves is the interest earned from placing them on the deposit facility with the central bank. Assuming that the recourse to the deposit facility is overnight (one day) and that the interest rate of the deposit facility is 2.25%, the amount of lost interest for all banks in the euro area is fairly substantial at around EUR 15 million per year. For an individual bank, however, the amounts are much less significant - the opportunity cost of holding excess reserves of EUR 100,000 for one day is only 6.25 euro. This gain does not justify filling in a form on a computer or picking up the phone. Staff members often do not stay until 18:30, since the money market normally opens at around 8:00 and covering the day until 18:30 would imply excessive labour costs. We will refer to this cost as the '*cost to* *stay*'.[4] Note that from the definitions it follows that:

$$
\begin{aligned}
r_t^{II} &= r_t^I + \varepsilon_t \\
r_t^{III} &= r_t^I + \varepsilon_t + m_t - d_t \qquad (1) \\
s_t &= \sum_{k=1}^{t} r_k^{III} - Tq \qquad (2)
\end{aligned}
$$

Excess reserves are hence defined as $\Psi(s_t)$; where $\Psi(x)$ is a function that takes the value of x for $x > 0$ and the value of 0 otherwise.

5.2 Liquidity management framework in the euro area

It further follows from the specific nature of the operational framework of the ECB, and in particular from the operational procedures applied to the two standing facilities that:

$$d_t = h_t \left\{ \Theta(s_{t-1}) \Psi\left(r_t^{II}\right) + \Theta(-s_{t-1}) \Psi\left(s_{t-1} + r_t^{II}\right) \right\} \qquad (3)$$

$$m_t = \begin{cases} \Psi\left(-r_t^{II}\right) & \text{if } t < T \\ \max\left\{ \Psi\left(-r_t^{II}\right), h_t \Psi\left(-s_{t-1} - r_t^{II}\right) \right\} & \text{if } t = T \end{cases} \qquad (4)$$

where $\Theta(x)$ is a function that takes the value of 1 if $x \geq 0$ and the value of zero otherwise. Although at first sight equations (4) and (3) appear complicated, they can be easily explained. First, recourse to the deposit facility requires an active decision by a bank, and this explains the term h_t in equation (3). Furthermore, the remuneration rate for reserves is higher than the remuneration rate of the deposit facility, and therefore no use will be made of the deposit facility if the reserve holdings count towards reserve requirements, but once they exceed that amount they should be placed in it, or otherwise they will not be remunerated at all. Second, recourse to the marginal lending facility is automatic in the event of negative holdings. Negative holdings trigger an immediate response from the ECB, as no bank is allowed to have an uncollateralised overdraft overnight. Additionally, on the last day of the maintenance period, and if the bank treasurer decides to stay, it pays to avoid the penalty of possible unfulfilled reserve requirements by making use of the marginal lending facility. Obviously, this is so if the penalty rate exceeds the rate of the marginal lending facility, which is always the case.

[4]For the sake of simplicity only this type of transaction cost is incorporated. There are for example some '*once and for all*' set up costs to make recourse to the deposit facility possible for a bank. These costs may consist in signing a specific operational agreement with the central bank, or in agreeing internally on the 'credit line' to be granted to the central bank. Although placing deposits in the central bank is free of risk, internal procedures in banks may be such that the central bank is treated as a normal counterpart. These costs may be sufficient to prompt a counterparty, that thinks that has little need for the deposit facility, to spare them. Indeed, only around 48% of credit institutions have access to the deposit facility.

5.3 Expected cash flow (CF) of staying or leaving at 17.30

The expected CF related to reserve holdings with the central bank if the treasurer decides to stay or leave is:

$$E\{CF_t^{stay}\} = \begin{cases} \mathcal{C}_t\left(i_t^m, i_t^r, 0, i_t^d\right) - \delta & \text{if } t < T \\ \mathcal{C}_t\left(i_t^m, i_t^r, i_t^m, i_t^d\right) - \delta & \text{if } t = T \end{cases}$$

$$E\{CF_t^{leave}\} = \begin{cases} \mathcal{C}_t\left(i_t^m, i_t^r, 0, 0\right) & \text{if } t < T \\ \mathcal{C}_t\left(i_t^m, i_t^r, i_t^p, 0\right) & \text{if } t = T \end{cases}$$

where

$$\mathcal{C}_t\left(a,b,c,d\right) = a\int_{-\infty}^{-r_t^I}\Delta_\varepsilon + b\int_{-r_t^I}^{B-r_t^I}\Delta_\varepsilon + c\int_{-r_t^I}^{B-r_t^I}\Delta_{B\varepsilon} + d\int_{B-r_t^I}^{\infty}\Delta_\varepsilon$$

where $B = \Psi(-s_{t-1})$, and where to save on notation we have denoted $\Delta_\varepsilon = \left(r_t^I + \varepsilon\right) f_{\varepsilon_t} d\varepsilon$, and $\Delta_{B\varepsilon} = \left(r_t^I + \varepsilon - B\right) f_{\varepsilon_t} d\varepsilon$. The integrals in the equation weight shocks by their probability, and the coefficients outside the integrals represent their return. The first integral refers to large negative shocks that would leave the bank with negative reserve holdings by closing time and would thus trigger the use of the marginal lending facility at the i_t^m rate. The second integral refers to shocks that would leave the bank with positive reserve holdings, all of which would be remunerated at the i_t^r rate. The third integral refers to shocks that would induce unfulfilled reserve requirements, and this explains why this integral has a coefficient different from zero only at the end of the maintenance period. This coefficient is i_t^m if the treasurer decides to stay and i_t^p, the penalty rate if he decides to leave. The fourth integral refers to shocks that induce cash holdings in excess of reserve requirements. These will only be remunerated at the deposit rate i_t^d if the treasurer stays, but will not be remunerated, i.e. coefficient zero, if the treasurer leaves. The solutions to those integrals in $\mathcal{C}_t\left(a,b,c,d\right)$ under normality assumptions are provided in the appendix. It then follows that the optimal decision on staying or leaving will depend on which has the largest cash flow, i.e.

$$h_t = \Psi\left(E\{CF_t^{stay}\} - E\{CF_t^{leave}\}\right) \tag{5}$$

5.4 Modelling Assumptions

Thus far all equations presented in the paper are linked to the particular nature of the operational framework of the ECB. We now incorporate our first modelling assumptions:

Assumption 1 *Banks face a probability $1-p$ of being hit by a payment shock ε_t. ε_t is normally distributed with mean 0 and variance $\sigma^2 = \alpha_1 + \alpha_2 q$, where α_1 and α_2 are nonnegative.*

Assumption 2 *Treasurers know ex ante the distribution of* ε_t.

Assumption 3 *Banks aim to fulfil reserve requirements proportionally. By the time money markets close, reserve holdings should be that amount that needs to be held daily (until the end of the maintenance period) to fulfil reserve requirements.*

Assumption 4 *Banks keep precautionary holdings* g *with the central bank; where* $g = \beta_1 + \beta_2 q$ *and* β_1 *and* β_2 *are nonnegative.*

No data on the individual banks' end of day liquidity shocks is available, nor do we have data for the payment system activity of banks which could be regarded as a proxy. Assumption 1 implies that liquidity shocks are positively correlated with bank's reserve requirements, reflecting the idea that large banks are exposed to larger liquidity shocks. The parameter α_1 is needed otherwise banks with zero reserve requirements would also have zero shocks. From anecdotal evidence, the distribution of liquidity shocks is likely to exhibit leptokurtosis: this explains the decision to have distribution of shocks with a probability p being zero.

Valimaki (2001) and Perez-Quiros and Rodriguez-Mendizabal (2001) suggested that the exact modelling of optimizing reserve fulfilment behaviour subject to liquidity shocks over an entire reserve maintenance period of 30 days is extremely complex. It is not only difficult to calibrate with data, but is also unlikely to be followed by bank treasurers who often follow simple rules of thumb. Assumption 3 states that banks follow a rather simple and straightforward strategy in their fulfilment of reserve requirements. This assumption together with assumption 4 on precautionary holdings can be formulated into:

$$r_t^I = g + \frac{\Psi\left(T(q-g) - \sum_{k=1}^{t-1} r_k^{III}\right)}{T-t+1} \tag{6}$$

Equations (1) to (6) complete the formulation of the model.

6 Simulation results

6.1 Simulation method

We use capital letters to define the euro area aggregate equivalents of those variables defined in section 5 above.[5] For example M_t is the aggregate use of the marginal lending facility in the euro area, i.e. the sum of m_t for all banks. Excess reserves were defined as $\Psi(s_t)$, we now denote the aggregate value of excess reserves by XR_t.

[5]Once more, and for presentational purposes, we ignore in the formulation the difficulties associated with weekend days. The appendix addresses this issue.

The data covers 23 maintenance periods, with the first maintenance period beginning on 24 April 2001 and the last ending on 23 March 2003.[6] We thus adopt the strategy of using a second subindex to denote the maintenance period. For example, $M_{n,t}$ is the aggregate use of the marginal lending facility for day t of maintenance period n, with the total number $N = 23$. We further defined the parameter vector to be estimated by $\boldsymbol{\gamma} = \{p, \delta, \alpha_1, \alpha_2, \beta_1, \beta_2\}'$, and the vector $\boldsymbol{Y}_{n,t} = \{XR_{n,t}, M_{n,t}, D_{n,t}\}'$. Simulated least squares has been used to estimate these parameters. The discrepancy function to be minimized under this estimation method is given by

$$\min_{\boldsymbol{\gamma}} \sum_{n=1}^{N} \sum_{t=1}^{T} (\boldsymbol{Y}_{n,t} - E\{\boldsymbol{Y}_{n,t}\})' (\boldsymbol{Y}_{n,t} - E\{\boldsymbol{Y}_{n,t}\}) \tag{7}$$

and where for P a large number, the value of $E\{\boldsymbol{Y}_{n,t}\}$ is estimated by $P^{-1} \sum_{j=1}^{P} \boldsymbol{Y}_{n,t}^{j}$, where $\boldsymbol{Y}_{n,t}^{j}$ is simulated from our model. We define our estimate $\hat{\boldsymbol{\gamma}}$ as that $\boldsymbol{\gamma}$ that solves (7). Using this parameter vector $\hat{\boldsymbol{\gamma}}$ fifty simulations over the same sample period were computed. This provided estimates of the mean and standard deviation of all relevant series.

6.2 Simulation results

The estimated parameters are displayed in table 2. The variance of liquidity shocks is composed of two terms: $\alpha_1 = 0.019$ million of euro and the coefficient $\alpha_2 = 0.17$ that multiplies the level of required reserves. The surprisingly low fixed term results probably from the high number of banks with zero reserve requirements, which after all do not generate so much excess reserves. Indeed, there are many specialized institutions among those zero reserve requirement banks which are typically not exposed to any stochastic flows of reserves. For instance, a bank with average required reserves of EUR 17 million would have a variance of shocks of around EUR 25 billion, whereby only in 62% of days such shocks would actually occur, as revealed by the parameter p of 0.38. The cost of staying, δ, is EUR 200, which looks relatively high. However, when taking into account that a recourse to the deposit facility not only requires the presence of one staff member, but also likely some manager and a back office team, then this figure appears plausible. Furthermore, one should note that in the euro area the payment system opens at 8 and money markets are rather active already at 9:00. Therefore, ordinary staff with a maximum 40 hours working week tends to be unwilling to stay until 18:30, and staff presence of that time may therefore require establishing an expensive shift work system.

Figure 5 compares the actual intra-maintenance period pattern of excess reserves with the average pattern from the fifty simulations for the 21 maintenance periods from 24 July

[6]The estimation could not be performed over an earlier time horizon because accurate daily German excess reserve data was not available.

2001 to 23 March 2002. The simulations for both X1 and X2 fit the actual data overall quite well for all maintenance periods (whether it ended on a weekend or not), except for the first two maintenance periods of 2002 which were affected by the euro cash changeover. These maintenance periods were thus excluded from the results reported in the tables and also from figure 5. At the start of the maintenance period, many of the treasurers with positive reserve requirements would choose to leave the office at 17:30 since there will normally be little possibility of generating excess reserves. The problem for the treasurer arises as he gradually fulfils his reserve requirements, because it increases the probability that a positive shock will force him to fulfil his reserve requirements before the last day of the maintenance period and thus lead him to hold 'excess', non-remunerated reserves, when faced with a positive liquidity shock.

The upper part of table 3 also compares the actual data for excess reserves with the simulated results, calculated as a percentage of reserve requirements. Results for X1 and X2 refer to the actual value on the last day of the maintenance period; results for the use of the marginal lending facility (ML) and the use of the deposit facility refer to the average used over the maintenance period. Broadly speaking our model replicates the fact that the level of excess reserves is high while the average use of both standing facilities is low. The value for X2 is 12.7%, and for X1 is 3.26% while the average use of the ML and DF facilities is 0.99% and 0.21% respectively. These values are very similar to those observed in the euro area. Furthermore, as shown in figure 5, the daily pattern of the simulated series of excess reserves follows also very closely that of the actual series. It needs to be admitted that the obtained figure for the recourse to the marginal lending facility seems to over-estimate actual recourse (which is only slightly higher than actual recourse to the deposit facility). The fact that end of day liquidity absorbing shocks can force banks already early in the maintenance period into recourse to the marginal lending facility, while the same rarely holds for the deposit facility, makes the actual figures more surprising than the ones obtained in the simulation. Maybe one reason for the relative similarity of the sizes of the two actual recourses stems from the practice of some banks to use the deposit facility already earlier in the maintenance period in case of liquidity injecting shocks, even if they still have reserve requirements to be fulfilled.

6.3 Simulation of policy scenarios

Using the model and the estimated parameters, some scenario analysis was performed to see the impact on the level and volatility of excess reserves of changing some of the key parameters of the monetary policy operational framework. The following scenarios were simulated:

i. Increase all key ECB interest rates by 2%
ii. Decrease all key ECB interest rates by 2%
iii. Narrow symmetrically the corridor set by standing facilities by 100 basis points
iv. Widen symmetrically the corridor set by standing facilities by 200 basis points
v. Abolish the deposit facility rate (leaving other rates unchanged)
vi. Increase the penalty rate by 5% (leaving other rates unchanged)
vii. Decrease the penalty rate by 2.5% (leaving other rates unchanged)
viii. Increase banks' reserve requirements by 100%
ix. Decrease banks' reserve requirements by 50%
x. Increase the variance payment system shocks by 100%
xi. Decrease the variance payment system shocks by 50%

The different policy scenarios were simulated over the same time horizon, (24 July 2001 to 23 March 2002), with 50 simulations for each scenario, such that eventually, data for 50 times 21 maintenance periods was generated for each. The average accumulated excess reserves as a percentage of reserve requirements and the standard deviation were calculated for each scenario, see table 3. The bottom part of table 3 displays, for easier reading, the figures for the hypothetical scenarios *as percent of the figures of the baseline scenario.* For monetary policy implementation, the impact on the standard deviation is perhaps the most important, as this determines how easy it is to forecast excess reserves when the ECB makes the allotment decisions in its open market operations.

As expected, excess reserves in the category X1 are practically unaffected by the different policy scenarios. However, there is a more significant impact on excess reserves in category X2 and therefore a corresponding impact on total excess reserves.

Scenario i and ii. Increasing all key ECB interest rates by 2% leads to a reduction of around 75% for X2 excess reserves, and its standard deviation decreases proportionally. This result was to be expected, as increasing interest rates raises the opportunity cost of holding excess reserves and the model predicts that this would increase the likelihood that the treasurer would stay late in the office. Similarly, decreasing all key ECB rates by 2%, i.e. decreasing the opportunity cost of staying in the office, leads to an increase in excess reserves. However, the effect is much stronger than under the previous scenario: total excess reserves increase to 237% of the baseline scenario. This stronger reaction of excess reserves to a lowering of rates suggests a (plausible) convexity in the relationship between rates and excess reserves. The standard deviation also increases significantly and more than proportionally, reaching 326% of the baseline standard deviation. Hence, excess reserves are likely to become significantly more difficult to forecast when rates fall. Indeed, the ECB has recently, after several rate cuts, observed some more non-anticipated elements in excess reserves and a worsening of the performance of its forecasting.

Although the model therefore generates the plausible result that the level of excess reserves is to some extent interest rate dependent, this should not lead to the conclusion that excess reserves play an important role in the transmission mechanism of monetary policy. A central bank would simply consider the effects of the interest rate level when making its forecasts of the overall need for reserves to ensured balanced liquidity conditions.

Scenario iii and iv. When the corridor of standing facility rates is symmetrically tightened to a width of only 100 basis points (from the actual 200 basis points), excess reserves decline. This mainly reflects the increased level of the deposit facility. The opposite effect is obtained when the corridor is widened to a total of 400 basis points.

Scenario v. Under the fifth scenario, the deposit facility is completely abolished, eliminating any benefit of staying in the office. As expected, excess reserves increase substantially to 392% of the baseline scenario level. The standard deviation of excess reserves increases to more than 900% of the baseline level.

Scenario vi and vii. Changing the penalty rate, however, does not have a significant impact, although it would have been plausible that it increases the incentive of treasurers to stay in the office on the last business day of the maintenance period to ensure they have complied with reserve requirements. Reducing the penalty rate by 2.5% so that it would equal the marginal lending rate and there is effectively no penalty, leads to the expected effect of an increase in excess reserves, although this effect is rather small.

Scenarios viii and ix. Changes to banks' reserves requirements, have a significant impact. Doubling reserve requirements (from EUR 130 billion to EUR 260 billion) leads to a fall in excess reserves to 50% of their baseline level. Halving reserve requirements leads to a large increase in excess reserves to 162% of the baseline scenario level. Standard deviations of excess reserves change also along these lines.

Scenario x and xi. Changes in the volatility of payment shocks can be interpreted as: a) changes in the efficiency of payment systems, b) changes in the volume of payment activities, or c) changes in the smoothness of the functioning of money markets. Changes in the volatility of payment shocks also produce the expected effects. A doubling of the volatility of payment shocks increases the level of excess reserves to 300% and the standard deviation to even 774% of the baseline levels. A decrease of the variance of shocks has opposite effects. The cash change-over reserve maintenance period with its accumulated excess reserves of around 40% of required reserves can be understood as illustration of this case.

What would higher levels of volatility of excess reserves, as emerging under several of the scenarios above, mean for euro area money markets and the practice of day-to-day implementation of monetary policy by the ECB? Increased volatility normally implies ceteris paribus increased forecasting errors of excess reserves. The standard deviation of actual accumulated excess reserves in the Eurosystem forecasts has been around EUR 2 billion in the years 2001 and 2002. Since under some of the scenarios above, the standard deviation of excess reserves almost quadrupled, one can well imagine that also forecast errors might quadruple, leading to a standard deviation of forecast errors of around EUR 8 billion. This would actually make forecast errors in excess reserves the largest source of errors in the calibration of open market operations, i.e. before the other classical autonomous factors such as banknotes and Government deposits. Some additional volatility of the overnight interest rate would thus be experienced on the last days of the reserve maintenance period. To the extent that the ECB disliked such additional volatility, it could make additional efforts to forecast excess reserves. However, one could argue that this volatility of money market rates would remain limited to the shortest maturities and would not be transmitted along the yield curve towards maturities judged relevant for the transmission of monetary policy. In so far, the ECB may also simply accept such additional transitory volatility.

7 Conclusions

Although excess reserves should not play a particular role in monetary macroeconomics, it should not be forgotten that they represent a challenge in day-to-day monetary policy implementation because they constitute an only partially predictable reserve market factor, similar to other so-called autonomous liquidity factors like for instance the deposits of the Government with the central bank.

A simple transaction cost model of excess reserves presented was able to replicate very well the excess reserves patterns observed, in particular the intra-reserve maintenance period pattern. The model was mainly based on the (low) cost to treasurers of using the deposit facility. This was exemplified by the choice of either bearing a daily cost of staying in the office until money markets close to fine tune the end of day position, or leaving somewhat earlier and letting end of day payment shocks impact on reserve holdings.

The simulation of the model revealed that, as expected, one should observe an increase of excess reserves when the level of interest rates, and in particular the level of the deposit facility rate, declines. However, the resulting negative correlation between interest rates and excess reserves is not the basis for an excess reserves channel of monetary policy transmission because the excess reserves in the model are nothing that a bank could use to expand its loans and hence to create additional money. Excess reserves are not a stable quantity at the level of individual banks, but just a stochastic ex-post residual from payment shocks. Therefore, it does not make any economic sense to expect individual banks to expand loans if this residual increases on average.

In this context, we used our simple model to simulate the impact of various other changes to exogenous variables on the level and volatility of excess reserves. The results suggest not only that excess reserves may increase considerably under some changes of the framework for monetary policy implementation, but also that their volatility and hence unpredictability could. This could potentially cause an increase of the volatility of the overnight rate at the very end of the reserve maintenance period.

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Appendix A

$$\int_{-\infty}^{-r_t^I} \Delta_\varepsilon = -\sigma^2 f_\varepsilon\left(-r_t^I\right) + r_t^I \phi\left(\frac{-r_t^I}{\sigma}\right)$$

$$\int_{-r_t^I}^{B-r_t^I} \Delta_\varepsilon = \sigma^2\left\{f_\varepsilon\left(-r_t^I\right) - f_\varepsilon\left(B-r_t^I\right)\right\} + r_t^I\left\{\phi\left(\frac{B-r_t^I}{\sigma}\right) - \phi\left(\frac{-r_t^I}{\sigma}\right)\right\}$$

$$\int_{-r_t^I}^{B-r_t^I} \Delta_{B\varepsilon} = -B\left\{\phi\left(\frac{B-r_t^I}{\sigma}\right) - \phi\left(\frac{-r_t^I}{\sigma}\right)\right\} + \int_{-r_t^I}^{B-r_t^I} \Delta_\varepsilon$$

$$\int_{B-r_t^I}^{\infty} \Delta_\varepsilon = \sigma^2 f_\varepsilon\left(B-r_t^I\right) + r_t^I \phi^c\left(\frac{B-r_t^I}{\sigma}\right)$$

where $\phi(x)$ is the value of the cumulative normal distribution and $\phi(x)^c = 1 - \phi(x)$.

Appendix B: Model with weekend days

The much more complicated formulation presented below results from the fact that a new maintenance period may start over the weekend, and treasurers can only take actions from Monday to Friday. Recourse to the marginal lending facility and deposit facility on a Friday will be automatically extended to both Saturday and Sunday. This opens a variety of possible responses depending on whether the end of the maintenance period falls on a certain day of the week. The variables defined will adopt now the double subscript $_{t,z}$ where $z = \{Mon, Tue, \ldots, Sun\}$, and as before $t = \{1, 2, \ldots, T\}$. We further define the set of all days as $\mathbf{\Omega} = \{z : z \in \{Mon, \ldots, Sun\}; t = \{1, \ldots, T\}\}$, and use ν to denote the level of reserve requirements of next maintenance period.

$$m_{t,z} = \begin{cases} \Psi\left(-r_{t,z}^{II}\right) & \text{if } (t,z) \in \mathbf{\Omega}_0 \\ \max\left\{\Psi\left(-r_{t,z}^{II}\right), h_{t,z}\frac{1}{\lambda_z}\Psi\left(-s_{t-1,z-1} - \lambda_z r_{t,z}^{II}\right)\right\} & \text{if } (t,z) \in \mathbf{\Omega}_{1,4} \\ \max\left\{\Psi\left(-r_{t,z}^{II}\right), h_{t,z}\left(\tilde{\mu}_{t,z} - r_{t,z}^{II}\right)\right\} & \text{if } (t,z) \in \mathbf{\Omega}_{2,3} \\ m_{t-1,z-1} & \text{if } (t,z) \in \mathbf{\Omega}_5 \end{cases}$$

$$d_{t,z} = \begin{cases} h_{t,z}\left\{\Theta\left(s_{t-1,z-1}\right)\Psi\left(r_{t,z}^{II}\right) + \Theta\left(-s_{t-1,z-1}\right)\frac{1}{\lambda_z}\Psi\left(s_{t-1,z-1} + \lambda_z r_{t,z}^{II}\right)\right\} & \text{if } (t,z) \in \mathbf{\Omega}_{0,1,4} \\ h_{t,z}\left(r_{t,z}^{II} - \mu_{t,z}\right) & \text{if } (t,z) \in \mathbf{\Omega}_{2,3} \\ d_{t-1,z-1} & \text{if } (t,z) \in \mathbf{\Omega}_5 \end{cases}$$

where the sets $\mathbf{\Omega}_i$ for $i = 0$ to 6 are defined as:

$$\begin{aligned} \mathbf{\Omega}_1 &= \{z : z \in \{Mon, \ldots, Thu\}; t = T\} \\ \mathbf{\Omega}_2 &= \{z : z \in Fri; t = T\} \\ \mathbf{\Omega}_3 &= \{z : z \in Fri; t = T-1\} \\ \mathbf{\Omega}_4 &= \{z : z \in Fri; t = T-2\} \\ \mathbf{\Omega}_5 &= \{z : z \in \{Sat, Sun\}\} \\ \mathbf{\Omega}_0 &= \{\mathbf{\Omega}_1 \cup \mathbf{\Omega}_2 \cup \ldots \cup \mathbf{\Omega}_5\}^c \\ \mathbf{\Omega}_6 &= \{z : z \in Fri\} \cap \mathbf{\Omega}_0 \end{aligned}$$

where ^{c} denotes the complement set, and where we have adopted the notation $\mathbf{\Omega}_{i,j} = \{\mathbf{\Omega}_i \cup \mathbf{\Omega}_j\}$; and λ_z is defined as follows:

$$\lambda_z = \begin{cases} 3 & \text{if } z \in \mathbf{\Omega}_{4,6} \\ 2 & \text{if } z \in \mathbf{\Omega}_3 \\ 1 & \text{otherwise} \end{cases} \tag{8}$$

Note that $\mathbf{\Omega}_0, \mathbf{\Omega}_1, \ldots, \mathbf{\Omega}_5$ are disjoint sets such that $\mathbf{\Omega} = \mathbf{\Omega}_0 \cup \mathbf{\Omega}_1 \cup \ldots \cup \mathbf{\Omega}_5$, and $\mathbf{\Omega}_6$ is simply a subset of $\mathbf{\Omega}_0$.

Finally, $\mu_{t,z}$ is defined as that μ which maximizes the cash flow function $\mathcal{M}_{t,z}$, subject to $0 \leq \mu \leq r^{II}_{t,z}$ and $x = i^d_{t,z}$, where $\mathcal{M}_{t,z}$ is defined as:

$$\mathcal{M}_{t,z} = 3\left(r^{II}_{t,z} - \mu\right)x + \mathcal{F}^b_{t,z} + \mathcal{F}^a_{t,z} - \Psi\left(-s_{t-1,z-1} - \lambda_z \mu\right) i^p_{t,z} \tag{9}$$

where:

$$\mathcal{F}^b_{t,z} = \sum_{j=1}^{\lambda_z} \left\{\mu - \Psi\left(s_{t-1,z-1} + j\mu\right)\right\} i^r_{t,z}$$

$$\mathcal{F}^a_{t,z} = \sum_{j=\lambda_z+1}^{3} \left\{\mu - \Psi\left(T\nu + (j-\lambda_z)\mu\right)\right\} i^r_{t,z}$$

$\tilde{\mu}_{t,z}$ is defined as that μ which solves (9) subject to $\mu \geq r^{II}_{t,z}$ and $x = i^m_{t,z}$. The corresponding maximum values resulting from these two constrained optimization problems will be denoted by $\mathcal{M}^*_{t,z}$ and $\tilde{\mathcal{M}}^*_{t,z}$ respectively. The expression above follows from the fact that funds placed in the deposit facility will be remunerated at the deposit facility rate i^d, but funds held as normal reserves with the central bank will only be remunerated at the rate i^r as long as not exceeding the amount of required reserves. The different components of equation (9) are explained as follows: the first summand gives the cash flow resulting from placing money in the deposit facility (use of the marginal facility for $\tilde{\mu}_{t,z}$); $\mathcal{F}^b_{t,z}$ gives the cash flow resulting from placing money in the account with the central bank in those days before the end of the current maintenance period, i.e. the remuneration for those holdings that do not exceed the reserve requirements. $\mathcal{F}^a_{t,z}$ represents that same cash flow after the end of the maintenance period. Finally, the last summand gives the costs of unfulfilling the reserve requirements. Note that the ECB rates will not change over the weekend and this is why their corresponding subindexes remain $_{t,z}$ in the formula.

Note that for the above formulas to hold we will adopt the convention of defining $r^I_{t,z} = r^{III}_{t-1,z-1} - m_{t-1,z-1} + d_{t-1,z-1}$ if $z \in \mathbf{\Omega}_5$, as the central bank is closed over the weekend. It is also important to note that the liquidity shock $\varepsilon_{t,z}$ is zero for $z \in \{Sat, Sun\}$.

$$E\{CF_{t,z}^{stay}\} = \begin{cases} \lambda_z \mathcal{C}_{t,z}\left(i_{t,z}^m, i_{t,z}^r, 0, i_{t,z}^d, 0\right) - \delta & \text{if } z \in \mathbf{\Omega}_0 \\ \lambda_z \mathcal{C}_{t,z}\left(i_{t,z}^m, i_{t,z}^r, i_{t,z}^m, i_{t,z}^d, 0\right) - \delta & \text{if } z \in \mathbf{\Omega}_{1,4} \\ \max\left\{E\left\{\mathcal{M}_{t,z}^*\right\}, E\left\{\tilde{\mathcal{M}}_{t,z}^*\right\}\right\} - \delta & \text{if } z \in \mathbf{\Omega}_{2,3} \\ \delta & \text{if } z \in \mathbf{\Omega}_5 \end{cases}$$

$$E\{CF_{t,z}^{leave}\} = \begin{cases} \lambda_z \mathcal{C}_{t,z}\left(i_{t,z}^m, i_{t,z}^r, 0, 0, 0\right) & \text{if } z \in \mathbf{\Omega}_0 \\ \lambda_z \mathcal{C}_{t,z}\left(i_{t,z}^m, i_{t,z}^r, i_{t,z}^p, 0, 0\right) & \text{if } z \in \mathbf{\Omega}_{1,4} \\ \mathcal{C}_{t,z}\left(3i_{t,z}^m, \lambda_z i_{t,z}^r, i_{t,z}^p, 0, (3-\lambda_z) i_{t,z}^r\right) & \text{if } z \in \mathbf{\Omega}_{2,3} \\ 0 & \text{if } z \in \mathbf{\Omega}_5 \end{cases}$$

where the function $\mathcal{C}_{t,z}(a, b, c, d, e)$ is equal to:

$$a \int_{-\infty}^{-r_{t,z}^I} \Delta_\varepsilon + b \int_{-r_{t,z}^I}^{B\lambda_z^{-1} - r_{t,z}^I} \Delta_\varepsilon + c \int_{-r_{t,z}^I}^{B\lambda_z^{-1} - r_{t,z}^I} \Delta_{B\varepsilon} + d \int_{B\lambda_z^{-1} - r_{t,z}^I}^{\infty} \Delta_\varepsilon + e \int_{-r_{t,z}^I}^{T\nu\lambda_z^{-1} - r_{t,z}^I} \Delta_\varepsilon$$

where $B = \Psi(-s_{t-1,z-1})$, and where to save on notation we have denoted $\Delta_\varepsilon = \left(r_{t,z}^I + \varepsilon\right) f_{\varepsilon_t} d\varepsilon$, and $\Delta_{B\varepsilon} = \left(\lambda_z (r_{t,z}^I + \varepsilon) - B\right) f_{\varepsilon_t} d\varepsilon$. The additional integral five is related to the difficulties associated with the end of the maintenance period ending over the weekend. Reserve holdings that can be remunerated over the next maintenance period are dealt with in the fifth integral. The solutions of the first four integrals under normality assumptions is similar to those provided in the previous appendix, the solution to the fith integral is given by:

$$\int_{-r_{t,z}^I}^{T\nu\lambda_z^{-1} - r_{t,z}^I} \Delta_\varepsilon = \sigma^2 \left\{ f_\varepsilon\left(-r_{t,z}^I\right) - f_\varepsilon\left(T\nu\lambda_z^{-1} - r_{t,z}^I\right)\right\} + r_{t,z}^I \left\{ \phi\left(\frac{T\nu\lambda_z^{-1} - r_{t,z}^I}{\sigma}\right) - \phi\left(\frac{-r_{t,z}^I}{\sigma}\right)\right\}$$

Finally, the formulation of $h_{t,z}$ and $r_{t,z}^I$ are

$$h_{t,z} = \Psi\left(E\{CF_{t,z}^{stay}\} - E\{CF_{t,z}^{leave}\}\right)$$

$$r_{t,z}^I = \frac{\Psi\left(Tq - \sum_{k=1}^{z-1} r_{t,k}^{III}\right)}{Z - z + 1}$$

Table 1: Distribution of reserve requirements in the euro area.[a]

Reserve Requirements (q) in EUR mill.	Number of banks
0	551
$0 < q \leq 10$	2076
$10 < q \leq 100$	738
$100 < q \leq 500$	114
$500 < q \leq 1000$	26
$1000 < q$	17

[a]The figures displayed are extracted from a sample of 3522 banks which accounted for 84% of total reserve requirements.

Table 2: Estimated parameters.[a]

parameter	value
α_1	19×10^{-6}
α_2	0.17
δ	2×10^{-7}
p	0.38
β_1	55×10^{-6}
β_2	0.33

[a]Recall that variance of the shocks, $\sigma^2 = \alpha_1 + \alpha_2 q$, δ is the 'cost of staying'; p is the probability that the shock is zero; β_1, β_2 are parameters associated with precautionary holdings, i.e. $g = \beta_1 + \beta_2 q$. α_1, β_1 and δ are in billions euro.

Table 3: Excess reserves as a (%) of reserve requirements.[a]

scenario	X1 mean	X1 st dev	X2 mean	X2 st dev	Total mean	Total st dev	ML mean	ML st dev	DF mean	DF st dev
euro area data	3.268	0.356	14.029	1.328	17.297	1.518	0.263	0.176	0.231	0.113
benchmark	3.261	0.011	12.706	0.268	15.966	0.268	0.997	0.010	0.212	0.010
Values										
Δ all rates by 2%	3.261	0.012	10.851	0.264	14.113	0.265	1.001	0.010	0.745	0.018
∇ all rates by 2%	3.260	0.074	14.472	1.006	17.732	1.000	1.002	0.011	0.182	0.255
∇ band by 0.5%	3.261	0.009	12.095	0.217	15.356	0.218	1.001	0.009	0.736	0.013
Δ band by 1%	3.261	0.010	13.367	0.232	16.628	0.233	1.001	0.010	0.198	0.008
abolish i^d	3.262	0.011	21.613	1.001	24.875	1.000	1.001	0.009	0.000	0.000
∇ of i^p by 2.5%	3.259	0.010	12.716	0.214	15.976	0.214	0.992	0.008	0.733	0.014
Δ of i^p by 5%	3.260	0.012	12.614	0.218	15.874	0.221	1.006	0.010	0.207	0.010
Δ of q by 100%	1.630	0.005	10.719	0.210	12.349	0.211	1.013	0.010	0.219	0.009
∇ of q by 50%	6.521	0.023	14.413	0.268	20.935	0.271	0.983	0.010	0.197	0.009
Δ σ by 100%	3.261	0.010	40.762	0.555	44.023	0.557	0.393	0.004	0.169	0.005
∇ σ 50%	3.262	0.011	3.365	0.079	6.627	0.081	2.554	0.025	0.313	0.020
% of benchmark										
Δ all rates by 2%	100	107	85	99	88	99	100	99	351	187
∇ all rates by 2%	100	677	114	375	111	373	100	110	86	2625
∇ band by 0.5%	100	84	95	81	96	82	100	88	347	137
Δ band by 1%	100	92	105	86	104	87	100	100	93	80
abolish i^d	100	101	170	373	156	373	100	88	0	0
∇ of i^p by 2.5%	100	95	100	80	100	80	99	72	345	145
Δ of i^p by 5%	100	110	99	81	99	82	100	95	98	102
Δ of q by 100%	50	50	84	78	77	79	101	92	103	94
∇ of q by 50%	200	206	113	100	131	101	98	97	93	95
Δ σ by 100%	100	90	321	207	276	208	39	37	80	50
∇ σ50%	100	97	26	30	42	30	255	235	147	203

[a]Figures refer to observations on the last day of the maintenance period. Sample period is 2001-5 to 2003-2. X1 denotes excess reserves generated by banks that are not obliged to fulfill minimum reserve requirements; X2 excess reserves generated by banks obliged to fulfill reserve requirements. ML denotes average use of marginal lending facility, and DF average use of deposit facility.

Figure 1: Daily time schedule for reserve management.

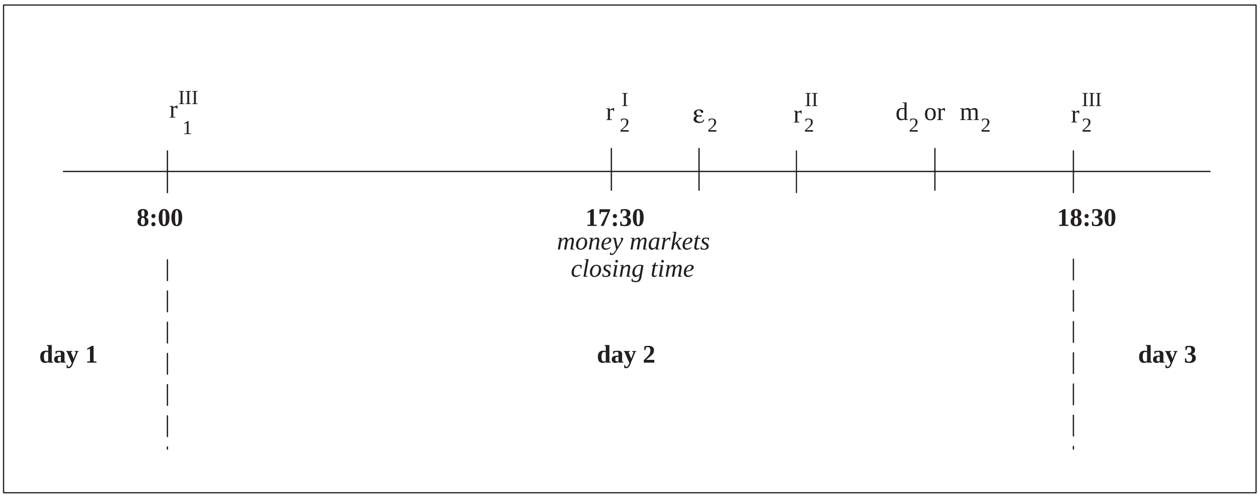


Figure 2: Evolution of average excess reserves per MP (1999-2002).

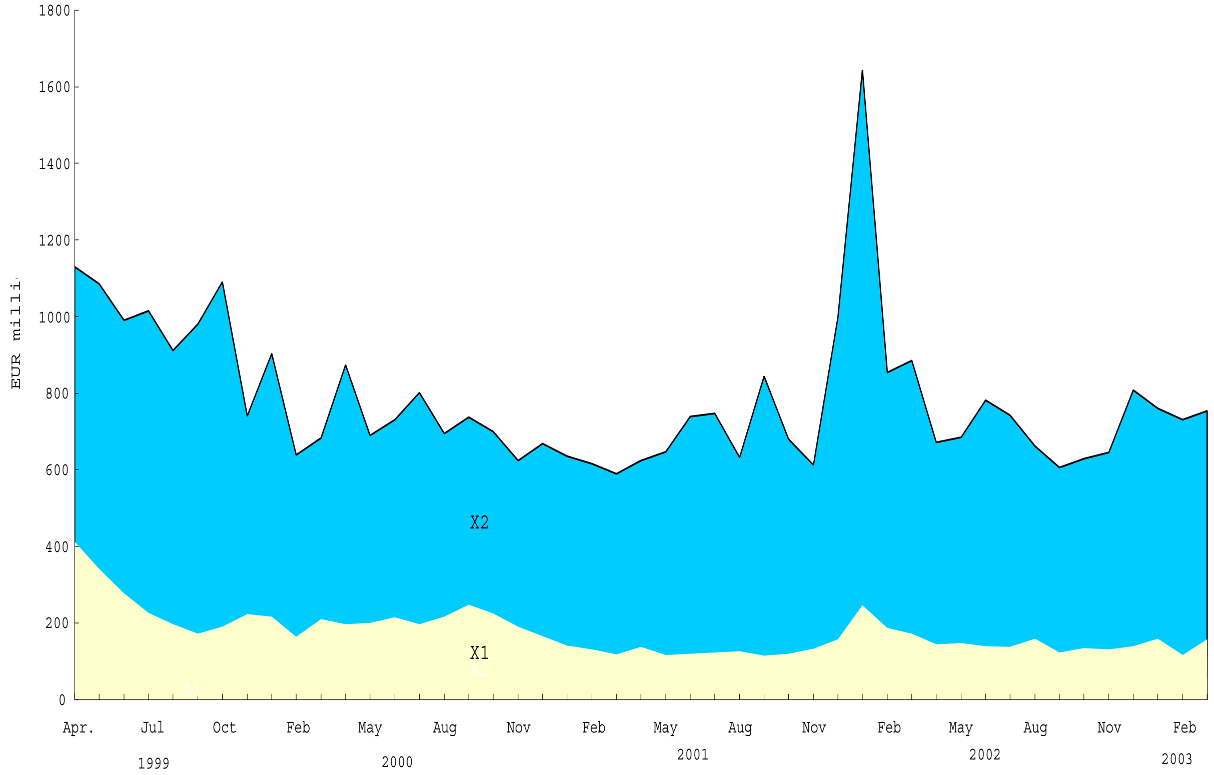


Figure 3: Intra-maintenance period evolution of total excess reserves. Euro area May-2001 to Nov-2002 (EUR mill). Average pattern for all periods is shown in bold

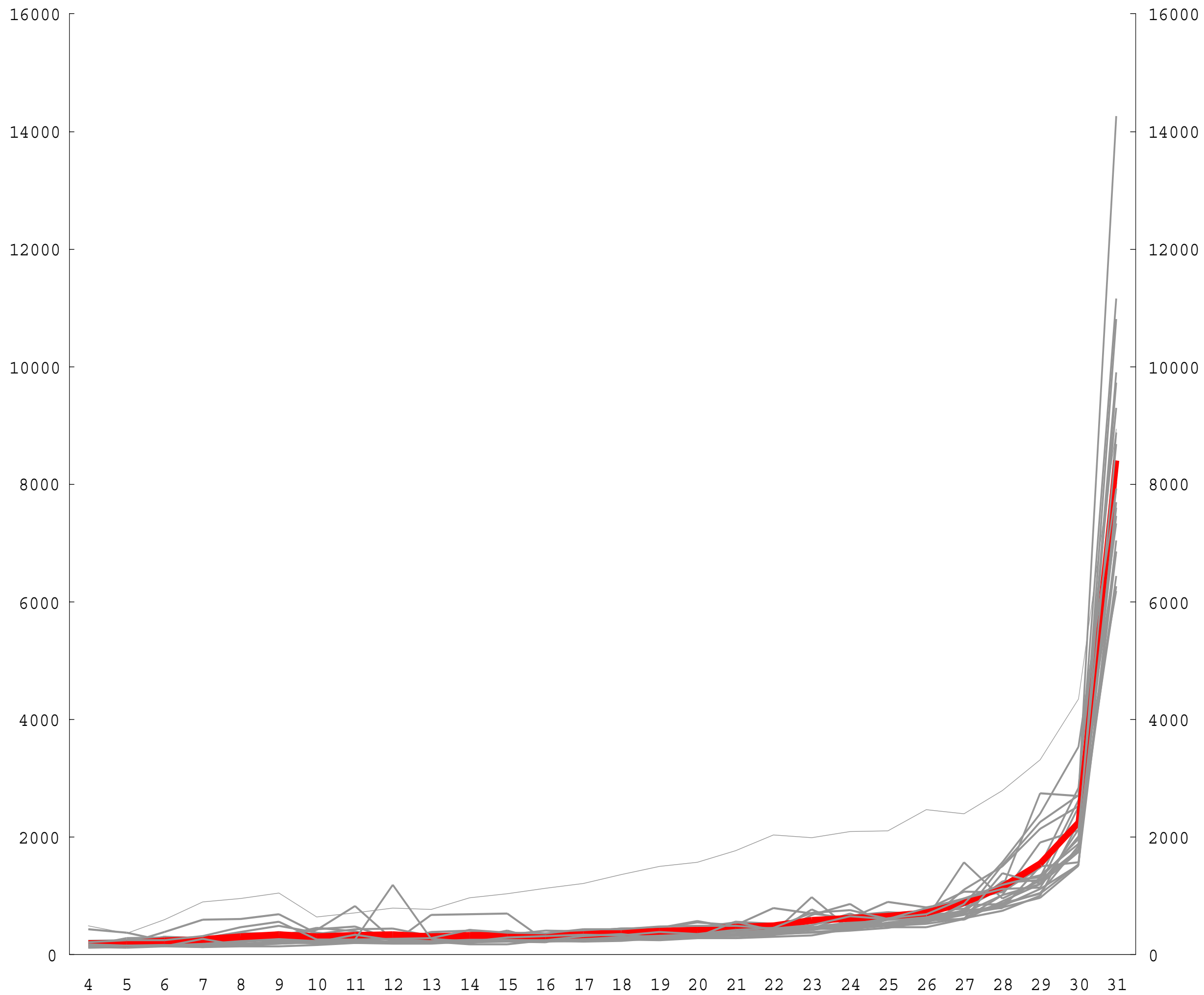


Figure 4: Use of Standing Facilities as a (%) of reserve requirements.

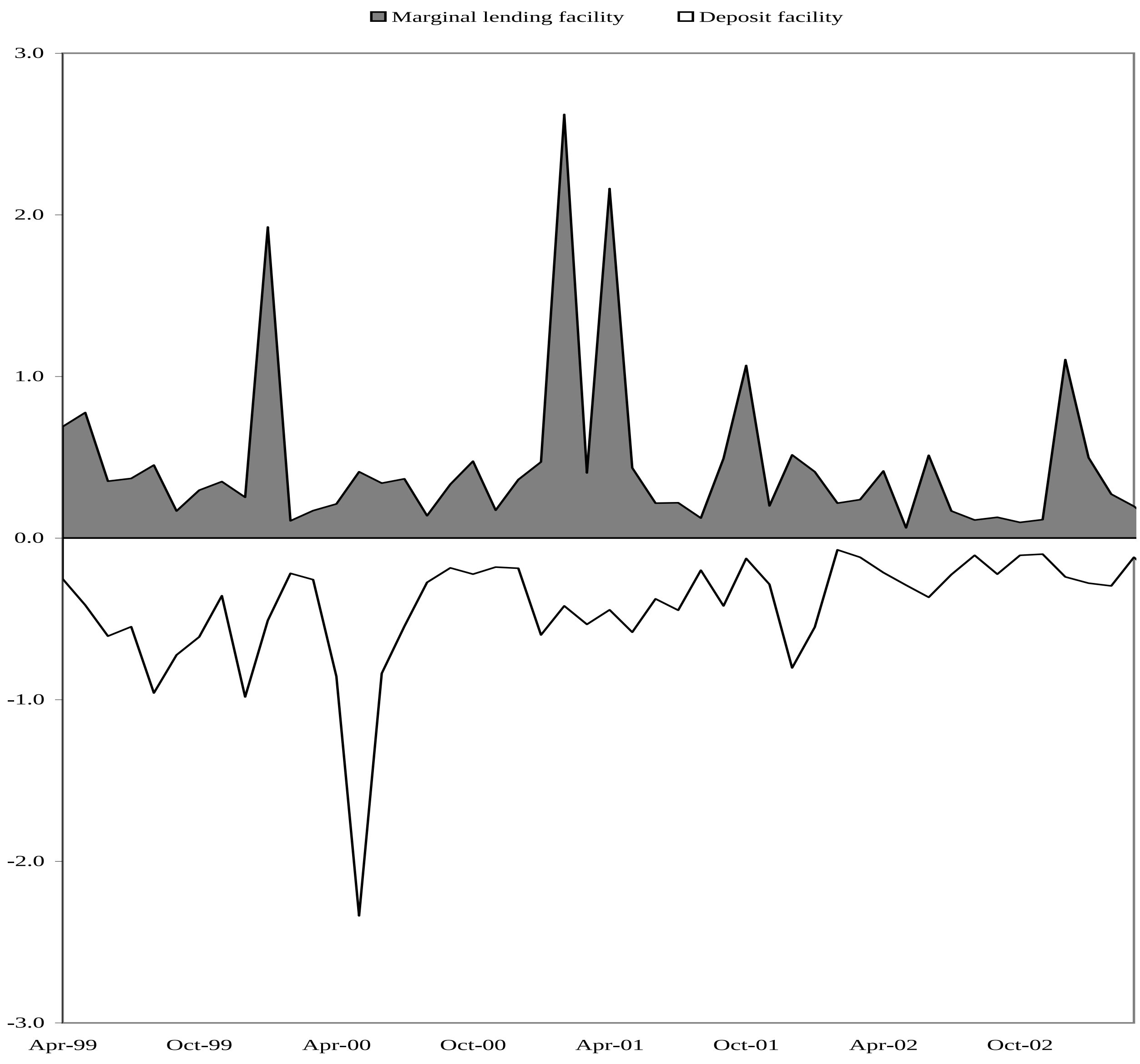
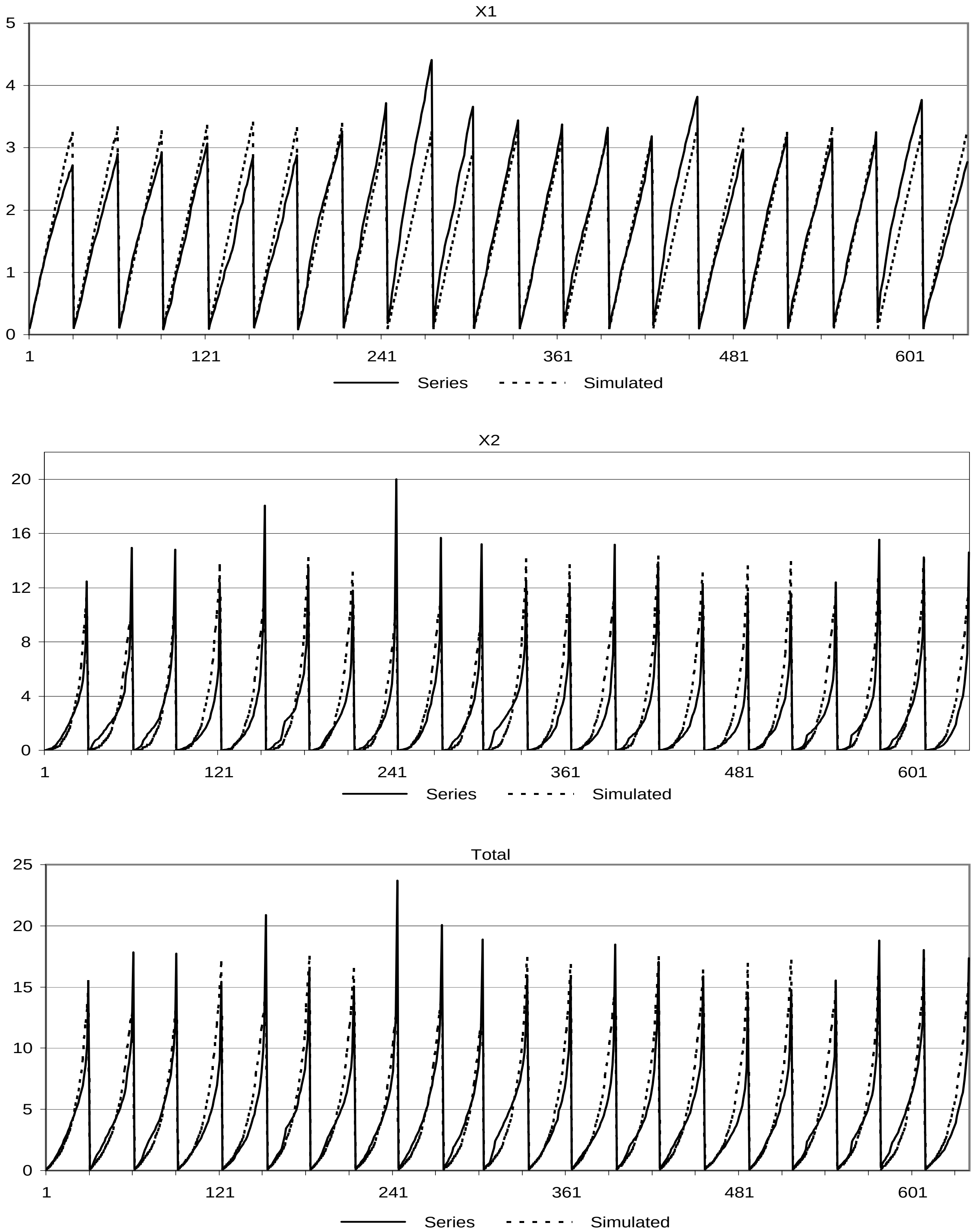


Figure 5: Excess reserves simulations (accumulated) from the model (2001-5 to 2003-3)



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