Excess reserves and the ECB's implementation of monetary policy

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Abstract

Banks usually hold reserves in excess of the minimum reserves they are required to hold on their accounts with their central bank. Excess reserves were regarded in the past as playing a 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, in theory, conducted with the main objective of steering the level of excess reserves. This view on excess reserves is usually referred to as 'reserve position doctrine'. This paper addresses four issues related to excess reserves. First it explains the *raison d'être* of excess reserves in the euro area. Second, it reviews the actual ECB's approach to excess reserves in the implementation of monetary policy. Third, a simple economic model is developed which replicates astonishingly well the empirical patterns of excess reserves in the euro area. The model is used to simulate the level of excess reserves that should be expected under various scenarios. Finally, 'reserve position doctrine' is revisited. It is argued that this doctrine is (also) inappropriate for the euro area.

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

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1 Introduction

In the 19th century and until around the 1920s, 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 main 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 the 'reserve position doctrine' (RPD) as a result of: *i*) the revival of the quantity theory of money by Irving Fisher among others, *ii*)the introduction of the money multiplier by C.A. Phillips in 1920, and *iii*) the difficulties in the implementation of monetary policy experienced by the Fed in its first decade.[1]

The 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 in the transmission of monetary policy, where excess reserves refer to the current account holdings of banks with their central bank beyond required reserves. Open market operations were therefore to be conducted with the main objective of steering the level of excess reserves. The RPD was also the key rationale for the perceived supremacy of open market operations over standing facilities which emerged during these decades. This situation has been reversed only since the beginning of the 1990s when central banks returned to more explicit interest rate targeting, and made somewhat ambiguous the difference between standing facilities and open market operations by conducting the latter more and more in the form of reverse operations. An early advocate of RPD was Keynes (1930, p. 226), who 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 would be 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

[1] The term 'reserve position doctrine' is due to Meigs (1962, pp. 7-22), who also surveys the literature before 1960.

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 a role for interest rates in the implementation of monetary policy, 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 what they probably regarded as petty-minded technical concepts like excess reserves, free reserves, borrowed reserves, etc. Nevertheless, monetarists were united with RPD through their common preference for quantities over rates in the implementation of monetary policy.

Academic views on excess reserves started to develop further in the 1960s with the publication of the precautionary demand models of Orr and Mellon (1961) and Poole (1968). These models laid down the micro-foundations of a bank demand for excess reserves and suggested that the demand for excess reserves should decrease with interest rates and increase with the magnitude of payment shocks. Following up on this work, Frost (1971) comes to the conclusion that the large accumulation of excess reserves during the 1930's is explained by the fact that banks find it profitable to hold excess reserves at very low interest rates because the transaction costs of constantly adjusting reserve positions is greater than the interest that could be earned. Kaufman and Lombra (1980) challenge previous views on excess reserves by arguing that "*the central role of the demand for excess reserves function in models of the money supply process is particularly suspect*", and that it does not even make sense to talk about a 'demand' function for excess reserves since excess reserves are basically only the residual ex post result of payment shocks. Still, 10 years later, the Shadow Open Market Committee [1991] argued that "*if banks have become reluctant to lend, as exponents of the credit crunch suppose, banks' excess reserves would have increased*", thereby expanding the role of excess reserves from the previous money multiplier logic to the new credit channel of monetary policy. Haubrich (1991) argues against this view, following mainly Kaufman and Lombra (1980). Recent work by Dow (2001), shows that the demand for excess reserves in the US is indeed positively correlated to payment system activity and negatively correlated to interest rates. Finally, Clouse and Dow (2002) use numerical methods to model excess reserves in a framework such as the one in the US.

While some doubts on RPD have thus emerged in the academic journal literature, recent textbooks predominantly tend to repeat RPD views. For instance Walsh (1998, p. 406) presents some intricate RPD variant as key to monetary policy transmission:

> *"In terms of an analysis of the reserve market and operating procedures, the most important... is the excess reserve ratio. Since reserves earn no interest, banks face an opportunity cost in holding excess reserves. As market rates rise, banks will tend to hold a lower average level of excess reserves. This drop in the excess reserves ratio will work to increase M1. This analysis implies that, holding the base constant, fluctuations in market interest rates will induce movements in the money supply"*

Hence RPD is still alive and spreads through popular textbooks to new generations of monetary economists.

Turning to central banks, it appears that until 1979, central banks had mainly paid more (e.g. the Fed) or less (e.g. the Bank of England) intense lip service to RPD variants. The Fed during the 1950s and 1960s presented 'free reserves', i.e. the difference between excess reserves and discount window borrowing, as a key indicator of the monetary policy stance. During the 1970s, the FED targeted interest rates more explicitly, and therefore in practice fully ignored RPD. The 1979-82 Fed experiment with short term monetary control was probably the most ambitious attempt to put some sort of RPD into practice. Since then, those central banks supporting at that time RPD have more and more joined again those which, like for instance the Bank of England, never had abandoned the idea that monetary policy transmission starts with the central bank setting short term interest rates.[2] Noteworthy in this context 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). Still, the BOJ acknowledged that it is "as drastic as is unlikely to be taken under ordinary circumstances."

The purpose of this paper is to investigate to what extent excess reserves are and should (not) be relevant today in the implementation of monetary policy focusing on the specific case of the operational framework of the Eurosystem. Section 2 presents the relevant aspects of this operational framework and compares the implied raison d'être of excess reserves with the one in the US. Section 3 provides some stylized facts of the euro area excess reserves data and explains the Eurosystem's technique to deal with excess reserves in its day-to-day implementation of monetary policy. The forecasting model for excess reserves employed by the ECB to calibrate its allotment decisions is described. Section 4 develops a simple economic model of excess reserves in the euro area. Section 5 estimates the model parameters with the help of daily data. This simple model allows to replicate astonishingly well the actual path of excess reserves in the euro area. In contrast to the previous literature, which either used only monthly averages of excess reserves (e.g. Frost (1971)), or which did not

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

provide any estimation on the basis of actual data (e.g. Clouse and Dow (2002)), we estimate a model of the daily pattern of excess reserves within the maintenance period. The daily intra-maintenance period pattern of excess reserves provides important insights into what factors cause banks to hold excess reserves that cannot be obtained when working with monthly averages. Section 5 also 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 6 concludes by revisiting RPD in the light shed by the analysis presented in this paper.

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

2.1 Excess reserves within the operational framework of the Eurosystem

Excess reserves cannot be understood without considering the environment in which they are generated. This environment is determined by: the operational framework set out by the central bank, the reserves supply policy of the central bank, the structure of the payment system, and the volume of payment activity. 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 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. Currently reserve requirements in the euro area amount to around EUR 130 billion. Compliance with reserve requirements is determined on the basis of the average reserve holdings over a maintanance period of one month. Reserve holdings not exceeding the minimum reserve requirements are remunerated at market rates, excess reserves are not remunerated at all. It should be highlighted that in the present paper the term excess reserves strictly refers to the diference between *accumulated* reserve holdings, e.g. at day t of the maintanance 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 maintanance period. Daily differences between reserve holdings and reserve requirements are of little significance in the averaging system of the euro area. 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. The accumulation of excess reserves will thus not be linear over the reserve maintenance period, but convex with a peak towards the end. Finally, it is also important to note that the reserve maintenance period in the euro area has always ended on the same day of the month (namely the 23rd) regardless of the weekday. As we will see, the weekday on which the maintenance period ends will have sizable effects on the level of excess reserves.

- **Weekly open market operations.** But for extraordinary circumstances, the ECB conducts an open market operation only once a week. This implies that, in order to avoid an impact of liquidity imbalances on short-term interest rates the ECB must rely on the quality of its autonomous factor forecasts and the willingness of banks to average out transitory fluctuations of reserves.[3]

- **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.

[3] See Bindseil and Seitz (2001), Cabrero, Camba-Mendez, Hirsch, and Nieto (2002) and ECB (2002) on the role of forecasting autonomous factors in the liquidity management 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, ie. 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. Section 3 below provides some details on the procedure used at the ECB to forecast excess reserves, and presents an assessment of the potential error in the allotment decisions induced by these forecasting errors.

Finally, it needs to be noted that 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. Together with the relative high number of credit institutions in the euro area (more than 7000), this implies that the generation of excess reserves should be relatively regular over time, except for the reserve maintenance period pattern. As will be seen below, this is indeed the case.

2.2 Comparison to the US case

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 for 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 reserve requirements is somewhat weaker in the US, and that excess reserves are overall somewhat higher. Furthermore, the fact that the US reserve maintenance period always ends on the same weekday (Wednesday) implies that no weekday effect can occur. Secondly, and most importantly, 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 would be 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. The models which will be presented in this paper clearly refer to the case of the euro area, and they would need some modification to be applied to a system without a deposit facility. Finally, the Fed allows banks to *carry-over* some reserve deficits or reserve surpluses into the following reserve maintenance period. This specification will contribute 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.

3 The ECB's handling of excess reserves

3.1 Stylised facts

Excess reserves can be split into two main categories.

- Excess reserves generated by banks that are not obliged to fulfil minimum reserve requirements (X1).
- Excess reserves generated by banks obliged to fulfil reserve requirements (X2).

Excess reserves of type X1 include the current account holdings of counterparties that: *i*) are in principle subject to reserve requirements but do not have to hold reserves because of a lump sum allowance of EUR 100,000 for reserve requirements; *ii*) do not have to hold reserves with an NCB because they are not 'domestic' counterparties (these counterparties have 'remote access' to the national payment systems of non-domestic banks or non-financial institutions, but they are not subject to reserve requirements with the respective central bank and have no access to the standing facilities); *iii*) fulfil reserve requirements through an intermediary, but still hold their own account at the central bank.

Figure 2 shows the evolution of average excess reserves per maintanance period in the euro area for the period January 2000 to March 2003. The daily average level of excess reserves has been 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 uncertanties 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. For many small institutions it might be more costly to extend the working hours of some employees than to obtain the deposit rate of the excess reserves transferred to the deposit facility at the end of the day. 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.

A final interesting aspect of X2 excess reserves is that they are systematically higher when a maintenance period ends on a weekend. Again using the sample from January 2000 to March 2003, we find that for maintenance periods ending on weekdays, average X2 excess reserves amounted to EUR 552 million. However, for maintenance periods ending on Saturdays, this increases slightly to EUR 584 million; and for periods ending on Sundays it increases even more to EUR 674 million. X1 excess reserves, on the other hand, appear unaffected by the day on which the maintenance period ends: on average EUR 158 million for weekdays, EUR 171 for Saturdays, and EUR 162 million for Sundays.

In addition to the data on daily excess reserves, the ECB has also collected data on the monthly reserve requirements of approximately 3500 individual banks for the period from January 1999 to August 2001. This data is also very important for the calibration of the model presented in the paper. These banks' reserve requirements account 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. 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. The reserve requirements of the remaining banks 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 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.

3.2 The ECB's forecasting of excess reserves

The ECB regards excess reserves as an exogenous liquidity factor, see ECB (2002). This means that excess reserves need to be forecasted accurately for the ECB to inject sufficient liquidity in the banking system ensuring reserve requirements are fulfilled in a smooth and proportional manner over the maintenance period.

An econometric model of excess reserves. Visual observation of the series of excess reserves suggests that the periodic nature of its fluctuations might be well explained by a periodic autoregressive model (PAR). A PAR model extends a standard autoregressive time series model (AR) by allowing its parameters to vary with a certain regular pattern. For a univariate time series y_t, a PAR model of order p, denoted by PAR(p), is defined as follows:

$$y_t = \mu_s + \phi_{s,1}\, y_{t-1} + \ldots + \phi_{s,p}\, y_{t-p} + \varepsilon_t \tag{1}$$

where μ_s is an intercept term, and $\phi_{s,i}$ for $i = 1$ to p are the autoregressive parameters, and where ε_t is an *iid* stochastic process with zero mean and standard deviation σ_s. It is further assumed that the set of parameter values $\boldsymbol{\omega}_s = \{\mu_s, \phi_{s,1}, \ldots, \phi_{s,p}, \sigma_s\}$ changes with a certain regular pattern. This structure is flexible enough to accommodate disparities in the dynamic behaviour of excess reserves over the different days of the maintenance period.

In the present context, and if we assume that there are 30 days in a maintenance period, we could define $s = 30$ and thus require the estimation of 30 sets of parameters associated with model (1) above. A set of parameters, say $\boldsymbol{\omega}_1$ would be used to describe the dynamics of y_t when t corresponds to the first day of the maintanance period; a set of parameters $\boldsymbol{\omega}_2$ would be associated with y_t when t the second day of the maintenance period, and so on. A likelihood ratio test can be used to check the null hypothesis of equality of two sets of parameters, i.e. $H_0 : \boldsymbol{\omega}_i = \boldsymbol{\omega}_j$ (see Franses (1996) for further details). The results of this analysis (not reported in this paper) suggested that the dynamics of the series over most of the days of the maintenance period could be well described by the same set of parameters. However, the dynamics of the series for the last days of the maintenance period required a different set of parameters.

Model (1) was extended to accommodate deterministic dummies to account for date effects such as Saturday and Sunday effects. The number of lags was selected by a standard Bayesian Information Criteria and insignificant lags were ignored.

The number of observations for the German series of excess reserves is very small. This has prompted us to exclude German excess reserves from the euro area series and model it separately. The model adopted for the euro area data was specified for the data excluding Germany with periodicity imposed for the intervals defined by the periods 0, 1, 2, 4, 13, 18, 26, 27. Therefore, and using a similar notation to that above, the eigth different sets of parameters estimated corresponded to $\boldsymbol{\omega}_1$, $\boldsymbol{\omega}_{2\ to\ 9}$, $\boldsymbol{\omega}_{10\ to\ 13}$, $\boldsymbol{\omega}_{14\ to\ 23}$, $\boldsymbol{\omega}_{24\ to\ 25}$, $\boldsymbol{\omega}_{26}$, $\boldsymbol{\omega}_{27}$ and $\boldsymbol{\omega}_{28}$, where $\boldsymbol{\omega}_{i\ to\ j}$ denotes the set of parameters estimated for t belonging to days i to j of the maintenance period, and all maintanance periods in the sample have been rounded to 28 days by discarding the first days. For the German data an unrestricted autoregressive model in 28 seasonal differences (i.e. the dependent variable defined as $z_t = \Delta_{28} y_t = y_t - y_{t-28}$ was selected.

Forecasting excess reserves. The model's out-of-sample forecasting performance was measured by the root mean squared forecasting error (RMSE). Results are shown in table 1. The figures reported correspond to forecasting errors of the level of excess reserves on the last day of the maintenance period. Forecasts were made at different forecasting horizons; the longest horizon is five days before the end of the maintenance period. The forecast quality naturally decreases at longer horizons for all models.

The first row of table 1 gives the RMSE for the PAR model for the euro area excluding Germany for the period August 1999 to March 2003. The second row gives the RMSE for the AR model for the same countries and the same period. The PAR model achieves a clear reduction of the RMSE compared with the simple regression model at longer forecasting horizons (3 and higher). The performance of the AR model (with seasonal differences) for the German data is shown in the third row. Data for Germany is only available for the period May 2001 to March 2003. To obtain a forecast for the total euro area, the forecast of the PAR model for the euro area excluding Germany is combined with the forecast for Germany made from the AR model. The forecasting performance of this combined forecast is shown in the fourth row (PAR-AR model) for the period May 2001 to March 2003.

In practice, the forecasts are usually checked further against expert knowledge before a final consensus forecast is agreed. table 2 shows the forecasts of excess reserves for 2001 and the first half of 2002, that the ECB actually used in the allotment decisions made for the last main refinancing operations of the maintenance period, i.e these forecast are ‘consensus’ forecasts. The forecasts were initially rounded to EUR 50 million prior to December 2001, but subsequently rounded to EUR 10 million. The accumulated forecast error simply corresponds to the forecast error multiplied by a standard number of days of a reserve maintenance period. The last column displays the impact of the forecasting error on the allotment in the last tender of the maintenance period (the ECB always rounds its allotment amounts to EUR 1 billion). The table reveals that in an 18 month period, the allotment decision in the last main refinancing operation of the reserve maintenance period would have been different on five occasions if the ECB had had a perfect forecast of excess reserves.

The large forecast error in December 2001 may have been related to the fact that the last business day of the maintenance period was also the last business day before the Christmas holiday season. It is worth mentioning that some of the forecast errors in excess reserves in early 2002 were related to the cash-changeover period, which obviously had an idiosyncratic impact on the treasury management of the banks.

4 A simple economic model of excess reserves

4.1 Introduction

This section shows that the pattern of excess reserves observed in the euro area can be simulated to a very large extent within an extremely simple ‘transaction costs’ framework. We first need an assumption on *banks’ strategy regarding their reserve fulfilment path* within a reserve maintenance period and individual liquidity shocks. This problem was analyzed for instance by Valimaki (2001) and Perez-Quiros and Rodriguez-Mendizabal (2001). They suggest 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. Hence, we instead assume that banks follow a rather simple and straightforward strategy in their fulfilment of reserve requirements.

Second, we need to look at how *transactions costs* affect the behaviour of treasurers, since without transaction costs, all excess reserves would be eliminated through recourse by banks to the deposit facility. 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. Two main types of transaction costs may be distinguished which could preclude a systematic use of the deposit facility:

i. There are some '*once and for all*' set up costs to make the recourse to the deposit facility possible for a bank. These costs may consist in signing a specific operational agreement with the relevant national central bank, or in agreeing internally on the 'credit line' to be granted to the central bank (of course, it is free of risk to deposit funds in the central bank, but internal procedures in banks may be such that the central bank is treated as a normal counterpart). Although these costs do not appear to be high, they may be sufficient to prevent a counterparty, which thinks that it has little need for the deposit facility, to spare them. Indeed, out of the 7100 credit institutions in the euro area, only around 3400 have access to the deposit facility.

ii. Second, even when the set up of the access to the deposit facility has taken place, the treasurer may still not make use of the facility. For instance, even if he notices excess reserves on the relevant account at 18:30, there should be a minimum below which it is not worth doing the required transaction. As already mentioned, excess reserves of EUR 100,000 would only cost EUR 6.25, which does not justify filling in a form on a computer or picking up the phone. It could also play an important role that 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*'.

For the sake of simplicity, only the second category of transaction costs will be incorporated in our model. 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 shock on the first day of the period would have to be large enough to force him to fulfil his total reserve requirements not just for one day but for the whole maintenance period. If there is a small positive shock, which pushes him above his average reserve fulfilment, he can always smooth it out the next day by holding lower reserves than average. 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.

A final characteristic of the data which was formally incorporated in the economic model was the "weekend effect" observed in section 3. The main explanation for the "weekend effect" is that when payment shocks occur on Friday and the treasurer is not able to take recourse to the deposit facility either because he left already or the bank has no access at all to the deposit facility, then this shock has a double effect on excess reserves if the maintenance period ends on Saturday, and a triple effect when it ends on Sunday, but no particular effect if it ends on Friday.

4.2 Variable definition

We define T as the total number of maintenance periods, and the associated subindex t for $t = 1, \ldots, T$ will be used to denote a certain reserve maintenance period. We further define Z as the total number of days in a maintenance period, i.e. 30 or 31 in the euro area, and the corresponding subindex z for $z = 1, \ldots, Z$ denotes a particular day of that maintenance period. These days being calendar days, we adopt the convention of attaching a day of the week to that subindex, i.e. a given day $_{t,z}$ being associated with say Monday. For a variable $x_{t,z}$ we further adopt the convention of defining $x_{t,z-1} = x_{t-1,z}$ when $z = 1$. For a given bank at time period $_{t,z}$ we further define:

- $q_t \in \Re^+$, reserve requirements.
- $r^I_{t,z} \in \Re^+$, actual reserve holdings before the occurrence of the end of day payment shock, and possible recourse to the standing facilities.
- $\varepsilon_{t,z} \in \Re$, end of day payment shock (liquidity shock).
- $r^{II}_{t,z} \in \Re$, actual reserve holdings after the end of day payment shock but before the possible recourse to standing facilities.
- $d_{t,z} \in \Re^+$, recourse to the deposit facility.
- $m_{t,z} \in \Re^+$, recourse to the marginal lending facility.
- $r^{III}_{t,z} \in \Re^+$, actual reserve holdings at the very end of the day, i.e. after both the payment shock and the possible recourse to standing facilities have occurred.
- $h_{t,z} \in \{0, 1\}$, the 'stay or go' dummy, a variable that takes the value 0 if the treasurer decides to leave at 17:30, and the value 1 if he decides to stay until 18:30.
- $s_{t,z} \in \Re$, cumulative 'gross' excess reserves after recourse to standing facilities.
- δ, is the cost of 'staying in the office'. This cost factor is assumed to be constant for all banks and for every period.

Note that it is not rational for a bank to make use of both standing facilities at the same time, and therefore it should hold that $d_{t,z} > 0 \Rightarrow m_{t,z} = 0$ and $m_{t,z} > 0 \Rightarrow d_{t,z} = 0$. Finally, we need to define the key ECB interest rates:

- $r^d_{t,z}$, is the rate of the deposit facility.
- $r^m_{t,z}$, is the rate of the marginal lending facility.
- $r^r_{t,z}$, is the remuneration rate of reserve requirements.
- $r^p_{t,z}$, is the penalty rate applied to the part of reserve requirements not fulfilled.

Currently in the Eurosystem, the deposit facility and marginal lending facility form a symmetric 200 basis point corridor around the minimum bid rate applied in the ECB's open market operations. The remuneration rate is approximately equal to the minimum bid rate. The penalty rate is 250 basis points above the marginal lending facility rate.

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. But 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, i.e. when no further payment shock can take place as payment systems are closed. Figure 1 shows the daily time schedule for reserve management faced by treasurers, and should help to understand the definitions given above. It then follows that:

$$\begin{aligned} r^{II}_{t,z} &= r^I_{t,z} + \varepsilon_{t,z} \\ r^{III}_{t,z} &= r^I_{t,z} + \varepsilon_{t,z} + m_{t,z} - d_{t,z} \\ s_{t,z} &= \sum_{k=1}^{z} r^{III}_{t,k} - Zq_t \end{aligned} \tag{2}$$

where $\Psi(x)$ is a function which takes the value of x for $x > 0$ and a value of 0 otherwise. Note that excess reserves are hence defined as $\Psi(s_{t,z})$.

4.3 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:

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

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

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

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

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 where $\Theta(x)$ is as a function which takes the value of 1 if $x \geq 0$ and the value of zero otherwise, and λ_z is defined as follows:

$$\lambda_z = \begin{cases} 3 & \text{if } z \in \mathbf{\Omega}_{4,6} \\ 2 & \text{if } z \in \mathbf{\Omega}_3 \\ 1 & \text{otherwise} \end{cases} \tag{5}$$

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 $p = r^d_{t,z}$, where $\mathcal{M}_{t,z}$ is defined as:

$$\mathcal{M}_{t,z} = 3\left(r^{II}_{t,z} - \mu\right)p + \mathcal{F}^b_{t,z} + \mathcal{F}^a_{t,z} - \Psi\left(-s_{t,z-1} - \lambda_z\mu\right)r^p_{t,z} \tag{6}$$

where:

$$\begin{aligned} \mathcal{F}^b_{t,z} &= \sum_{j=1}^{\lambda_z}\left\{\mu - \Psi\left(s_{t,z-1} + j\mu\right)\right\}r^r_{t,z} \\ \mathcal{F}^a_{t,z} &= \sum_{j=\lambda_z+1}^{3}\left\{\mu - \Psi\left(Zq_{t+1} + (j - \lambda_z)\mu\right)\right\}r^r_{t,z} \end{aligned}$$

$\tilde{\mu}_{t,z}$ is defined as that μ which solves (6) subject to $\mu \geq r^{II}_{t,z}$ and $p = r^{m}_{t,z}$. 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 r^{d}, but funds held as normal reserves with the central bank will only be remunerated at the rate r^{r} as long as not exceeding the amount of required reserves. The different components of equation (6) 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.

Although at first sight equations (3) and (4) appear complicated, they can be easily explained. First, recourse to the marginal lending facility will be the maximum of two terms, the first term applies when there are negative holdings in the bank account at the end of the day, this triggers an immediate response from the ECB, as no bank is allowed to have an uncollateralised overdraft overnight; the second term only applies for the last days of the maintenance period (including Friday when the last day of the maintenance period is over the weekend) and if the bank treasurer decides to stay, then it pays to avoid the penalty of unfulfilling reserve requirements by filling the account holdings by that amount. Obviously, this is so if the penalty rate exceeds the rate of the marginal lending facility, which is always the case. Second, recourse to the deposit facility requires an active decision by a bank, and this explains the term $h_{t,z}$ in equation (4). Third, the remuneration rate for reserves is higher than the deposit facility, and therefore no use will be made of the deposit facility if those holdings count towards reserve requirements, but once they exceed that amount they should be placed, or otherwise they will not be remunerated at all. Four, note that when the maintenance period ends on Friday or Saturday. Finally, the ECB does not operate over the weekend, and therefore, those amounts deposited or borrowed on Friday will roll over Saturday and Sunday. This explains the first line of both equations.

Note that for the above formulas to hold we will adopt the convention of defining $r^{I}_{t,z} = r^{III}_{t,z-1} - m_{t,z-1} + d_{t,z-1}$ 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 $z \in \{Sat, Sun\}$. It is important to point out once more that equations (3) and (4), are in no way dependent on the optimizing assumptions on the side of the liquidity managers at the banks.

4.4 Expected cash flow of staying or leaving at 17.30

Assume initially that a decision has been made on $r^I_{t,z}$, then it follows that the expected cash flow for the bank if they decide to stay or leave is as follows:

$$C^{stay}_{t,z} = \begin{cases} \lambda_z \mathcal{C}_{t,z}\left(r^m_{t,z}, r^r_{t,z}, 0, r^d_{t,z}, 0\right) - \delta & \text{if } z \in \mathbf{\Omega}_{0,6} \\ \lambda_z \mathcal{C}_{t,z}\left(r^m_{t,z}, r^r_{t,z}, r^m_{t,z}, r^d_{t,z}, 0\right) - \delta & \text{if } z \in \mathbf{\Omega}_{1,4} \\ \max\left\{E\left\{\mathcal{M}^*_{t,z}\right\}, E\left\{\tilde{\mathcal{M}}^*_{t,z}\right\}\right\} - \delta & \text{if } z \in \mathbf{\Omega}_{2,3} \\ \delta & \text{if } z \in \mathbf{\Omega}_5 \end{cases}$$

$$C^{leave}_{t,z} = \begin{cases} \lambda_z \mathcal{C}_{t,z}\left(r^m_{t,z}, r^r_{t,z}, 0, 0, 0\right) & \text{if } z \in \mathbf{\Omega}_{0,6} \\ \lambda_z \mathcal{C}_{t,z}\left(r^m_{t,z}, r^r_{t,z}, r^p_{t,z}, 0, 0\right) & \text{if } z \in \mathbf{\Omega}_{1,4} \\ \mathcal{C}_{t,z}\left(3r^m_{t,z}, \lambda_z r^r_{t,z}, r^p_{t,z}, 0, (3-\lambda_z) r^r_{t,z}\right) & \text{if } z \in \mathbf{\Omega}_{2,3} \\ 0 & \text{if } z \in \mathbf{\Omega}_5 \end{cases}$$

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

$$a\int_{-\infty}^{-r^I_{t,z}} \Delta_\varepsilon + b\int_{-r^I_{t,z}}^{B\lambda_z^{-1}-r^I_{t,z}} \Delta_\varepsilon + c\int_{-r^I_{t,z}}^{B\lambda_z^{-1}-r^I_{t,z}} \Delta_{B\varepsilon} + d\int_{B\lambda_z^{-1}-r^I_{t,z}}^{\infty} \Delta_\varepsilon + e\int_{-r^I_{t,z}}^{Zq_{t+1}\lambda_z^{-1}-r^I_{t,z}} \Delta_\varepsilon$$

where $B = \Psi(-s_{t,z-1})$, and where to save on notation we have denoted $\Delta_\varepsilon = \left(r^I_{t,z} + \varepsilon\right) f_{\varepsilon_t} d\varepsilon$, and $\Delta_{B\varepsilon} = \left(\lambda_z(r^I_{t,z} + \varepsilon) - B\right) f_{\varepsilon_t} d\varepsilon$. To fully understand the nature of the cash flow function we proceed to explain the economic meaning of those integrals. The integrals weight shocks by their probability, and the coefficients outside the integrals represent their return. The first integral gives those large negative shocks that would leave a bank with negative reserve holdings by closing time. The second gives the final amount of positive reserves holding that will be remunerated, i.e. do not exceed reserve requirements. The third gives the unfulfilled reserve requirements, and this explains that this integral only has a coefficient different from zero when $z \in \mathbf{\Omega}_{1,2,3,4}$, i.e. at the end of the maintenance period. The fourth integral gives those events that leave the cash holdings of the bank in excess of the reserve requirements. 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 to those integrals in $\mathcal{C}(a,b,c,d,e)$ under normality assumptions are provided in the appendix. Note that it then follows that the optimal decision on staying or leaving will depend on which has the largest cash flow, i.e.

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

Thus far all equations presented in the paper are linked to the particular nature of the operational framework of the ECB, and are in no way affected by any modelling assumptions. We now incorporate our first modelling assumptions:

Assumption 1 *Distributional assumptions on the liquidity shocks. Banks face a probability* $1-p$ *of being hit by a payment shock* $\varepsilon_{t,z}$. *This payment shock* $\varepsilon_{t,z}$ *is normally distributed with zero mean and variance* $\sigma_t^2 = \alpha_1 + \alpha_2 q_t$, *where* α_1 *and* α_2 *are two nonnegative parameters.*

Assumption 2 *All treasurers who have access to the standing facilities know ex ante the distribution of their end of day liquidity shocks.*

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. The variance of these shocks is different for each bank, but it is assumed to remain constant over the duration of the maintenance period.[4] It is further assumed that the liquidity shocks are positively correlated with the bank's reserve requirement, reflecting the idea that large banks should be exposed to larger liquidity shocks. The parameter α_1 is needed otherwise the 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.

4.5 Behavioural Equations

It simply remains to explain how banks make decisions on $r_{t,z}^I$ to complete the model. We will work under the following assumption.

Assumption 3 *Banks aim to fulfill their reserve requirements proportionally. By the time money markets close, banks aim to stay in the proportional reserve fulfillment path and will respond to correct deviations from it. And where the proportional reserve fulfillment path is defined by that level of reserve holdings that at time* t *needs to be daily held for the remaining days of the maintenance period to exactly fulfilled the reserve requirements.*

This is formulated as follows:

$$r_{t,z}^I = \frac{\Psi \left(Z q_t - \sum_{k=1}^{z-1} r_{t,k}^{III} \right)}{Z - z + 1} \tag{7}$$

[4]In practice, the variance of the shocks could change depending on the day of the maintenance period. For example, the recourse to the standing facilities is higher at the end of the month, possibly because of a higher level of payment shocks.

5 Simulation of the Model

5.1 Method

There are four model parameters that need to be estimated: p, δ, α_1 and α_2. Simulated least squares has been used to estimate those parameters. The discrepancy function to be minimized under this estimation method is given by $\sum_{t=1}^{N} \sum_{z=1}^{Z} (S_{t,z} - E\{S_{t,z}\})$, and where for P a large number, the value of $E\{S_{t,z}\}$ is estimated by $P^{-1} \sum_{j=1}^{P} S_{t,z}^{j}$, where $S_{t,z}^{j}$ is a series of aggregated excess reserves simulated from our model. The parameters were estimated using data that span over twenty three maintenance periods, with the first maintenance period beginning on 24 April 2001 and the twenty third maintenance period ending on 23 March 2003. The estimation could not be performed over an earlier time horizon because accurate daily German excess reserve data was not available. The estimated parameters are shown in table 3. It was checked whether the parameters obtained appeared realistic, e.g. whether the cost of staying in the office was within a reasonable range, or whether the variance of shocks relative to a bank's reserve requirements were of a reasonable size. Using these parameter values, we then computed fifty simulations over the same period of time. This provided us with estimates of the mean and standard deviation of the series of excess reserves simulated by our simple model.

5.2 Results and analysis

Figure 4 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 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 simulation and from figure 4.

The upper part of table 4 also compares the actual data for excess reserves with the simulated results, calculated as a percentage of reserve requirements. The tables break down the results, firstly, by the type of excess reserves (X1 or X2) and, secondly, by the day of the week on which the maintenance period ended. Again one can see that for maintenance periods ending on normal weekdays the model can fit the actual data very closely. The mean level of accumulated total excess reserves as a proportion of minimum reserves was 20.8% for the actual data and 19.5% for the simulated data. For maintenance periods ending on a Friday or a weekend, the simulated results for X1 are reasonable close to the actual data. The simulated excess reserves X2 series also match the actual data well, although there are some slight anomalies. The model's simulations appear to predict that the highest average level of excess reserves would occur when the maintenance period ends on a Saturday, second highest when the period ends on a Friday and lowest when the period ends on a Sunday. This is in contrast to the actual data which shows that the highest level occurs when the period ends on a Sunday, with the lowest level of excess reserves occurring when the period ends on a Friday. Apparently, some further elements of the treasury management of banks would need to be incorporated in order to capture better the actual weekend pattern.

The obtained four parameters of the model (see table 3) can be commented upon as follows. The variance of liquidity shocks is composed of a fixed term 0.027 million and a variable term of 1.42 times 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 52% of days such shocks would actually occur, as revealed by the parameter p of 0.48. Finally, the cost of staying is EUR 500, 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. Also 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.

5.3 Simulated 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. This allows for insights which are not offered by the available actual data due to the non-existent or too limited variation in the relevant exogenous parameters. Note that in the period for which the parameters were estimated the average level of the deposit and marginal lending facility rates were 2.47% and 4.47% respectively, while the penalty rate for the non-fulfilment of reserve requirements was equal to the marginal lending rate plus 250 basis points, i.e. 6.97%. 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 (to 100 basis points)

iv. Widen symmetrically the corridor set by standing facilities by 200 basis points (to 400 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 of the variance of money market and payment system shocks by 100%

xi. Decrease of the variance of money market and 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 tables 4 and 5, whereby the latter table 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. We will concentrate in the following on the simulation results for maintenance periods ending on weekdays (other than Friday) since there are much more observations for those and especially the standard deviation figures are thus more reliable.

Firstly, increasing all key ECB interest rates by 2% leads to reduction to around 75% of X2 excess reserves. The standard deviation decreases approximately 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. The fact that this could not yet be observed in the real data needs to be explained by other non-measured factors which blur the relationship for the relatively short sample period available so far.

Similarly, in the second scenario, 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 even more than proportionally, reaching 326% of the baseline standard deviation. Hence, excess reserves are likely to become significantly more difficult for the central bank to be 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 models which would be in line with this prediction of the model (although, as mentioned, the increase of excess reserves could not yet be observed).

Although the model therefore generates the plausible result that the level of excess reserves is to some extent interest rate dependent (which cannot yet be derived from the actual data), 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.

Under the third scenario, in which 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 somewhat which may mainly reflect the increased level of the deposit facility. The opposite effect is obtained when the corridor is widened to a total of 400 basis points.

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 even increases to more than 900% of the baseline level.

Changing the penalty rate (scenario iv), 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.

The scenarios viii and ix of increasing and decreasing all banks' reserves requirements, have again 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 approximately proportionally.

Finally, the scenarios of increasing and decreasing the volatility of shocks (scenarios 10 and 11), which can be interpreted e.g. as a decreasing or as an increase of the efficiency of payment systems, as an increase or decrease of payment activities, or as a decrease of increase of the smoothness of the functioning of money markets, also produces 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. Table 2 had revealed that the standard deviation of actual accumulated excess reserves forecasts had 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 would dislike 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.

6 Conclusion: revisiting RPD

Over around 60 years, namely from the 1920s to the 1980s, variants of RPD, in all of which excess reserves play some role, represented the dominant academic view on how the central bank initiates monetary policy impulses. Also central banks paid over this period lip service to RPD, and especially the Fed went relatively close during some years to put related concepts into practice in the form of free-, borrowed, and non-borrowed reserves targeting. While at the latest in the 1990s, the academic journal literature tended to show less interest in RPD, and central banks openly returned to short term interest rate control (the Fed again taking a kind of lead role), RPD still continues to dominate monetary policy textbooks.

From our analysis of excess reserves in the euro area, the rejection of RPD is fully supported. Consider again the two main findings that lead to this conclusion.

First, the ECB apparently cannot easily control excess reserves since, as the empirical model in section 3 has shown, excess reserves mainly depend on exogenous factors without a relation to monetary policy instruments or economic conditions: (i) excess reserves follow a striking intra-reserve maintenance period pattern; (ii) they are significantly higher in reserve maintenance periods ending on weekend days; (iii) they are significantly higher in case of exceptional friction in the money market such as e.g. during the cash-changeover; (iv) particular events in the first part of the maintenance period, probably relating to payment shocks, are generally significant in the sense that excess reserves in the middle of the reserve maintenance period are very significant to predict end of maintenance period levels, although they normally constitute only 12% of the accumulated excess reserves total over the maintenance period; (v) In contrast, it is not possible to show empirically that excess reserves depend in the euro area on the level of interest rates or on reserve market conditions (although this is somewhat plausible and indeed suggested by the model simulations). The combination of uncontrollability and dependence on parameters which have no macroeconomic significance makes the idea that excess reserves could be the starting point of monetary policy transmission more than doubtful.

Second, the simple transaction cost model of excess reserves that was able to replicate very well the excess reserves patterns observed, in particular the intra- reserve maintenance period pattern, confirms further that there should not be a sensible relationship between the level of excess reserves and monetary conditions. The model was mainly based on the (low) cost to treasurers of using the deposit facility, which was exemplified by a daily cost of waiting for the final closing of the market to fine tune the end of day position, against leaving somewhat earlier and letting end of day payment shocks impact on reserve holdings. The specific features of this intra-maintenance period path (increasing each day in a convex way) suggests that previous studies, which only focused on averages over reserve maintenance periods or even longer periods of time, in fact had little chance to infer the actual logic of excess reserves generation. In any case, it is hard to imagine any sensible monetary policy transmission mechanism focusing on excess reserves on the basis of this model.

Still, 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, declines sufficiently. Could the resulting negative correlation between interest rates and excess reserves not be the basis for an excess reserves channel of monetary policy transmission? Obviously not, 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. It does therefore not make any economic sense to expect individual banks to expand loans if this residual increases on average.

While the previous points are specific to excess reserves in the euro area, one may briefly turn to the case of the US in which no deposit facility limits the possible amount of excess reserves. Could RPD still be valid in this context? In the case of the US, two sorts of excess reserves need to be distinguished. Those relating to an aggregate surplus of reserves, which thus cannot be eliminated through the interbank money market, and those which relate to imperfections of the interbank market and payment system. While the analysis of the latter category is not too different from the euro area case, the former is quite different, since indeed the Fed can set this type of 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, to trigger an expansionary impulse by injecting through open market operations excess reserves in order to trigger additional loans, like textbooks are continuing to tell us? An observation made already 130 years ago by Bagehot (1873, pp. 58) in his book *Lombard Street* explains the problem with this idea:

> "*But though the value of money is not settled in an exceptional way, there is nevertheless a peculiarity about it, as there is about many articles. It 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.* "

Bagehot's description of the money market is exactly opposite to the indeed counter-intuitive idea of Keynes provided in the introduction, according to which credit quantities could adapt faster than money market rates. [5] 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 recognised by market participants,

[5] Bagehot's description of the money market does not seem to have been less valid in the 1920, during which Keynes developed his Treaties on Money, as for instance the Macmillan Committee hearings of 1929 suggest. Today's money markets are even more efficient, and thus prices react even faster to imbalances of quantities than at those times.

lead to large and immediate changes of short term interest rates. In particular, engineering through open market operations more excess reserves than the technical levels determined by exogenous factors as described for the euro area in the present paper, simply means driving 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 the respective episodes in these countries 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) that it provides little guidance on the future evolution of short term rates, and therefore fundamentally destabilizes the yield curve and therefore key intertemporal decisions by economic agents; (3) that 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.

Therefore, also the ability of central banks which do *not* offer a deposit facility are unlikely to be able to make sense of an excess reserves channel as starting point of a purely quantity oriented transmission mechanism, and Kaufman and Lombra (1980) should have been right to find the past modelling of excess reserves in macroeconomic models 'particularly suspect'. But this conclusion also makes RPD in general and the perceived supremacy of open market operations dubious.

Finally, 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 day-to-day monetary policy implementation, 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. In this context, we used our simple model to simulate the impact of various changes of 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 would cause an increase of the volatility of the overnight rate at the very end of the reserve maintenance period, which could either be ignored by the ECB (since it is transitory and is hence not transmitted along the money market yield curve), or addressed either by additional efforts in forecasting excess reserves for each reserve maintenance period or even by a higher frequency of end of the reserve maintenance period fine-tuning open market operations.

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Appendix A

$$\int_{-\infty}^{-r^I_{t,z}} \Delta_\varepsilon = -\sigma^2 f_\varepsilon\left(-r^I_{t,z}\right) + r^I_{t,z}\phi\left(\frac{-r^I_{t,z}}{\sigma}\right)$$

$$\int_{-r^I_{t,z}}^{B\lambda_z^{-1}-r^I_{t,z}} \Delta_\varepsilon = \sigma^2\left\{f_\varepsilon\left(-r^I_{t,z}\right) - f_\varepsilon\left(B\lambda_z^{-1} - r^I_{t,z}\right)\right\} + r^I_{t,z}\left\{\phi\left(\frac{B\lambda^{-1} - r^I_{t,z}}{\sigma}\right) - \phi\left(\frac{-r^I_{t,z}}{\sigma}\right)\right\}$$

$$\int_{-r^I_{t,z}}^{B\lambda_z^{-1}-r^I_{t,z}} \Delta_{B\varepsilon} = -B\left\{\phi\left(\frac{B\lambda^{-1} - r^I_{t,z}}{\sigma}\right) - \phi\left(\frac{-r^I_{t,z}}{\sigma}\right)\right\} + \lambda_z \int_{-r^I_{t,z}}^{B\lambda_z^{-1}-r^I_{t,z}} \Delta_\varepsilon$$

$$\int_{B\lambda_z^{-1}-r^I_{t,z}}^{\infty} \Delta_\varepsilon = \sigma^2 f_\varepsilon\left(B\lambda_z^{-1} - r^I_{t,z}\right) + r^I_{t,z}\phi^c\left(\frac{B\lambda^{-1} - r^I_{t,z}}{\sigma}\right)$$

$$\int_{-r^I_{t,z}}^{Zq_{t+1}\lambda_z^{-1}-r^I_{t,z}} \Delta_\varepsilon = \sigma^2\left\{f_\varepsilon\left(-r^I_{t,z}\right) - f_\varepsilon\left(Zq_{t+1}\lambda_z^{-1} - r^I_{t,z}\right)\right\} + r^I_{t,z}\left\{\phi\left(\frac{Zq_{t+1}\lambda^{-1} - r^I_{t,z}}{\sigma}\right) - \phi\left(\frac{-r^I_{t,z}}{\sigma}\right)\right\}$$

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

Table 1: RMSE for excess reserves on the last day of the maintenance period (mill euro).[a]

model	Forecasting horizon 1	2	3	4	5
PAR (euro area*)	213	310	392	450	480
AR (euro area*)	210	312	416	470	508
AR (Germany)	340	450	490	560	610
PAR-AR (euro area)	212	315	424	491	531

[a]Based on recursively estimated out-of sample forecasts over the period 2001.5 to 2003.3. euro area* excludes German data on excess reserves. See text for further details.

Table 2: Liquidity Management of the ECB and Excess reserve forecasts (mill euro).[a]

RMP	Forecast	Actual value	error	Acc. error	Allotment error	Rounded All. error
May 2001	600	620	20	600	600	1000
Jun 2001	650	690	40	1200	300	0
Jul 2001	600	691	91	2730	455	0
Aug 2001	650	627	-23	-690	-345	0
Sep 2001	750	785	35	1050	210	0
Oct 2001	600	656	56	1680	240	0
Nov 2001	600	599	-1	-30	-10	0
Dec 2001	800	1005	205	6150	1538	2000
Jan 2002	1720	1668	-49	-1461	-1461	-1000
Feb 2002	800	818	18	546	136	0
Mar 2002	770	851	81	2427	485	0
Apr 2002	830	652	-178	-5332	-667	-1000
May 2002	610	691	81	2419	806	1000
Jun 2002	800	775	-25	-750	-150	0
Jul 2002	700	727	27	810	189	0
Aug 2002	700	654	-46	-1380	-138	0
Sep 2002	620	601	-19	-570	-114	0
Oct 2002	660	619	-41	-1230	-41	0
Nov 2002	710	622	-88	-2640	-352	0
Dec 2002	750	753	3	90	18	0
Jan 2003	800	704	-96	-2880	-1440	-1000
Feb 2003	800	707	-93	-2790	-558	0
Mar 2003	700	698	-2	60	12	0
St dev	225	221	72	2219		
RMSE			72	2232		

[a]Forecast refers to daily average excess reserves over the remaining days of the maintanance period. These forecasts are computed on the day of the allotment of the last main refinancing operation of the maintenance period. Accumulated error is equal to the forecast error multiplied by the number of days of the maintenance period. Allotment error is equal to the forecast error multiplied by the remaining number of days in the maintenance period. Rounded All. error rounds up to the billion the Allotment error. See text for further details.

Table 3: Estimated parameters.[a]

parameter	value
α_1	27×10^{-7}
α_2	1.42
δ	5×10^{-7}
p	0.48

[a]recall that variance of the shocks, $\sigma^2_{it} = \alpha_1 + \alpha_2 q_{it}$, δ is the 'cost of staying', and p is the probability that the shock is zero. α_1 and δ are in billions euro.

Table 4: Excess reserves as a (%) of reserve requirements.[a]

scenario		weekdays mean	weekdays st dev	Fri mean	Fri st dev	Sat mean	Sat st dev	Sun mean	Sun st dev
euro area data	X1	4.0	0.39	4.5	0.40	4.6	0.80	4.12	0.45
	X2	16.8	1.59	15.2	0.35	18.9	1.79	20.7	2.96
	Total	20.8	1.75	19.7	0.75	23.5	2.38	24.8	3.07
benchmark model	X1	4.2	0.05	4.3	0.05	4.2	0.08	4.1	0.05
	X2	15.3	1.00	19.8	2.67	20.4	3.92	17.1	0.57
	Total	19.5	1.01	24.1	2.67	24.6	3.97	21.2	0.58
increase all rates by 2%	X1	4.2	0.05	4.4	0.03	4.2	0.04	4.2	0.05
	X2	11.5	0.67	15.3	3.15	16.2	0.33	12.6	0.33
	Total	15.7	0.67	19.7	3.17	20.4	0.33	16.8	0.33
decrease all rates by 2%	X1	4.3	0.04	4.3	0.05	4.2	0.04	4.2	0.04
	X2	41.9	3.30	41.8	3.26	37.7	4.40	49.8	6.64
	Total	46.2	3.29	46.1	3.27	41.9	4.41	54.0	6.63
tightening band by 0.5%	X1	4.3	0.04	4.3	0.04	4.2	0.04	4.2	0.04
	X2	14.5	0.97	17.1	2.85	15.4	4.11	16.6	1.01
	Total	18.8	0.98	21.4	2.84	19.6	4.11	20.8	1.01
broadening band by 1%	X1	4.3	0.05	4.3	0.05	4.2	0.04	4.2	0.04
	X2	20.4	1.44	23.7	3.51	22.7	5.07	23.9	1.01
	Total	24.7	1.44	28.0	3.51	26.9	5.07	28.1	1.01
abolish r^d	X1	4.3	0.04	4.3	0.05	4.2	0.04	4.2	0.05
	X2	72.1	9.49	68.1	7.97	65.7	8.14	63.9	8.94
	Total	76.4	9.48	72.4	7.98	69.9	8.14	68.3	8.94
increase of r^p by 5%	X1	4.2	0.05	4.3	0.05	4.2	0.04	4.2	0.04
	X2	15.3	0.85	22.4	3.73	15.0	4.08	16.3	0.58
	Total	19.5	0.85	26.7	3.73	19.2	4.08	20.5	0.58
decrease of r^p by 2.5%	X1	4.3	0.04	4.3	0.03	4.2	0.05	4.2	0.04
	X2	16.0	1.12	19.7	3.43	17.1	4.03	18.6	0.59
	Total	20.3	1.12	24.0	3.42	21.3	4.03	22.8	0.60
increase of q by 100%	X1	4.2	0.04	4.3	0.05	4.2	0.04	4.2	0.04
	X2	5.3	0.34	11.2	2.27	12.6	2.46	4.8	0.59
	Total	9.7	0.34	15.5	2.27	20.8	2.47	9.0	0.59
decrease of q by 50%	X1	4.3	0.04	4.4	0.05	4.2	0.04	4.3	0.05
	X2	27.3	1.70	36.3	5.62	32.4	6.46	29.3	1.31
	Total	31.6	1.71	40.7	5.62	36.6	7.47	32.6	1.32
increase σ 100%	X1	8.4	0.08	8.6	0.09	8.3	0.08	8.4	0.06
	X2	50.1	6.03	50.7	4.71	49.7	4.51	49.9	1.35
	Total	58.5	7.82	59.3	4.69	58.0	4.50	59.3	1.35
decrease σ 50%	X1	2.2	0.02	2.2	0.02	2.2	0.02	2.1	0.02
	X2	6.5	0.32	11.2	2.14	10.1	2.53	7.5	0.16
	Total	8.7	0.32	13.4	2.13	12.3	2.53	9.6	1.16

[a]Figures refer to observations on the last day of the maintenance period. Sample period is 2001-5 to 2003-3.

Table 5: Excess reserves as a (%) of reserve requirements (Simulations in % with benchmark).[a]

scenario		weekdays mean	weekdays st dev	Fri mean	Fri st dev	Sat mean	Sat st dev	Sun mean	Sun st dev
euro area data	X1	4	0.39	4.5	0.4	4.6	0.8	4.12	0.45
	X2	16.8	1.59	15.2	0.35	18.9	1.79	20.7	2.96
	Total	20.8	1.75	19.7	0.75	23.5	2.38	24.8	3.07
benchmark model	X1	4.2	0.05	4.3	0.05	4.2	0.08	4.1	0.05
	X2	15.3	1	19.8	2.67	20.4	3.92	17.1	0.57
	Total	19.5	1.01	24.1	2.67	24.6	3.97	17.5	0.58
increase all rates by 2%	X1	100	100	102	60	100	50	102	100
	X2	75	67	77	118	79	8	74	58
	Total	81	66	82	119	83	8	79	57
decrease all rates by 2%	X1	102	80	100	100	100	50	102	80
	X2	274	330	211	122	185	112	291	1165
	Total	237	326	191	122	170	111	255	1143
tightening band by 0.5%	X1	102	80	100	80	100	50	102	80
	X2	95	97	86	107	75	105	97	177
	Total	96	97	89	106	80	104	98	174
broadening band by 1%	X1	102	100	100	100	100	50	102	80
	X2	133	144	120	131	111	129	140	177
	Total	127	143	116	131	109	128	133	174
abolish r^d	X1	102	80	100	100	100	50	102	100
	X2	471	949	344	299	322	208	374	1568
	Total	392	939	300	299	284	205	322	1541
increase of r^p by 5%	X1	100	100	100	100	100	50	102	80
	X2	100	85	113	140	74	104	95	102
	Total	100	84	111	140	78	103	97	100
decrease of r^p by 2.5%	X1	102	80	100	60	100	63	102	80
	X2	105	112	99	128	84	103	109	104
	Total	104	111	100	128	87	102	109	103
increase of q by 100%	X1	100	80	100	100	100	50	102	80
	X2	35	34	57	85	62	63	28	104
	Total	50	34	64	85	85	62	42	102
decrease of q by 50%	X1	102	80	102	100	100	50	105	100
	X2	178	170	183	210	159	165	171	230
	Total	162	169	169	210	149	188	154	228
increase σ 100%	X1	200	160	200	180	198	100	205	120
	X2	327	603	256	176	244	115	292	237
	Total	300	774	246	176	236	113	280	233
decrease σ 50%	X1	52	40	51	40	52	25	51	40
	X2	42	32	57	80	50	65	44	28
	Total	45	32	56	80	50	64	45	200

[a]Figures refer to observations on the last day of the maintenance period. Sample period is 2001-5 to 2003-3.

Figure 1: Daily time schedule for reserve management.

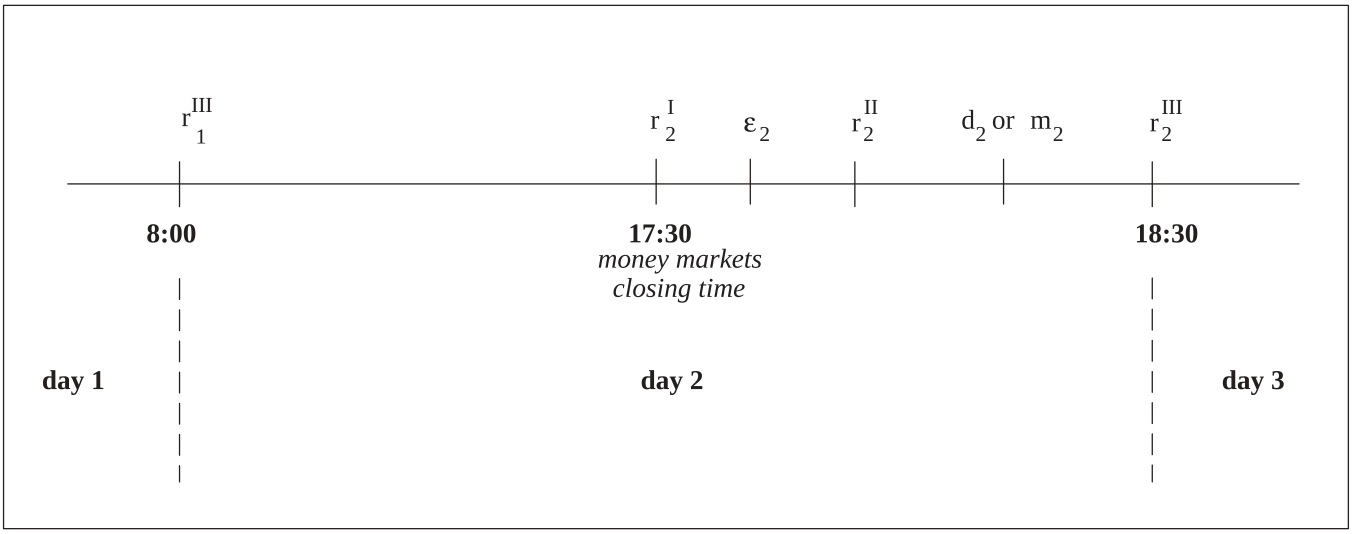

Figure 2: Evolution of average excess reserves per MP (1999-2002).

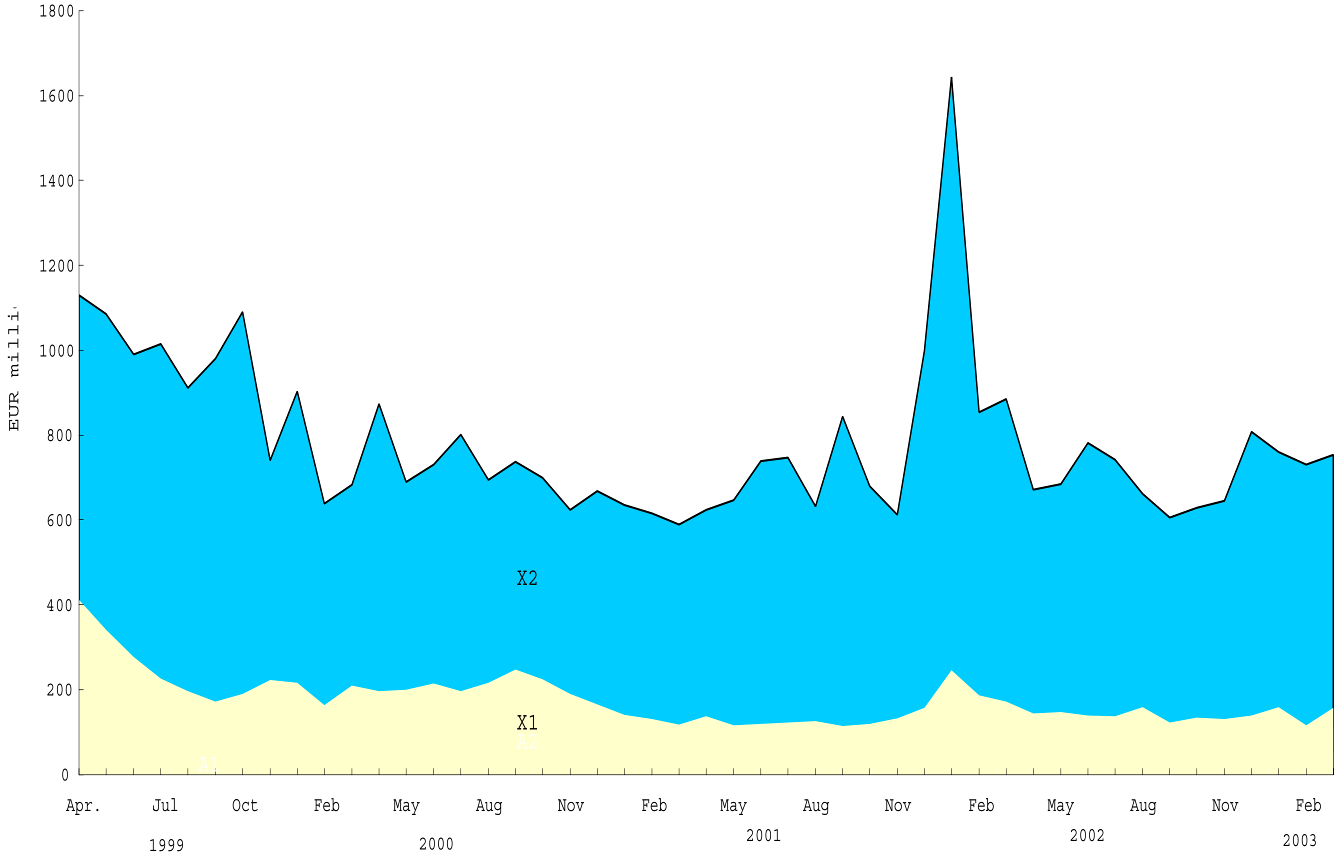

Figure 3: Intra-maintenance period evolution of total excess reserves. Euro area 2001-5 to 2002-11 (EUR mill). Average pattern for all periods is shown in bold

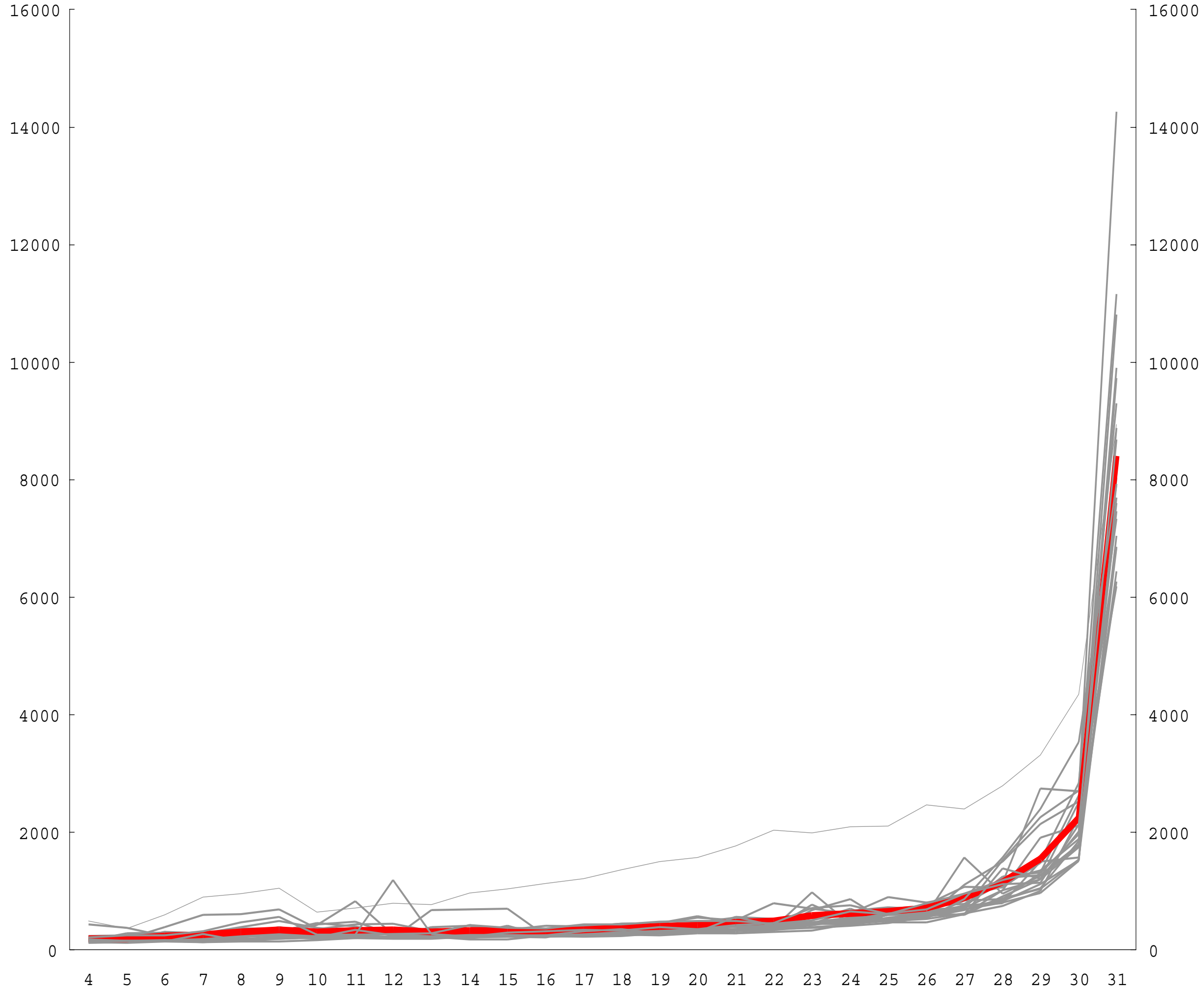

Figure 4: Excess reserves simulations (accumulated) from the model (2001-5 to 2003-3).