Faculdade de Economia da Universidade de Coimbra

Grupo de Estudos Monetários e Financeiros (GEMF)

Av. Dias da Silva, 165 – 3004-512 COIMBRA, PORTUGAL

http://www4.fe.uc.pt/gemf/ - gemf@sonata.fe.uc.pt

FÁTIMA TERESA SOL MURTA

The Portuguese Money Market: An analysis of the daily session

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The Portuguese Money Market:
An analysis of the daily session

Fátima Teresa Sol Murta*

Faculdade de Economia da Universidade de Coimbra
fasol@sonata.fe.uc.pt

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ABSTRACT

We use intra-daily data related to the Portuguese Money Market to analyse the evolution of the volume of operations, interest rate and interest rate volatility throughout the daily market session. We find a pattern in the volatility, which differs according to the stage of the reserves maintenance period. The interest rate volatility does not show a U-shaped pattern across the trading day, which we explain through features of the Single Monetary Policy.

RÉSUMÉ

Dans ce papier nous étudions le fonctionnement du Marché Monétaire Portuguais à partir de données de haute fréquence. Nous analysons l'évolution, pendant la journée, du volume des óperations, du taux d'intérêt et de la volatilité du taux d'intérêt. Nous identifions une dynamique de la volatilité qui est différent d'accord avec le moment de la période de constitution de reserves. La volatilité du taux d'intérêt n'est pas caractérisée par a *U-shaped pattern* ce qui est expliqué par les caractéristiques de la Politique Monétaire Unique.

Keywords: Overnight interest rate, reserve requirements, high-frequency data.
Mots clés: Taux d'intérêt overnight, reserves obligatoires, données de haute fréquence.

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* Please address correspondance to: Fátima Teresa Sol Murta, Faculdade de Economia da Universidade de Coimbra, Av. Dias da Silva, nº 165, 3004-512 Coimbra, Portugal; Tel: 351 239 790500.

1. Introduction

The money markets have previously been widely studied and the results are given in economic literature. Their role in the transmission of monetary policy as well as the price they form determine the importance of these markets. The shortest term interest rate in the economy is formed in this market and it influences the term structure of interest rates. Therefore it is of crucial importance to understand the way the money market works, and how its interest rate emerges from the interaction of the market participants.

Over recent decades, several studies have been carried out that analyse the bank's demand for reserves, from the interbank market as well as the processes followed by the short-term interest rates, especially, the overnight interest rate. The great majority of these studies analyse the USA Federal Funds Market. The works of Spindt and Hoffmeister (1988) and Hamilton (1996), which aim to study the evolution of the level and volatility of the overnight interest rate throughout the reserve maintenance requirement period, have been developed further by numerous subsequent papers. The banks need to fulfill their reserve requirements, and this is a fundamental reason for the demand on Central Bank funds, and a determinant factor in the formation of the overnight interest rate.

The aim of this paper is to analyse the Portuguese Interbank Money Market, i.e. the Mercado Monetário Português - MMI. This market has some institutional characteristics, which are very different from those of the USA money market, particularly as the MMI belongs to a wide transactional space, the Euro zone. The main features of the Single Monetary Policy and the operational framework of the Eurosystem are very different from those of the Federal Reserve System. We intend to identify the features of the MMI, and the patterns shown by the short-term interest rate, and compare them with those documented in the literature. Using high-frequency data, we analyse market behaviour during the day, concentrating on liquidity and the intraday interest rate, and searching for the U-shaped patterns documented in literature. The U-shaped pattern of some variables, such as traded volume, returns and variances, has been identified in both stock and futures markets. It shows the evolution of these variables as attaining their maximum value in the early morning, then falling until midday, and subsequently increasing again the close of the market. The literature explains this pattern in terms of the reaction of the market to new information and the corresponding clustering of activity or, alternatively, as a result of trading stoppages.

This artic le proceeds as follows: Section 2 provides a review of the literature. In Section 3 we describe the institutional features of the Portuguese domestic money market. Section 4 describes the data and Section 5 describes the behaviour of the variables in the market. Section 6 presents an estimation of an ARCH model for the overnight interest rate and its volatility. Section 7 concludes.

2. Review of the literature

Studies of interbank markets in recent decades have analysed the behaviour of the level and volatility of the short-term interest rates, throughout the reserves maintenance period. Evidence that the short-term interest rate time-series showed heteroskedasticity has been shown by several authors. The development of ARCH (Autoregressive Conditional Heteroskedasticity) and GARCH (Generalized Autoregressive Conditional Heteroskedasticity) models enabled the estimations of the evolution of short-term interest rate to be made.

Studies have recently been carried out that use high-frequency data to analyse intraday patterns in the short-term interest rate. The availability of this data, has allowed researchers to describe the features of the processes of trade, and to identify intraday patterns in interest rate.

The work of Spindt and Hoffmeister (1988) includes a model that describes the determination of trading prices in a continuous market. The authors purport the behaviour of the banks in this market assuming that there is a single, large-funds trading bank i.e. the dealer and numerous small institutions i.e. retail institutions. The dealer is the "market maker", he is always prepared to buy funds (at a bid rate), and to sell funds (at a asked rate). The retail banks are price takers, they offer or demand funds to and from the dealer (at the bid or asked rate). The Central Bank does not participate directly in this trading market. However, it supplies or drains liquidity from the market through open market operations. Thus the Central Bank determines the amount of pressure felt by the banks in their demand for reserves. The dealer would like to maximize his expected trading profits, subject to his reserve requirement constraint. This problem is solved by a two-stage strategy: firstly, the dealer determines his end-of-day reserve balance. The reserve balance should fall within a critical range, defined by a lower and an upper limit; should the reserve balance fall outside this range, funds will be sold or bought in order to get back within the set limits. Secondly, the dealer chooses the asked and the bid rates that would maximize his profit, according to the earlier reserve strategy. The objective of this model, like that of Ho and Saunders (1985), is to characterise the money market microstructure.

Spindt and Hoffmeister (1988) also study the need for reserve balances, according to the requirements set by the Central Bank. They analyse the accumulated reserve position, wich depends on the stochastic inflows and outflows, and the daily work-off rate supported by the bank in order to satisfy its reserve requirement. The reserves are calculated as an average, over a maintenance period of several days. So, the work-off rate increases as the settlement day approaches. The later any unexpected change in the funds of the bank occurs, the greater the funds' demand/supply reactions to accommodate this change are. An empirical verification of this model is given by an estimation of daily funds rate variance. This variance is not constant throughout the reserves maintenance period. The interest rate variance increases towards the end of the maintenance period and is at its greatest value on the settlement day [1].

The results of this paper are taken further in the article by Griffiths and Winters (1995), which uses the same methods of funds rate volatility estimation[2]. Griffiths and Winters (1995) show that the banks have an incentive to lend funds on the first few trading days of the reserves maintenance period, creating an accumulated short position, as well as on Fridays (Friday balances count three-fold). If the institutions do not do this, they incur an opportunity cost, depending on the market interest rate (which is greater than the discount rate). However, on the settlement day, it increases the need to satisfy the reserve requirement and adds pressure to the bank's demand for funds from the money market or the Central Bank. The researchers predict and identify empirically the following features of the funds rate: the overnight funds rate decreases on Fridays and increases on Mondays. Moreover, its variance is not constant – as it increases on the last two days of the maintenance period, as well as on Fridays, and decreases on Mondays. Evidence has been found that the intraday variance follows a pattern, which increases throughout the day, as Spindt and Hoofmeister suggest.

These two previous studies analyse the overnight money market interest rate and conclude the existence of a periodic pattern in interest rate over the reserves maintenance period as well as in its volatility. This evidence has continued to be tested in latter investigations.

Another fundamental work in this area is Hamilton (1996). It describes the institutional features of the USA money market, and proposes a theoretical model for the behaviour of the banks in their demand for reserves and develops an empirical description of the time-series process that generates the daily funds rate. This description rejects the martingale hypothesis for the interest rate over the maintenance period.

The reserve requirements are satisfied according to an average provision. Thus, the reserves held on any day of the maintenance period are perfect substitutes for purposes of satisfying reserve requirements. Accepting this hypothesis, if $i_t > E_t(i_{t+1})$ the banks will lend in the market on day t, diminishing their excess reserves or augmenting the need for borrow later in the market. If all banks

[1] This model also predicts that the variance of the funds rate increases across the trading day. However, the available data does not permit a verification of this prediction.

[2] In Spindt and Hoffmeister (1988) and in Griffiths and Winters (1995) an estimation of the interest rate volatility is obtained by the using the Parkinson's estimator. This estimator uses information regarding daily highs and lows of the overnight interest rate. See Parkinson (1980) for the method of extreme values.

do this arbitrage, i_t decreases and i_{t+1} increases. The logical implication of this is that the interest rate changes are unpredictable and that the interest rate should follow a martingale within the maintenance period[3].

This appealing theoretical hypothesis is inconsistent with empirical estimation[4]. An empirical estimation of interest rate and its volatility, was made by Hamilton (1996) covering the period of 1984-1990. The data is described using a model that accepts ARCH effects and rejects the martingale hypothesis. The Hamilton's empirical estimation supports the following conclusions:

- During the reserves maintenance period, the overnight interest rate tends to be lower on Fridays and to increase on Mondays. Similarly, on a day preceding a bank holiday the overnight rate decreases only to increase again on the following day. When the weekend is preceded by a bank holiday, these effects are even more pronounced.
- On the settlement day the overnight interest rate tends to rise.
- The overnight volatility follows a pattern too, tending to increase on the last three days of the reserves maintenance period, especially on settlement day.
- The overnight volatility shows a tendency to rise on the last day of the quarter and on the last day of the year.

These conclusions do not validate the martingale hypothesis. Hamilton explains the patterns identified with the overnight interest rate using a model of the banking system where there are two groups of banks, the lending banks and the borrowing banks. In this model, <u>transaction costs</u>, <u>market imperfections</u> (such as, the borrowing bank not being able to find a bank wishing to lend the needed amount) and the <u>liquidity yield of reserves</u> give rise to interest rate, that mimic those displayed by actual data. He presents simulations of the interest rate in his paper.

The fundamental conclusion of Hamilton's article is that reserves are not perfect substitutes between different days of the reserves maintenance period. Rather, the overnight interest rate and its volatility follow a predictable pattern over the maintenance period. The Central Bank needs to take this periodic pattern into account in order to intervene in the market. This pattern is due to transaction costs, market imperfections and the liquidity yield of reserves.

In recent years, other research on money markets and short-term interest rates has been carried out. This work was inspired by Hamilton's work and focuse on several aspects such as Central Bank intervention and the role of interbank payments. Bartolini, Bertola and Prati (2001)

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[3] If t is the last day of the maintenance period, we can not follow this rationale. The reserve balances of day t and day t+1 are not substitutes. They can have only some degree of substituability if the banks can carry over an amount for the next period.

[4] As in the two papers referred to above.

restate the inexistence of a martingale on the interest rate within the reserves maintenance period and associate the overnight interest rate with Central Bank liquidity management (supplying/absorbing funds). Their work links the money market interest rate (prices) with the banks' excess reserves balances (quantities). Once again, they find evidence that the average overnight interest rate tends to rise on settlement day, as does its volatility. The existence of strong periodic patterns in interest rate is due to uncertainty regarding the liquidity flows and to transaction costs. Trading in the interbank market represents a cost to the bank, but it can choose to trade later in the maintenance period, when it has more information regarding its need for reserves.

The same pattern is identified with excess reserves balances: they decrease slightly over the first few days of the maintenance period and rise sharply thereafter. This pattern of evolution is not due to the supply of funds from the non-bank sector of the economy (families, companies, public sector). It is the intervention of the Central Bank that absorbs liquidity from the banks during the initial days of the maintenance period and that later injects into, what constitutes, an interest-rate-smoothing policy.

Another paper seeking to explain the non-existence of the martingale on overnight interest rate during the reserves maintenance period is Furfine (2000). The author stresses the effect of interbank payments and their uncertainty on the behaviour of interest rates. The larger the payments volume faced by a bank, the larger the uncertainty and the greater the reserves balance that the bank wishes to hold. The volatility of the overnight rate also follows the same pattern as that found in the volatility of payment activity, except on the settlement day, when the volatility in the overnight rate is greater than that in payments. On settlement day, the need to satisfy the reserve requirements, is more important then the payments effect.

All articles reviewed thus far analyse the USA money market and the Federal funds interest rate. However, other research has been done on similar issues for the European money market and its prices. Examples include: Quiróz and Mendizábal (2001); Gaspar, Quirós and Sicilia (2001).

Quiróz and Mendizábal (2001), follow the same approach as Hamilton (1996) and Bartolini et al. (2001), studying the overnight interest rate behaviour and attempting to identify the perfect substitutability between reserves within the maintenance period, that is, whether the overnight interest rate follows a martingale or not. The authors compare the spread between the German overnight rate and the rate of the main refinancing operations of the Bundesbank in the years leading up to European Monetary Union (EMU) with the spread between EONIA[5] and the rate of the main

[5] EONIA- *Euro Overnight Index Average*: the reference overnight interest rate of the euro money market. It is calculated as a weighted average of interest rates on unsecured overnight contracts on deposits denominated in euros, as reported by a panel of 57 euro-area banks.

refinancing operations of the ECB. The empirical analysis of the changes in interest rate and its variance was performed using an ARCH type model (actually an EGARCH was used, which allows effects in variance that depend on the magnitudes of the lagged residuals and on their signs[6] to be studied) and finds evidence that before January 1999 the interest rate tended to be higher at the end of the maintenance period but that this did not happen subsequently. On the other hand, the volatility of the interest rate was found to change - tending to be higher at the end of the maintenance period and this effect was greater before the 3rd Stage of EMU. Quiróz and Mendizábal were unable reject the martingale hypothesis after January 1999.

An explanation for this difference in the behaviour of interest rate is given by the procedures of the ECB. After January 1999, the ECB introduced a deposit facility (and an interest rate deposit facility) that did not exist in Germany before the 3rd Stage of EMU. This deposit facility constitutes a floor for the overnight rate and is combined with the lending facility to form a corridor. The overnight rate remains inside this corridor. It is this new Central Bank procedure that contributes to the reduction in volatility, not a shift in the bank's risk aversion or market imperfections.

Gaspar, Quirós and Sicilia (2001) analysed the first three weeks following the implementation of the Single Monetary Policy, and showed how they represented a "learning period" for the European banks. They also tested the martingale hypothesis with respect to the announcement of monetary policy decisions. If the market correctly anticipates the ECB's actions, the interest rate will not be affected by the announcements made after meetings of the Governing Council. The empirical estimation of the interest rate changes (using an EGARCH model) shows that monetary policy announcements do not affect either the mean interest rates or their variance. This can be interpreted as markets correctly anticipating interest rate decisions made by the ECB.

The newly available high-frequency data covering recent years has permitted investigation to take place into money market microstructure. Such analysis has already been performed on stock and futures markets. On this subject, we can consult the papers of Furfine (1999), Furfine (2001), Cyree and Winters (2001), Angelini (2000) and Hartmann, Manna and Manzanares (2001).

Furfine (1999) analyses the USA money market transactions according to the kind of institution involved, especially according to the size of the bank, and concludes that this is a highly concentrated market. Other analysed features, which also depend on size of the bank are: the side of the market (lending or borrowing) that the bank is on, the time the banks trade, the number and type of counter-parties and, finally, whether the asymmetrical information leads to difficulties in borrowing. A determination of the overnight interest rate is further considered in Furfine (2001),

[6] The exponential GARCH, or E-GARCH, was suggested by Nelson (1991), creating a model where the variance responds assymetrically to positive and negative shocks. The E-GARCH models can be found in Hamilton (1994).

where the prices of the funds transacted subject to differences in credit risk across borrowers are studied.

Cyree and Winters (2001) study the intraday patterns in overnight interest rate. As with prices, volumes, and volatilities in several markets, it is possible to identify a U-shaped pattern in the overnight interest rate over the trading day. This means that the overnight rate attains its maximum value in the early morning, then falls until midday, and finally increases again until the close of the market. Two competing theories, based on the analysis of the trading processes, explain this pattern. One is based on the role of private information regarding future prices, which may be different between different institutions, and the other is based on trading stoppages. The authors believe that, with a knowledge of the money market features, the existence of private information is not necessary to explain the behaviour of the variables. The trading stoppages (at the end of the day) along with the knowledge that banks need to satisfy their reserve requirements, are sufficient. Cyree and Winters (2001) estimate the processes followed by the overnight interest rate as well as its volatility, for the period February 1984 to January 1996, using a GARCH model. They conclude that the larger variations occur at the beginning and end of the trading day. There is one exception: on the settlement day the volatility rises throughout the trading day.

Angelini (2000) presents a study of the Italian money market, for the period between July 1993 and December 1996. The author states that the banks' intraday behaviour in the interbank market is explained as the outcome of their optimisation processes. The banks minimize the total cost of holding reserves with uncertainty regarding both their end-of-day position and the interest rate that they pay/receive on reserve transactions. Their choice regarding the timing of operations in the market represents a trade-off between these two sources of uncertainty. The observation of intraday data shows that on the latter days of the maintenance period, the volatility of interest rate is substantially larger than during the rest of the period. An empirical estimation shows that banks shift a significant share of transactions from the afternoon to the early morning. This evidence is consistent with the hypothesis of risk aversion.

Finally, the work of Hartmann, Manna and Manzanares (2001) comprehensively describes the institutional framework of the euro money market, the Central Bank's policies and the instruments available for their implementation. These are: refinancing operations, standing facilities and minimum reserve requirements. A brief description of the function of European payment systems, especially TARGET[7], is also given. Then the authors analyse 6 months' of intraday data

[7] TARGET – *Trans-European Automated Real-Time Gross Transfer System*, is a payment system composed of one real-time gross settlement (RTGS) in each of the European union member States and the ECB payment mechanism. TARGET allows cross-border transfers in real-time. This payment infrastructure has been created to provide a safe, reliable and efficient system for cross-border payments and to serve the needs of Single Monetary Policy. For the TARGET, see the ECB web site and the ECB's TARGET Annual Report (2001).

(November 1999-March 2000) recorded by 6 brokers from several European countries and recorded on the Italian money market. Market activity (described by trading volume per hour) and overnight interest rate volatility show a U-shaped pattern, as identified in other markets. An analysis of the effects of announcements and interest rate decisions suggest a correct anticipation of the ECB's monetary policy decisions.

In conclusion, we can say that the literature reviewed above studies the interbank markets with the aim of characterising the behaviour of the institutions that operate in the market and the way that behaviour determines short-term interest rates. All examine the processes followed by overnight interest rates and by their volatility. With daily data, they explore the periodic pattern of short-term interest rates and interest rate volatility within the reserves maintenance period. When high-frequency data are available, the intraday pattern (over a trading day) is given. The results show that the interest rate changes are not constant throughout the maintenance period and that the same applies to their volatility[8]. The overnight volatility is greater on the latter days of maintenance period. The study of daily market sessions identifies a U-shaped pattern associated with these variables.

As with the literature on stock or futures markets, the literature on money markets shows that heteroskedasticity in overnight interest rate variance is important. In the last few years, the study of money markets using ARCH type models has outlined new features of the short-term interest rate processes. The patterns identified in overnight volatility are determined by the behaviour of the trading institutions and the institutional characteristics of the market. The understanding of these features is essential to the study of interbank money markets.

3. The Portuguese Money Market

The Portuguese Money Market, known as the Mercado Monetário Interbancário- MMI is the Portuguese domestic interbank market. It was created in the seventies, when the Portuguese banking system was extremely closed and closely controlled by the Central Bank- the Banco de Portugal. Since its creation, the MMI has continuously adapted to a more competitive environment based on the free interaction of supply and demand[9].

[8] However, it is not possible to reject the martingale hypothesis on the European money market after the 3rd Stage of EMU, as shown by Quiróz and Mendizábal (2001) and Gaspar, Quiróz and Sicilia (2001).
[9] The creation and evolution of MMI are described in Sol (1996).

Nowadays, on the MMI, and in accordance with Instruction nº 51/98 from the Banco de Portugal, only the institutions subject to the minimum reserve requirements of European System of Central Banks (ESCB) can trade in the market. In this market the banks borrow and lend Central Bank money. These loans are unsecured and their terms can run for up to a year. However, the vast majority of these loans are very short term, and often only run overnight. The loans can also be forward loans with one or two days to run before the delivery date[10]. The conditions set for the loans, their size, the interest rates and the terms are freely agreed between the lending bank and the borrowing bank. The MMI is an over-the-counter (OTC) market.

The trading is executed through SITEME[11], an eletronic infrastructure created for the processing of interbank transfers and payments between the Central Bank and other banks. When two banks agree on a loan, this operation is communicated to the Banco de Portugal, which transfers the funds between the accounts of the two banks. On the repayment day, the Central Bank reverses the transfer of funds along with the interest accrued [12].

4. Data

This paper analyses the MMI and the way trading takes place throughout the day. Our data is intraday data collected by the Markets and Reserves Management Department of the Banco de Portugal, that were kindly made available for the purposes of our ongoing research. The data covers the period from May to October 2001. For each of the loans in the MMI, we have the following information: the day and time (in hours, minutes and seconds) of the operation and the day in which the operation is registered in the SITEME, the size of the loan, the interest rate and the term of the loan. This database includes 4542 transactions between 2 May and 31 October.

In our study we only used the data relative to the spot overnight loans and the spot overnight rate (this segment being the most important in the money market, representing 85% of the MMI's transactions[13]) because our purpose was to identify the process followed by overnight interest rate and its volatility.

[10] The spot segment is the most important in the market.
[11] The SITEME features are described in Banco de Portugal (2000).
[12] The interest is calculated according to the formula: Effective Number of Days/360.
[13] The term of the MMI's loans can be up to a year. However, like other money markets, this is a very short-term market. The operations that have a term longer than 7 days, represent only 5% of the spot market.

5. Description of the overnight loans market

5.1. A look at overnight loans during the day

The data available enables us to identify the behaviour of the market throughout the trading day. The MMI opens at 7 a.m. and closes at 5 p.m. We have organised the data according to one-hour periods. Table 1 shows the evolution of overnight loans during the day.

Table 1: Overnight transactions during the day

Time[14]	Nº of loans	Average volume (thousands of euros)	Average volume per transaction (thousands of euros)	Average interest rate	Interest rate variance
8-9	79	1 703 509	21 563	4.332	0.144
9-10	539	10 744 609	19 934	4.294	0.130
10-11	486	7 928 299	16 313	4.299	0.137
11-12	294	5 226 590	17 776	4.356	0.119
12-13	173	2 758 355	15 944	4.310	0.144
13-14	152	1 874 146	12 330	4.356	0.093
14-15	277	4 174 760	15 071	4.338	0.120
15-16	304	4 093 606	13 466	4.355	0.177
16-17	175	5 259 908	30 357	4.423	0.163

As can be seen from the table, the trading activity is not constant throughout the day. The market records a low number of operations before 9 a.m. The MMI opens at 7 a.m. and closes at 5 p.m. in order to function simultaneously with all EMU members. However, there is a time difference of one hour between Portugal and most other EMU members[15] where the market opens at 8 a.m. Also, Portuguese credit institutions open at 8 a.m., hence the MMI's relatively small number of loans at the beginning of each day.

[14] We eliminated the time interval between 7 a.m. to 8 a.m. because we had only one transaction before 8 a.m. That transaction as realized at 7:52 a.m. We added that operation to those realized between 8 a.m. and 9 a.m.
[15] Portugal and Ireland have the same official time. Portugal is one hour behind Germany, Austria, Belgium, Spain, France, Netherlands, Italy and Luxembourg, and is two hours behind Finland and Greece.

The volume of transactions in the market is highest between 9 a.m. and 10 a.m. This then decreases until midday, before rising again in the afternoon. The average volume per transaction follows approximately the same U-shaped pattern[16].

The average overnight interest rate fluctuates over the session and ends the day at its highest value. The interest rate volatility, wich is measured by its variance, also fluctuates. It has a minimum value during the lunch hour and then increases in the afternoon. The higher values at the end of the session are a result of some banks demanding reserve balances in order to fulfill their reserve requirements, and other banks supplying funds, trying to lend their excess reserves. Both effects concur to increase variance, while the vital importance of reserve requirements accounts for the upward tilt on the rates.

These patterns have already been identified in previous publications. Cyree and Winters (2001) found evidence that, in the USA money market, the biggest interest rate changes occur at the opening and closure of the day's trade and that the same trend is seen in interest rate volatility. The only exception was found to be on the settlement day, when the volatility rises steadily throughout the trading day.

5.2. A look at the overnight loans within the reserve maintenance period

One of the instruments of single monetary policy is the minimum reserve system, wich is described in the ECB document: 'The Single Monetary Policy in Stage Three' (November 2000). Within this framework, the ECB requires banks to hold reserves on accounts with the national Central Banks[17]. The minimum reserves are calculated by applying a reserve ratio to the reserve base. The reserve base is composed of two categories of liabilities: 1) deposits and debt securities with an agreed maturity of up to two years, to which a reserve ratio of 2% is applied, and; 2) deposits, repos and debt securities with an agreed maturity of over two years, to which a reserve ratio of 0% is applied[18]. There is a third category of liabilities, excluded from the reserve base, i.e. the liabilities vis-à-vis other institutions subject to the Eurosystem's reserve requirements and vis-à-vis the ECB and the national Central Banks[19].

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[16] The analysis of all spot transactions shows the same pattern in trading activity.
[17] The ECB elaborates and updates a list of every instution subject to reserve requirement system. This list is available on the ECB's website.
[18] Theses reserve ratios can be altered by the ECB.
[19] If the bank can not distinguish the securities or the money market paper wich do not make part of reserve base, the ECB allows the bank to apply a standardised deduction of a fixed percentage to each of the balance sheet items. Since the maintenance period began on 24 January 2000, the standard deduction is 30%.

The maintenance period is of one month, starting on the 24th calendar day of each month and ending on the 23rd calendar day of the following month. The reserve requirement of each institution is calculated from its balance sheet data relating to the previous month[20]. Each institution deducts a uniform lump-sum from its minimum reserve requirement, in each Member State where it has an establishment. Since 1 January 1999 this lump-sum is equal to 100 thousand euros.

The minimum reserve system enables banks to make use of averaging provisions, that is, compliance is determined on the basis of average end-of-day balances of reserve accounts over a one-month maintenance period.

These provisions put off the need to satisfy the reserve requirement to the settlement day, when the banks will need to borrow from the money market in the case of a reserves shortage, in order to avoid being penalised for non-compliance. Therefore, we can expect the money market to be under pressure by the end of the session, on the settlement day.

Our data period spans seven reserve maintenance periods, completely covering five of them, and corresponding to an approximate total of six periods. The 23rd day of the month is the designated settlement day, except when it occurs at weekends, which occured in our sample both in June and in September. In such cases, the last day on wich banks can operate in the money market is the preceding Friday, which is then regarded as the settlement day.

The next step is the analysis of market activity and interest rate behaviour on the last two days of each maintenance period in comparison with other days. Figures 1 to 4 (Annex 1) show the evolution of the number of transactions, the volume of transactions, the interest rate levels and the volatility throughout the trading day for these two groups of days. The last two days of each maintenance period are considered jointly because they show similar intraday patterns in these variables and because in previously published literature, Quirós and Mendizábal (2001) for instance, such similarities have already been documented[21].

[20] According to Regulation (CE) 2819/98 of the ECB, small institutions only need to report a limited set of balance sheet data on a quarterly basis. For these institutions, the balance sheet data of a specific quarter, are used to calculate, with a lag of one month, the reserve base for three consecutive reserve maintenance periods.

[21] It is normal to analyse the Federal funds interest rate for each day of maintenance period. In the USA the maintenance period is 2 weeks (10 weekdays) and it begins and ends in settled days of the week. Within the EMU, the maintenance period is much longer (1 month) and its first and last days are not settled days of the week. So, the effects on interest rates due to the passage of time are spread out over a longer period and they do not coincide with fixed days of the week. These two elements rend the analysis of each day of the maintenance period less relevant.

Figures 1 and 2 show respectively, the evolution of the number of loans performed per hour, and the transaction volume per hour. These two variables, for the two groups of days considered, behave in a similar way - decreasing in the morning, and having their minimum value around midday and then increasing in the afternoon. Thus they can be described as U-shaped. The explanation for this pattern can be ascribed to stoppages in the market or to the flows of information to which the banks are exposed. The first hours of the morning (7 a.m.-9 a.m.) and the last hour of trade disobey this rule, but that is almost certainly due to the opening and closing times of the Portuguese banks. They open at 8 a.m. and close to the public at 4 p.m.; hence the low trading activity during these periods.

However, there are some differences related to the stage of the reserves maintenance period. The daily number of operations is substantially greater at the end of the maintenance period and it is concentrated at both the beginning (9 a.m.-10.a.m.) and at the end of the day[22]. The same trend is seen with the average amount transacted per hour.

For the average interest rate, in the first part of maintenance period, we identify a regular pattern of behaviour throughout the day, as can be seen in figure 3. On the last two days of each maintenance period the interest rate shows a U-pattern.

The interest rate volatility, shown in figure 4, is the variable that shows a more differentiated behaviour throughout the maintenance period. In the first part, it decreases during the trading day. On the last two days of the maintenance period, however, it increases.

An analysis of the figures enables us to conclude that, on the last few days of the reserve maintenance periods, the behaviour of the banks in the MMI is different from on other days. The trading activity is more intense at the beginning of the morning and in the late afternoon. If the banks are averse to risk and expect an increase in interest rate volatility along the day, they intervene in the market earlier, in order to avoid interest rate uncertainty. Angelini (2000) identifies this behaviour and confirms it through empirical estimation. On the other hand, the activity is high at the end of the day, despite the high volatility of interest rates, because banks need to hold minimum reserve balances.

5.2. A look at overnight loans and ECB intervention

[22] On average, the settlement day has a larger number of transactions than the preceeding day.

The ECB manages the banks' liquidity through open market operations. The features of these operations, fixed by the ECB, also play a role in steering interest rates and signalling the stance of monetary policy.

There are several types of open market operations in the Eurosystem. The most important and common are the Main Refinancing Operations (MRO), which are reverse transactions, executed regularly each week and that have a two-week maturity. They provide the bulk of refinance to the banking sector and are executed in a decentralised manner by the national Central Banks in the form of tender procedures.

The standard tender procedure for the MRO is the following:

- The ECB and the national Central Banks make the tender announcements on Mondays (at the REUTERS agency). This occurs at 3:30 p.m. (2:30 p.m., Portuguese local time).

- On Tuesdays the counter parties submit their bids to the national Central Banks, who subsequently send them to the ECB. At 11:15 a.m. (10:15 a.m., Portuguese local time) the results of the tender are then announced. On Wednesdays the settlement of each transaction is executed.

Figures 5 to 8 examine the intraday evolution of trading activity and overnight interest rates on days with the MRO tender announcements, on days with the announcement of tender results, and on all other days where the MMI functions (with the exception of the two last days of reserves maintenance periods). The information regarding MRO days is available in ECB Monthly Bulletins.

A scrutiny of figures 5 to 8 shows no difference between MRO days and other days. For the various types of days, the variables portraying intraday behaviour are similar. The announcement of the tender and the announcement of its results do not seem to have a strong influence on the market, in terms of interest rates or their volatility. We can thus conclude the inexistence of asymmetric information in relation to ECB intervention.

6. Empirical estimation

An earlier examination of the figures from hourly average values, provides some insights into the way in which the MMI functions. However, we need to verify, empirically, what sort of process the variables considered follow during the day; and whether this process is the same for all market days. We now proceed to estimate the process followed by these variables empirically.

If there are tendencies in interest rate and its variance due to the trading process, namely, the U-pattern identified in other markets[23], then the martingale hypothesis across the trading day can be safely rejected. The martingale is given by:

$$E\left[i_{t+1} / \Omega_t\right] = i_t \qquad (1)$$

where Ω_t indicates the information available at time t.

As Hamilton (1996), Quirós et al. (2001), Gaspar et al (2001), applied to daily observations, and Cyree et al. (2001) carried out on high-frequency data, we use the following model to test the hypothesis:

$$i_t = i_{t-1} + b^{'} X_t + e_t \qquad (2)$$

where X_t indicates a vector of dummy variables that can influence the interest rate, and we suppose that $e_t \approx i.i.d.(0, s_t^2)$.

The variance of the residuals can be heteroskedastic, so s_t^2 is represented by:

$$s_t^2 = a_0 + \sum_{i=1}^{p} a_i e_{t-i}^2 + \sum_{i=1}^{q} b_i s_{t-i}^2 + \sum_{i=1}^{n} l_i V_{it} + u_t \qquad (3)$$

This function allows the existence of ARCH and GARCH effects on the volatility of interest rate changes, as well as the influence of dummy variables represented by V_i. This equation estimation admits the existence of moments in time where volatility is higher than others.

The model is tested using the vector of overnight interest rate changes as the endogenous variable.

Firstly, we can observe the statistics regarding overnight interest rate change series in table 2[24]:

Table 2: Statistics for the series $i_t - i_{t-1}$

Sample Mean	-0.0010650510	Variance	0.012491
Standard Error	0.1117651710	SE of Sample Mean	0.002305
t-Statistic	-0.46215	Signif Level (Mean=0)	0.64401680
Skewness	-0.28955	Signif Level (Sk=0)	0.00000001
Kurtosis	37.29703	Signif Level (Ku=0)	0.00000000
Jarque-Bera	136357.56555	Signif Level (JB=0)	0.00000000

[23] In a martigale, as in a random walk, the interest rate changes would be unpredictable. However, the martingale allows the conditional variance to depend on past realizations of the residuals or of the variance, and to be predictable. So, the martingale, unlike the random walk, allows the existence of ARCH effects. See Cuthbertson (1996).

[24] The calculation of statistics, along with the estimations and tests presented in this work, have been done using RATS, version 5.

The series shows a high degree of kurtosis (leptokurtic) and is left skewed. The Jarque-Bera test of normality shows a high value confirming the non-normality of the series. The fact that the series does not follow a normal distribution can be explained by the existence of periods of time where the volatility is high. To test this hypothesis we analyse the auto-correlation function (ACF) and the partial autocorrelation function (PACF) of squared interest rate changes. Table 3 presents the values of the autocorrelation functions and statistic-Q:

Table 3: Autocorrelation Function and Parcial Autocorrelation Function of squared overnight interest rate changes

	ACF	PACF	Q-Stat	P-value
1	0.5056	0.5056	602.0130	0.0000
2	0.1598	-0.1288	662.1524	0.0000
3	0.0762	0.0685	675.8526	0.0000
4	-0.0009	-0.0727	675.8547	0.0000
5	-0.0059	0.0378	675.9372	0.0000
10	0.0587	0.0406	710.1554	0.0000
15	0.0732	0.0427	764.2655	0.0000
20	0.0400	0.0370	829.1510	0.0000
25	0.0220	-0.0076	860.2027	0.0000

The first order autocorrelation is 0.5056 and then the values gradually decline in superior order lags. These autocorrelations are always significant and give p-values of zero. These autocorrelations show that the series of interest rate changes is characterised by *clustering*, that is, significant interest rate changes are followed by significant interest rate changes. This is a feature of heteroskedastic series[25].

Figure 9 illustrates the evolution of overnight interest rate changes. This series shows no particular tendency and includes both periods of high volatility and periods of relative tranquillity.

6.1. Estimation of the process followed by overnight rates throughout the reserves maintenance period

Taking the data for all the loans in the overnight spot market, we have performed model estimations (using several ARCH and GARCH formulations) that showed residual autocorrelation.

[25] See, for instance, Engle (2001)

Consequently, we investigated the ACF, the PACF and their graphics, from the whole series and, separately, from the last two days of maintenance period and from all other days. The graphics are given in Annex 2.

The ACF shows that the autocorrelations decline from the first lag (and display an oscillating decay) and the PACF shows that the partial autocorrelations also decline from the first lag[26]. These features are common to all series and to both parts into which the series was divided. The oscillating decay of autocorrelations from the first lag, together with the decline of partial autocorrelations from it, suggest that the series behave as ARMA(1,1) processes[27].

The orders of autoregressive and moving average processes have been included in the new estimations, leading to the acceptance of ARCH models for overnight changes. Dummy variables have also been included that relate the overnight rate changes and their volatility to moments in time. We created a dummy variable for the morning (opening of session - 12 p.m.) and one dummy for the afternoon (2 p.m.- end of session) [28] and also a dummy for the last two days of each maintenance period, days that are identified in the literature as days of high volatility. Finally, taking into account the terrorist attacks of 11 September in the USA and the economic instability that followed, we also introduced another dummy relating to the days that followed the attacks. This was the most important event that occurred during the 6 months of our data. In order to identify the effects of ECB liquidity management in the MMI, we created a dummy for the loans that follow the MRO announcements, and a dummy for the operations that followed the announcement of tender results.

The results are given in table 4[29]:

[26] As we can see in the graphics in annex 2, the ACF and PACF functions do not decay monotonically. However, in the RATS program the signalling of correlations had to be superior to two standard errors. This level was only found in a small number of lags (with the exception of the first ones).
[27] These subjects are in Enders (1995).
[28] We have not settled one dummy for each of the trading hours because the market presents a low number of daily trades and because this division of the trading day allows a more general observation of interest rate pattern.
[29] The model ARCH estimations have been realized by procedure Garch.src of RATS-Version 5, which uses the MLE-Maximum Likelihood Estimates method and tests the normalized residuals and the squared normalized residuals for serial correlation, and tests for ARCH, size and sign bias effects.

Table 4: Model estimation

	All series		Two last days of maintenance periods		All other days of maintenance periods	
AR1	-0.061341936		-0.195034445		0.029398626	
	(0.036490734)		(0.105290455)		(0.044182378)	
MA1	0.564531937	**	0.394771542	**	0.696389528	**
	(0.019290120)		(0.083406650)		(0.026627512)	
X1	0.000349509		0.001097643		-0.000150545	
	(0.000853032)		(0.003193680)		(0.000798800)	
X2	0.000994855		-0.006652872		0.001417727	*
	(0.000523184)		(0.005359784)		(0.000582811)	
X3	0.003934747		0.025460431		-0.006142153	
	(0.005841294)		(0.032579998)		(0.013560831)	
X4	-0.002799010	*	-		-	
	(0.001360256)					
X5	-0.000726640		-0.005892524		-0.001089691	
	(0.001531482)		(0.021969106)		(0.001572215)	
X6	-0.000681041		0.004259175		-0.001046392	
	(0.001696917)		(0.019531806)		(0.001634599)	
α_0	0.002929922	**	0.002156840	*	0.002834882	**
	(0.000073756)		(0.000865091)		(0.000077535)	
α_1	0.424317494	**	0.694236043	**	0.166171461	**
	(0.031605549)		(0.119927936)		(0.034969688)	
α_2	0.108154419	**	0.244582702	*	0.095499373	**
	(0.021658794)		(0.104052063)		(0.016830406)	
α_3	-		-		0.090516107	**
					(0.016012505)	
V1	-0.000756977	**	-0.000566611		0.000596754	**
	(0.000073677)		(0.000897956)		(0.000079296)	
V2	-0.002321577	**	0.004668651	**	-0.002292985	**
	(0.000080855)		(0.001543185)		(0.000082349)	
V3	0.004235541	**	0.039244028	**	0.075260773	**
	(0.000404893)		(0.011470357)		(0.009606907)	
V4	0.025908445	**	-		-	
	(0.001141313)					
V5	-0.000181512		-0.003068686		-0.000133628	
	(0.000093194)		(0.003401756)		(0.000091726)	
V6	-0.000437247	**	0.001256605		-0.000383980	**
	(0.000071269)		(0.002982777)		(0.000097447)	

Standard error estimates are given in parentheses
* Significant at the 5% level
**Significant at the 1% level
Xi indicates a dummy variable i that influences the mean of the series. Vi indicates the same dummy variable i that influences the variance of the series. Dummy 1 relates to the morning (opening of the market-12 p.m.); dummy 2 relates to the afternoon (2 p.m.-end of session); dummy 3 represents the days in September that followed the terrorist attacks on 11 September and dummy 4 represents the last two days of reserve maintenance periods. Dummy 5 represents the trading after MRO announcements and dummy 6 represents the trading after the announcement of tender results.
With these estimations, the test results fail to reject the hypothesis of non autocorrelation of residuals, of the inexistence of additional ARCH effects and of the inexistence of signal effects.

The estimated coefficients enable us to conclude the heteroskedasticity of overnight interest rate changes. In fact, we find ARCH effects in the series volatility. The complete series and the series for the last two days of a maintenance period are modelled through an ARCH(2) and the series concerning the other days of maintenance periods is modelled using an ARCH(3). All three models share a similar estimated constant (α_0). However, the ARCH effects are higher in the last two days of a reserve maintenance period.

The dummy variables assumed to influence the volatility are, with the exception of one, all significant to the interpretation of conditional variance. Dummy 4 for the two last days of a maintenance period, has a positive coefficient and is the highest of the dummy coefficients. This result, together with figure 4, encourage the study of these two days separately from the remainder of the series[30]. The estimated coefficients related to dummies 1 and 2 show differences between the last two days of each maintenance period and the remainder of the series. On the last two days, overnight volatility decreases in the morning and increases in the afternoon. However, the opposite is recorded on the other days. This result is consistent with figure 4.

As we expected, dummy 4 – relating to September 11th- shows an increase in volatility in the days that followed the terrorist attacks for the various estimated models[31].

The dummy variable that does not seem to be significant in the volatility interpretation is the announcement of MRO features. The announcement of tender results has a negative effect on the volatility, with the exception of the last two days of each maintenance period, where this effect is not significantly different from zero. After such announcements, the uncertainty over the ECB's liquidity distribution is eliminated, but, on the last few days of each maintenance period, this factor is not significant as banks are under pressure to hold minimum reserves. In earlier studies, e.g. Gaspar, Quirós and Sicilia (2001), the lack of importance of the announcement of ECB decisions has already been noted.

As for the interest rate changes, we can verify that the moving average factor MA(1) is significant in all cases, indicating that the impact of a shock is not immediately absorbed by the market. The autoregressive factor is not significantly different from zero. There is a predictable component that affects the interest rate so the martingale hypothesis is infringed[32].

The estimated coefficients of the dummies generally show very low values, wich are not significant. Therefore, there are no predictable patterns in overnight changes over the day. This is not

[30] The singularity of the last two days of a maintenance period has already been described in earlier literature regarding the European money market, e.g. Quirós, Rodriguéz and Mendizábal (2001).

[31] In the various estimations undertaken, for several formulations of ARCH and GARCH models, we have shown that the sign of each coefficient remains unchanged and is always significant, not only for the September 11th dummy but also for the other dummies.

[32] The coefficient estimated for the past value of the residual is always significantly different from zero. The coefficients are always of the type $|MA1|<1$, so the interest rate process is said to be invertible. It follows that the interest rate is dependent on its own past values and its behaviour does not respect the martingale conditions. See, for instance, Griffiths, Hill and Judge (1993).

surprising since the reserve balances that banks possess during the day do not enter into the calculation of minimum reserves: only end-of-day balances are used.

One exception is the coefficient concerning the last few days of a maintenance period, which is negative rather that positive, as we might have expected because of the pressure to hold minimum reserve balances. This could be due to situations in which the banking sector reaches the end of a maintenance period with excess liquidity.

Another exception is the afternoon coefficient for the first part of a reserves period, which is positive and significant at the 5% level, but otherwise very low. This result can be explained by considering the demand made on reserves by banks in order to reach their end-of-day balances. However, this has not been confirmed for the last two days of a maintenance period where there is an imperative need to hold minimum reserves, because of the threat of being penalised by the ECB. On the contrary, the coefficient for the afternoons is negative (but not significant). This difference supports the idea that, in the 6 months analysed, the banking system arrived at the end of maintenance periods with a "comfortable" reserves situation. In these last few days both volatility, and volume transacted per hour, were higher (see figure 2 in the annex).

The conditions of liquidity in the Eurosystem, throughout the reserve maintenance periods presented in this analysis, can be analysed in the ECB's Monthly Bulletins (from June to November 2001). With the exception of the period from 24th of September to 23rd of October, the liquidity conditions were "comfortable". The use of deposit facilities was superior to lending facilities and the banking system had reserve balances superior to the minimum requirement. There were no pressures to increase interest rates at the end of reserve maintenance periods. These conditions support the idea that, in the MMI, there is no pressure to increase overnight rates at the end of maintenance periods.

In conclusion, the overnight interest rate does not follow a time pattern. In particular, the overnight interest rate does not rise at the end of maintenance periods nor in the afternoon of each trading day. The existence of lending and deposit standing facilities explain the absence of an interest rate pattern. According to the regime of standing facilities, the ECB takes the end-of-day bank overdrafts as requests to access the lending facility[33]. Quirós and Mendizábal (2001) have already used the existence of standing facilities to justify the non-rejection of the martingale hypothesis in the European money market.

[33] To grant access to the lending facility, the counter parties need to possess eligible assets. Therefore, this facility is not a perfect substitute for borrowing from the MMI, where the loans are unsecured. However, Portuguese banks have "Títulos de Depósito do Banco de Portugal" that are securities first issued by the Banco de Portugal in 1994 at a time when the reserve ratio changed from 17% to 2% in order to soak up the banks' excess liquidity. These securities are immobilised, so they are perfect for using as eligible assets.

The interest rate volatility demonstrates a daily time pattern that is different according to the stage of the reserve maintenance period. Volatility is higher in the last few days of maintenance periods, especialy in the afternoon. This feature is explained by the pressure to hold reserves under the threat of penalty for any non-compliance with minimum reserve obligations.

Estimation of overnight interest rate changes and their volatility, do not show U-shaped patterns, although they are apparent in the number of loans and in the average traded volume. We did not find the coincidence of trade clustering with volatility clustering in the MMI, which had been previously reported by Admati and Pfleiderer (1988).

Taking market features into account, we can say that:

- Overnight interest rate does not show a strong intra-daily evolution because, throughout the day, the banks are neutral to the moment of lending/borrowing reserves. They can be characterized as "discretionary liquidity traders"[34]. It is the end-of-day balances that really matter. The existence of two interest rates for standing facilities, that make a corridor, contribute to the overnight interest rate stability.

- On the last two days of a reserve maintenance period, interest rate volatility increases during the day because banks need to hold minimum reserves, under the threat of a penalty of ECB. The pressure felt on holding reserves increases during the day. In the first part of maintenance periods, volatility decreases throughout the day because banks do not feel this pressure. As the hours pass, the uncertainty related to payments and receipts, and on their effect over the end-of-day reserves balance, diminishes. At the same time, there is no pressure to reach a minimum level of reserves, with the knowledge that the lending facility will cover any overdrafts[35].

7. Concluding remarks

The aim of this work is to characterise the intra-daily functioning of the MMI, namely, to test the existence of predictable patterns on the overnight interest rate process. We seek to verify the existence of patterns in the evolution of interest rate known in the literature as U-shaped patterns.

The analysis of the data identified intra-daily U-shaped patterns in the number of loans as well as in the average traded volume. However, such a pattern was not found in the overnight rate,

[34] According to Admati and Pfleiderer (1988) and as refered to in Cyree and Winters (2001).
[35] If the bank has the eligible assets in order to secure the debt.

nor in its volatility. The ARCH model estimation supported these findings. Overnight interest rate is stable over the trading day. Interest rate volatility increases during the trade session on the last two days of reserve maintenance periods and decreases during the trading session in the first part of maintenance periods.

The Single Monetary Policy features can explain the behaviour of overnight interest rate and its volatility. The two existent standing facilities form a corridor that constitutes a limit to the overnight rates and helps to limit their volatility. Together with the fact that the lending facility is automatically acceded to banks when they have end-of-day overdrafts, the absence of an intraday interest rate pattern is accounted for. This is also why volatility decreases over the trading day. Only in the last few days of reserve maintenance periods, when there is pressure to hold minimum reserves, does the volatility increase during the afternoon (being above average throughout the day).

The role of the MMI is to redistribute liquidity throughout the banking system. This work shows that overnight interest rate is formed on this market without significant disturbances and banks reasonably arbitrage interest rate through trading. Overnight interest rate volatility shows a predictable pattern according to reserve requirements and single monetary policy features.

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Annex 1

Figure 1

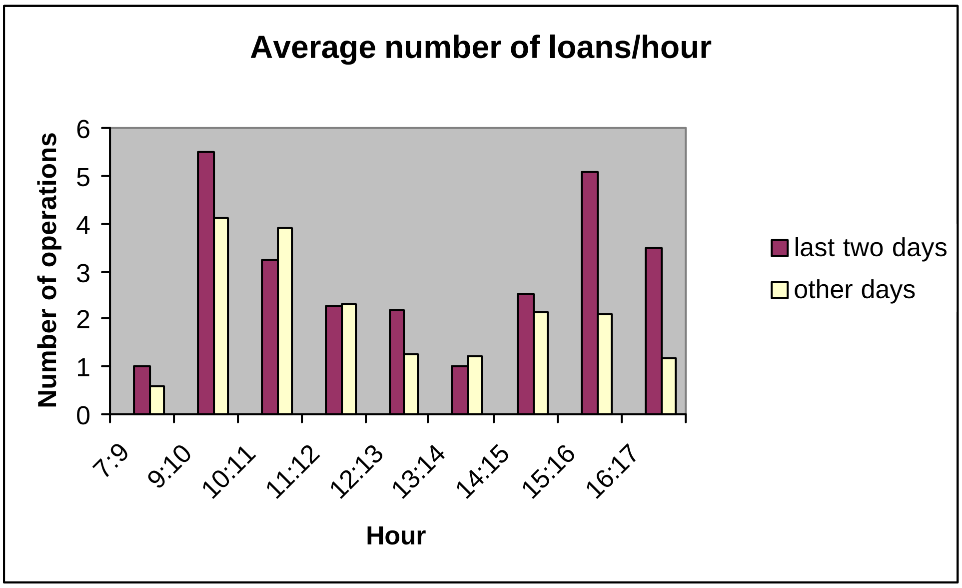


Figure 2

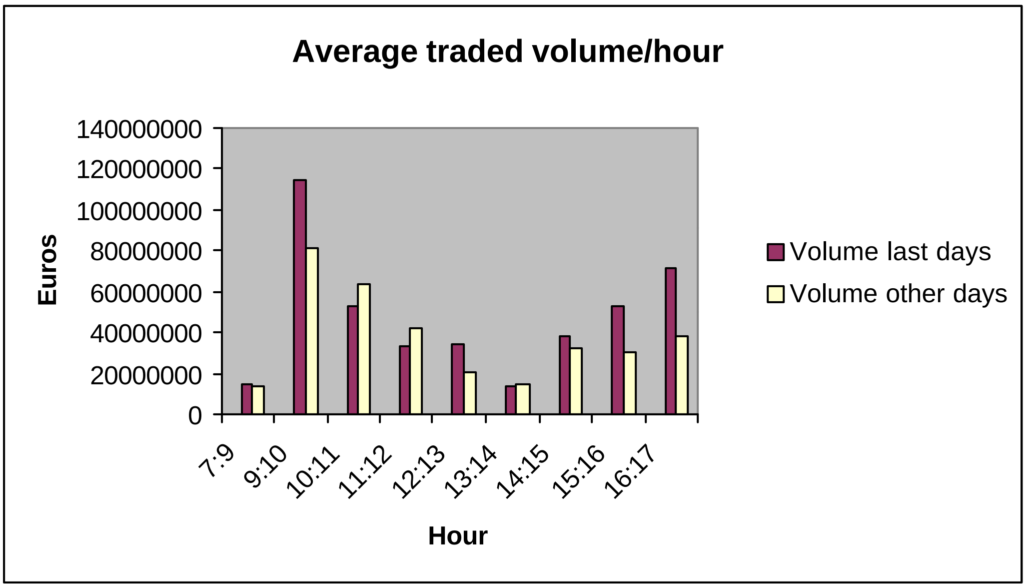


Figure 3

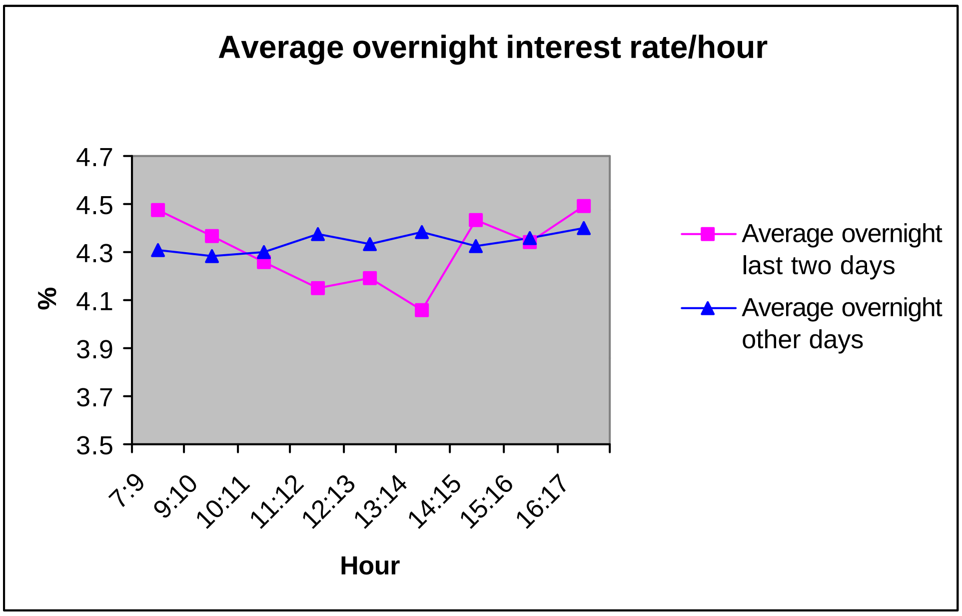
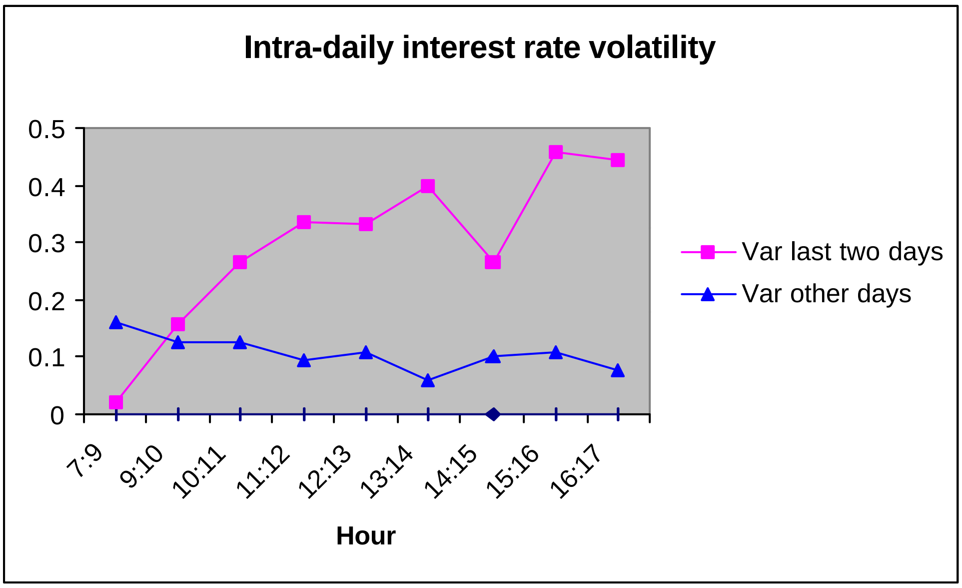


Figure 4



Note: Interest rate volatility was calculated from the interest rate variance.

Figure 5

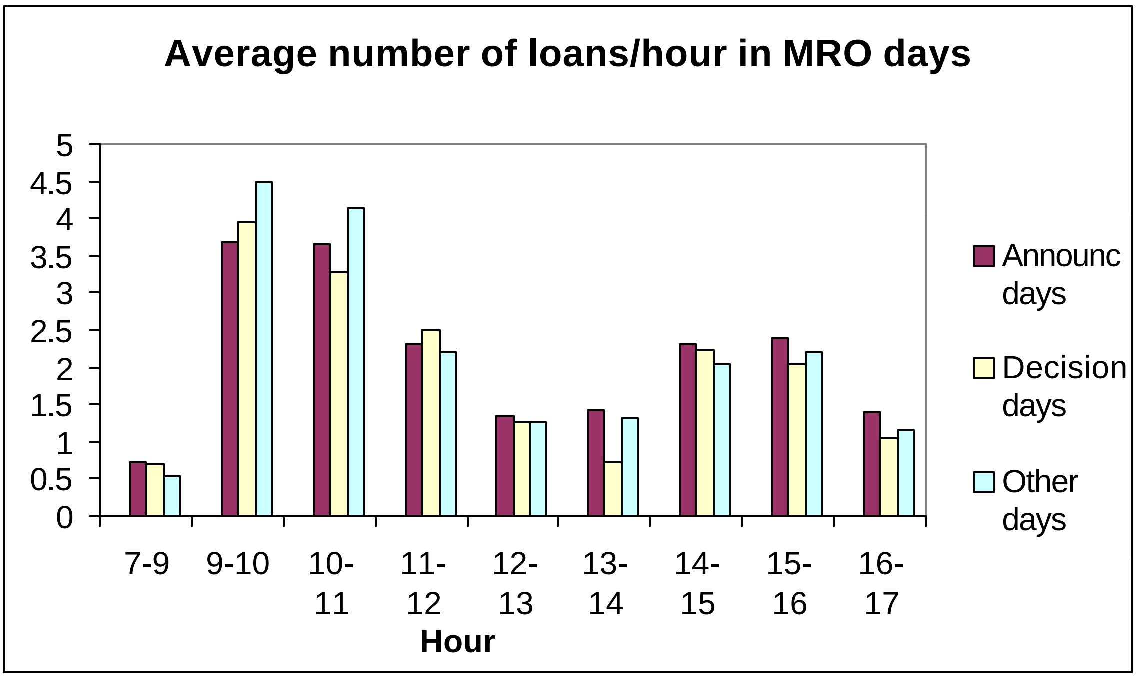


Figure 6

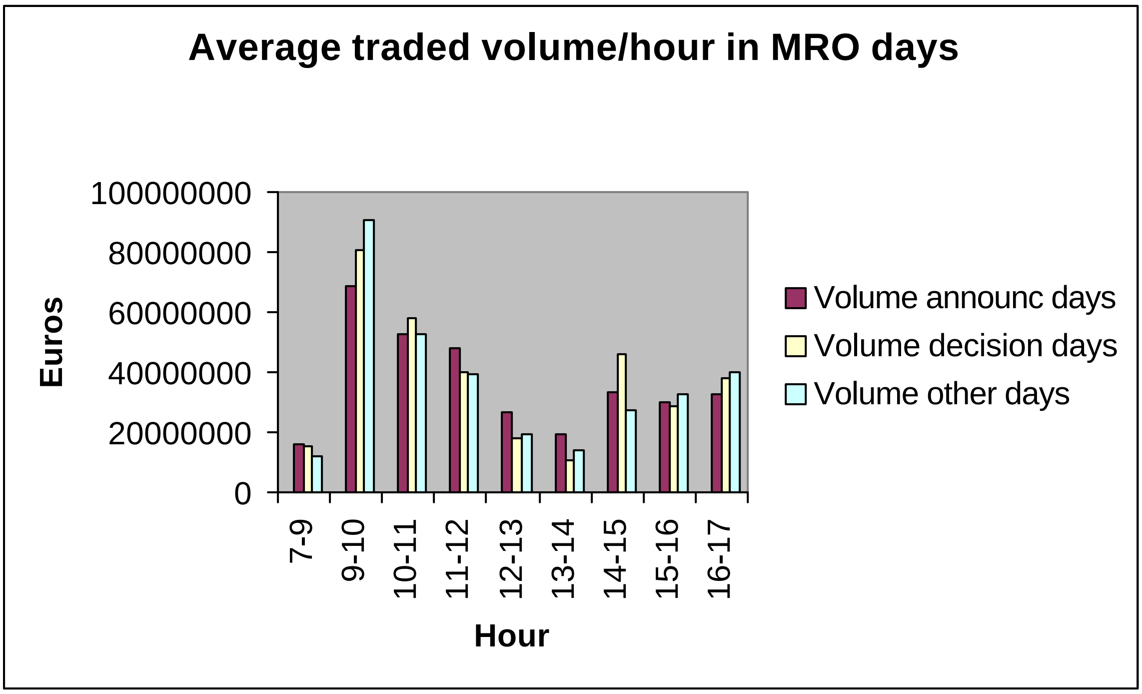


Figure 7

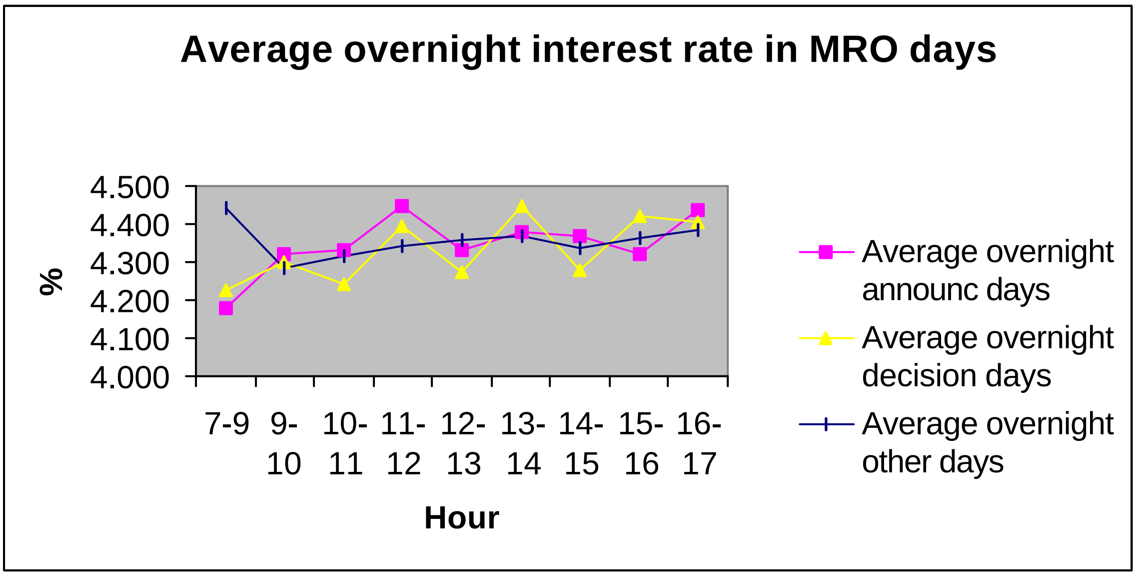
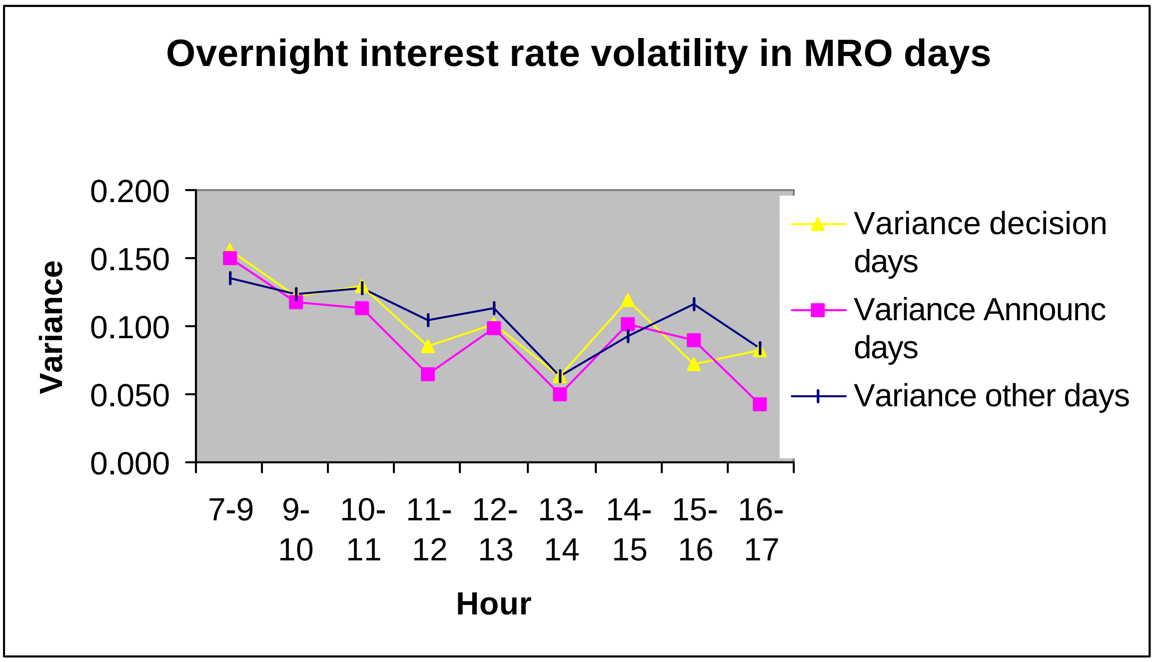
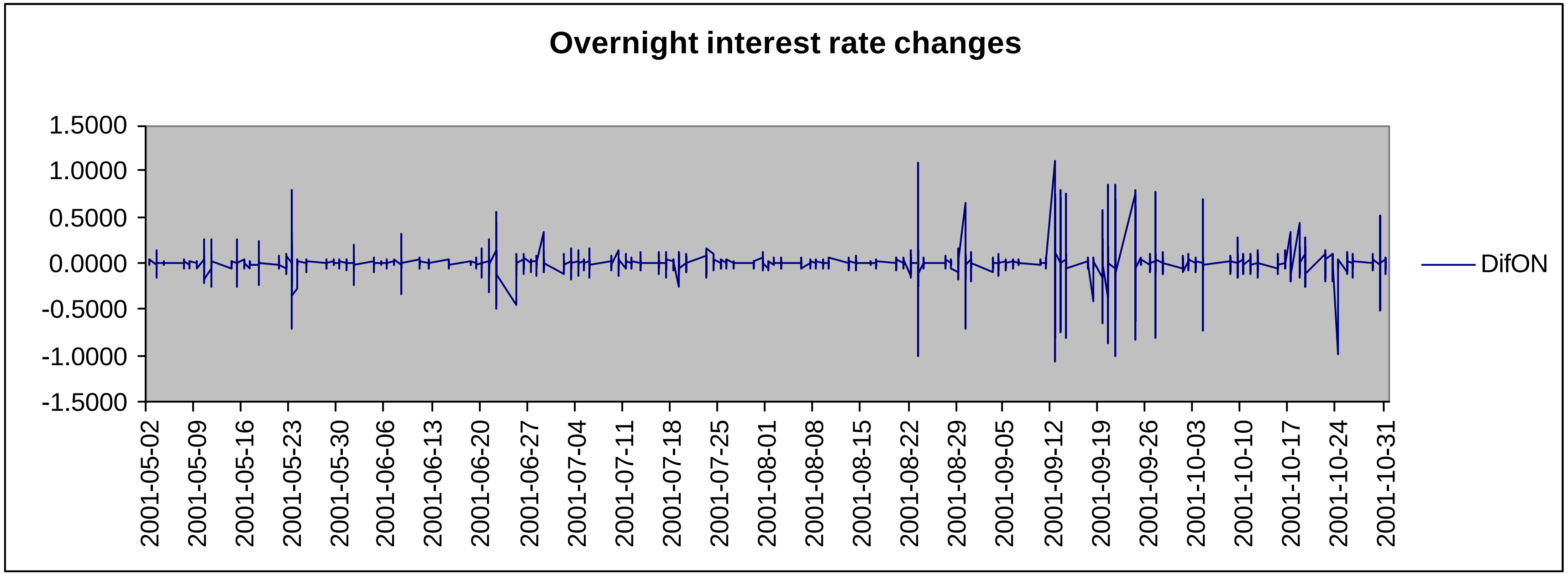


Figure 8



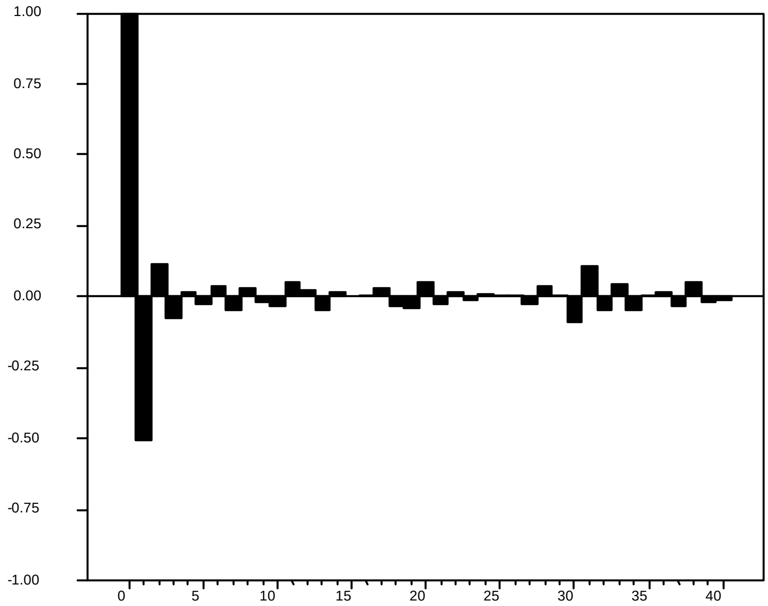
Note: Interest rate volatility was calculated from the interest rate variance.

Figure 9

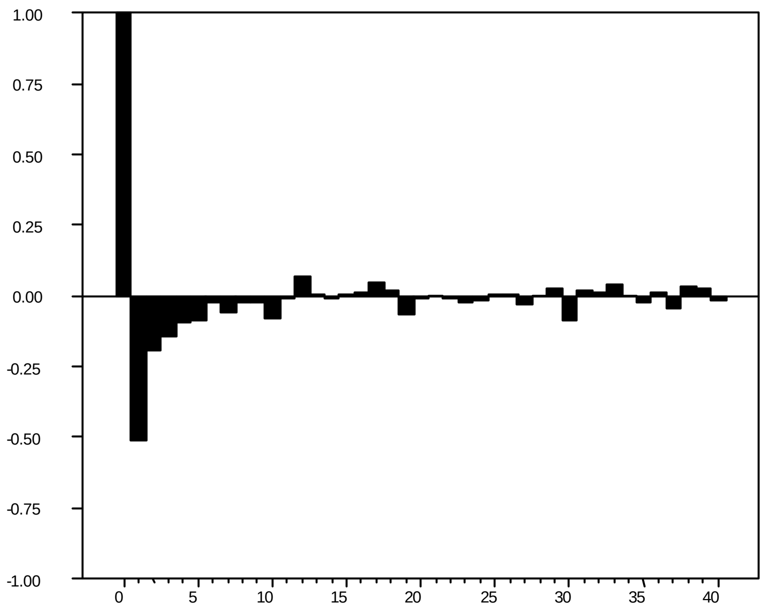

Overnight interest rate changes
1.5000
1.0000
0.5000
0.0000
-0.5000
-1.0000
-1.5000
2001-05-02
2001-05-09
2001-05-16
2001-05-23
2001-05-30
2001-06-06
2001-06-13
2001-06-20
2001-06-27
2001-07-04
2001-07-11
2001-07-18
2001-07-25
2001-08-01
2001-08-08
2001-08-15
2001-08-22
2001-08-29
2001-09-05
2001-09-12
2001-09-19
2001-09-26
2001-10-03
2001-10-10
2001-10-17
2001-10-24
2001-10-31
DifON

Annex 2

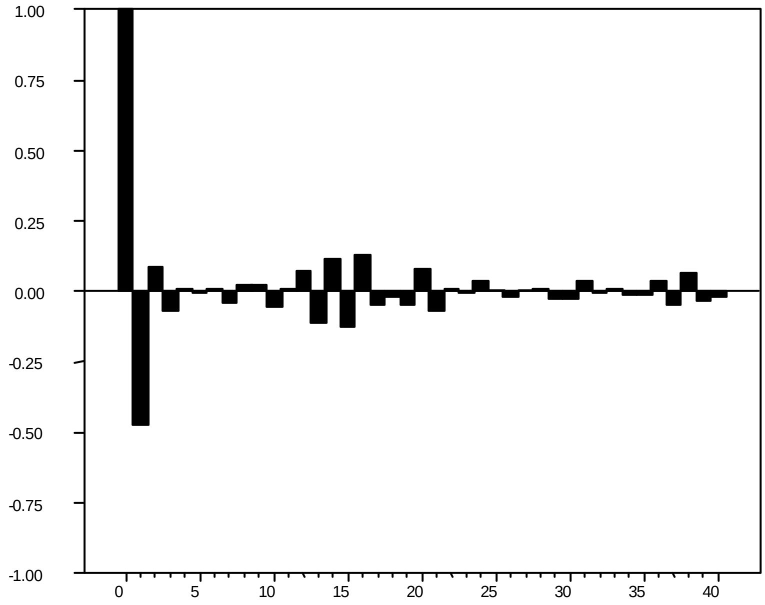
Graphic 1: ACF of the whole series of interest rate changes



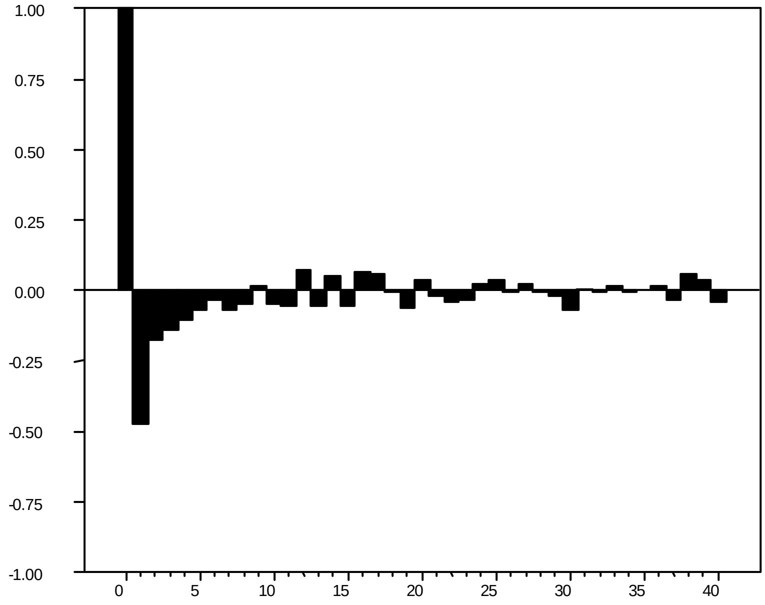
Graphic 2: PACF of the whole series of interest rate changes



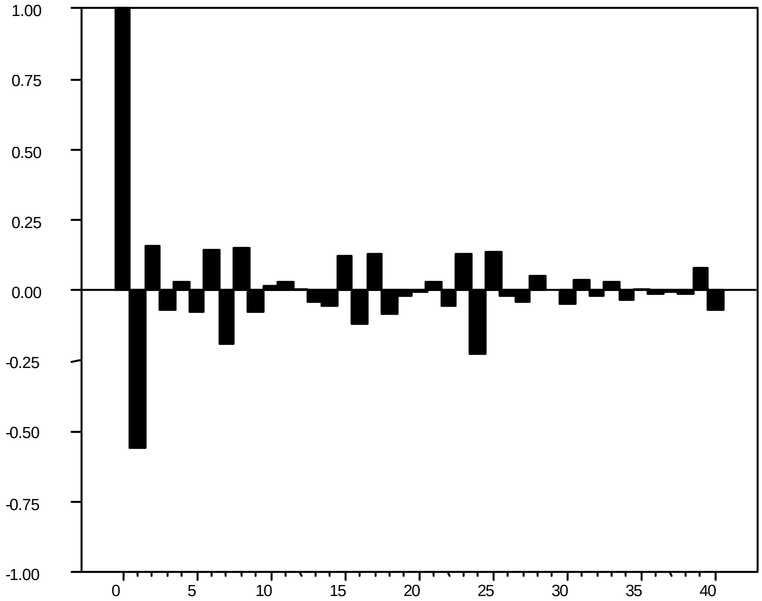
Graphic 3: ACF of the series of interest rate changes, excluding the last two days of reserve maintenance periods



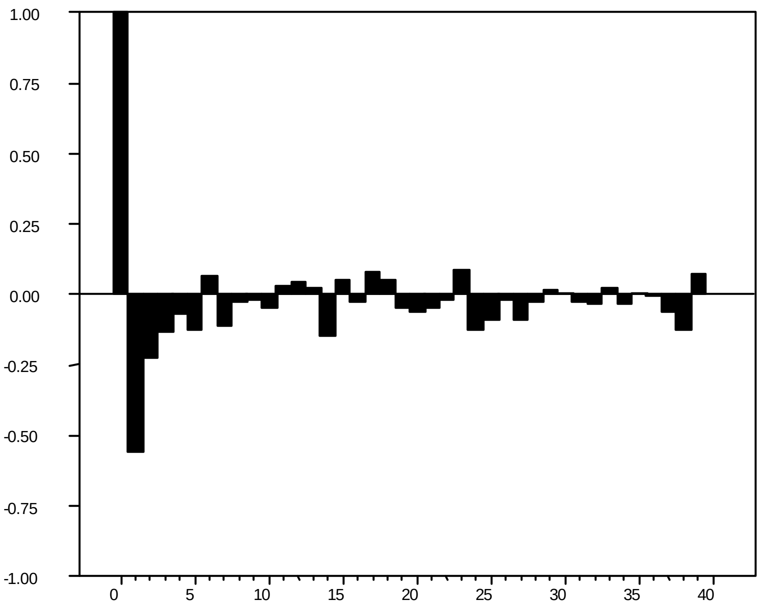
Graphic 4: PACF of the series of interest rate changes, excluding the last two days of reserve maintenance periods



Graphic 5: ACF of the series of interest rate changes for the last two days of reserve maintenance periods



Graphic 6: PACF of the series of interest rate changes for the last two days of reserve maintenance periods


1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
0
5
10
15
20
25
30
35
40

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