The demand for reserves and interest rate volatility before and after EMU: an application to the Portuguese money market

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Keywords: Reserve requirements; Interest rate volatility; GARCH models

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Abstract

We use Portuguese Money Market data to analyse the effect of the introduction of the Single Monetary Policy minimum reserve system on money market interest rate volatility. The spread between the overnight interest rate and the mid-point of the corridor of interest rate standing facilities is modelled trough GARCH models. The spread volatility shows a different behaviour before and after the EMU, consistent with increased flexibility under the new rules.

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1. Introduction

In recent years there have been significant changes in the use of reserve requirements in developed countries. Some years ago, reserve requirements were seen as an instrument to control the expansion of credit and money stock directly. Nowadays, the requirements for minimum reserves are used to create a stable demand for reserves in order to facilitate control over short-term interest rates. In Weiner (1992) we find a comparison between the traditional and the current role of requirement reserves in monetary policy. This is the case of the Euro Area where the Eurosystem's minimum reserve system is implemented to create or enlarge a structural liquidity shortage in the banking sector. This helps to make it possible to leave to the European Central Bank (ECB) the main role as a supplier of liquidity, through the implementation of open market operations.

Worldwide, the changing role of reserve requirements has been accompanied by a reduction in its volume. In Borio (1997) we can find a detailed characterization of reserve requirements in several countries, and this can be complemented by Sellon and Weiner (1996). This trend first arose from central banks' decisions which have reduced the institutional levels required, in order to improve the competitiveness of depository institutions in a deregulated environment. The requirement of holding reserves imposes a tax on the banking system as argued by Fama (1983), increasing the cost of banking services (the interest rates on credit) and decreasing the interest rate on deposits. A deregulated environment, where financial institutions other than banks perform similar functions without this restriction, represents strong competition to banks. This is the focus of Slovin, Sushka and Bendeck (1990) who analyze empirically the relation between changes in reserve regulation and the market value of banking stocks, concluding that the price of bank stocks reacts to changes in reserve requirements in a manner consistent with the hypothesis that they are a tax on bank activity. Also, with free circulation of capital, there is competition between the banking sectors of different countries. The pressure to improve competitiveness has led to the reduction of reserve requirements in most countries[1] and some of them, like England, Canada, and New Zealand have reduced the reserve ratios to zero.[2]

[1] The improved competitiveness of Portuguese banking sector was the main reason for the fall of the reserve ratio from 17% to 2% in 1994.

[2] However, a reserve ratio equal to zero can be accompanied by the obligation to hold positive daily balances, under the threat of a penalty.

Finally, in recent years the banks have acquired improved technological skills for reducing the reserve balances needed. This is the case for American banks where, since 1994[3], they have been able to improve *Retail Sweep Programs*[4]. As Anderson and Rasche (2000) and Bennett and Peristiani (2002) suggest, these programs have allowed many banks to become "*economically nounbound*", that is, the required reserves of these institutions are lower than the amount necessary for their ordinary course of business (note that, in USA, unlike in the Euro Area, vault cash is included in the maintenance of required balances).

The decline, or even the elimination, of requirement reserves in several countries in the last few decades, raises concerns about short term interest rate volatility, particularly overnight interest rate volatility. The literature describes some episodes of increasing volatility following reductions in required reserves balances but this connection between the level of reserves and interest rate volatility has not always been evident. The modeling of this relation has been proposed by Clouse and Elmendorf (1997) and VanHoose and Humphrey (2001).

The aim of this paper is to analyze the effects of the change in reserve requirements on the behavior of Portuguese interbank overnight rate volatility, before and after EMU, and the consequences of that change for Portuguese credit institutions' reserve management. It may be said that the introduction of the Single Monetary Policy reserve regime has contributed to the facilitating of reserve management by Portuguese credit institutions compared with the former regime.

This article proceeds as follows: Section 2 provides a review of the literature. Section 3 details the institutional features of the Portuguese domestic money market and the features of the two reserve systems encountered by Portuguese banks: before and after the EMU. Section 4 describes the data and the behaviour of market variables and presents the results of estimation of GARCH models. Concluding remarks can be found in Section 5.

2. Review of the literature

The decrease in, or elimination of, reserve requirements can lead to a relaxing of reserve function: the interest rate buffer, as Borio (1997) calls it. Reserve requirements are satisfied according to an average provision. Thus, the reserves held on any day of the maintenance period

[3] Thanks to the permission of Federal Reserve.

[4] The essence of *Retail Sweep Programs* is computer software that allows temporary switch deposits from one type of account (which is subject to reserve requirement ratios) to another (which is not subject of reserve requirement ratios), thereby reducing required reserve levels.

are perfect substitutes for the purposes of satisfying reserve requirements. The banks can perform an interest rate arbitrage: if the interest rate is high (low) the banks will lend (borrow) in the market. The decrease (increase) in the demand causes a fall (rise) in the overnight interest rate. If the banks demand reserves solely for their business needs (or if the working balances are binding), the averaging of balances is no longer possible. The demand for reserves is inelastic and the volatility of short-term interest rates is affected.

Several authors have identified episodes of changing volatility following changes in monetary policy and in reserve requirements in the USA. Nowak (1991) identified an increase in daily interest rate volatility as a consequence of the change, in 1984, in reserve accounting procedures, from a lagged to a contemporaneous accounting regime[5]. Dumitru and Stevens (1991), Bennett and Hilton (1997) and Clouse and Elmendorf (1997) describe the decrease in the American reserve ratio that occurred in December 1990, leading to a huge excess of liquidity which brought about a "dramatic" increase in daily and intra-daily overnight interest rate volatility. However, Bennett and Hilton (1997) and Clouse and Elmendorf (1997) did not identify an increase in volatility in the wake of the implementation of Retail Sweep Programs in 1994. The authors interpreted this as being due to the effects having been spread over many months. Also, Brunner and Low (1993) studied the period from 1984 to 1992 where two falls in reserve requirements occurred in the USA, and identified a decrease in interest rate volatility which the authors explained as being due to large excess reserve balance holdings that impeded overdrafts at the end of day[6]. Finally, Griffiths and Winters (2000) analyzed the effects of the 1994 increase in the allowable carryover of reserves in USA. This change was intended to increase the flexibility of the maintained reserve and to reduce the interest rate volatility. Griffiths and Winters (2000) did not identify the expected reduction in federal funds rate volatility but they found a decrease in the variance of the daily rate of three month Treasury Bills.

All of these articles are empirical works referring to the USA, and the main conclusion to be taken from their analyses is that the effects of changes in reserve requirements regimes on short-term interest volatility are ambiguous.

Modelling this ambiguity is the issue addressed by the Clouse and Elmendorf (1997) model.

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[5] Nowak (1991) wanted tackle the problem of using traditional econometric methods in heteroskedastic time series.

[6] This empirical analysis is based on monthly data which are not the most useful in the study of money market interest rates.

2.1. The model of Clouse and Elmendorf (1997)

Clouse and Elmendorf (1997) present a model of bank demand for reserve balances which shows that the level of required balances affects the daily volatility of overnight interest rates.

According to Clouse and Elmendorf (1997), the bank's demand for reserves can be divided in two parts.

The first is the demand for required reserves, which are imposed by the central bank and specified in terms of an average level over a maintenance period. So, there is a degree of substitutability between the balances from different days within the same maintenance period[7]. The demand function for required reserves is described as:

$$R_{jt} = L_j e^{(-\alpha\Delta_t + \mu_{jt})} \qquad (2.1)$$

where R_{jt} represents the required reserves demanded by bank *j* on day *t*, L_j indicates the desired requirement-related balance reserves by bank *j* when the actual funds rate equals the central bank target value[8] and there are no shocks, Δ_t is the difference between the actual and intended overnight interest rate, α is the interest semi-elasticity of the requirement-related balance[9] and μ_{jt} is a random shock to the requirement-related demand suffered by bank *j* on day *t*.

If the demand for requirement-related balance reserves is represented by this function, it is taken that, in the absence of random shocks, and with the actual funds rate equal to the target value, banks would choose to hold the same amount of reserve balances on each day of a maintenance period. We assume here a constant balance strategy. The larger Δ_t, the bigger the opportunity cost on holding required balances on day *t*, so, the smaller their demand.

The second element of demand for reserves is the daily demand that describes the balance a bank wants to hold to avoid *overdrafts* at the end of the day, or clearing demand.

[7] Clouse and Elmendorf (1997) include the *clearing balances* in this demand. In the USA, these are reserves held voluntarily by banks because these balances earn credits against Federal Reserve priced services. The clearing balances are not imposed by the central bank but, in this analysis, they are considered similar to reserve requirements because they are also specified in terms of an average level of balances over the maintenance period.

[8] In the USA, the Federal Reserve sets and announces a target value for the federal funds rate. The European Central Bank (ECB) does not set a target value for the overnight rate. Although, the minimum interest rate on Main Refinancing Operations (MRO) has a function of signaling the stance of monetary policy.

[9] According to this demand function, in logarithmics, we can see that $-\alpha = \partial \log R_{jt} / \partial \Delta_t$.

Overdrafts incur costs: borrowing on a marginal lending facility whose rate is higher than the market interest rate, or other penalties or administrative controls[10]. This is the business needs-related demand. The balances needed to avoid overdrafts are thus not substituted between different days; this demand is daily and insensitive to money market interest rates. The mathematical representation of this precautionary demand by bank *j* on day *t* is:

$$O_{jt} = K_j e^{(-\beta\Delta_t + \nu_{jt})} \quad (2.2)$$

where K_j is the desired clearing balance when the actual overnight rate equals its intended value and there are no shocks, β is the interest semi-elasticity of this kind of demand on reserves (and $\beta < \alpha$) and ν_{jt} is the random shock to precautionary demand suffered by bank *j* on day *t*.

Taking these two demands for reserves together, on day *t,* the effective demand for reserves of bank *j*, will be D_{jt} where:

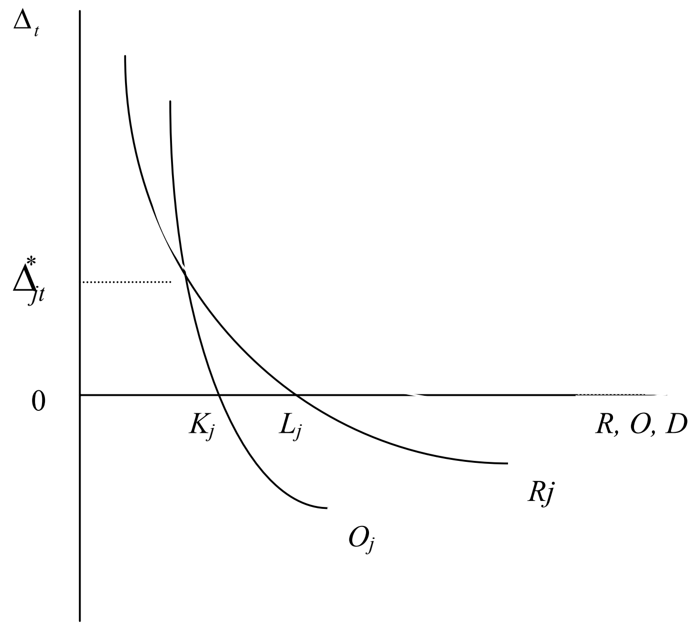
$$D_{jt} = \max\left(R_{jt}, O_{jt}\right) \quad (2.3)$$

Taking each possible value of deviation Δ_t one of the two demands on reserves is binding. When the market overnight rate is to close to its target value, it is the required-related demand that is binding. When the deviation is high it is the risk of overdraft that determines the bank's behavior relative to the demand for reserves.

Figure 1 shows the two demand functions. The stepper is the clearing demand, that is, the required related demand is more sensitive to interest rate changes.

[10] In the USA, banks have been characterized by a great reluctance to borrow through the Discount Window over the years, because they believe there is an implicit cost in Discount borrowing. See, for instance, Dutkowsky and McCoskey (2001).

Figure 1: The demand for reserves of bank *j*



The critical deviation (Δ^*_{jt}) is the value of the deviation between the market rate and the target rate, in which the two parts of the demand for reserves are equal, that is:

$$L_j e^{(-\alpha\Delta_t+\mu_{jt})} = K_j e^{(-\beta\Delta_t+\nu_{jt})}$$

In logarithmics :

$$l_{jt} + (-\alpha\Delta_t + \mu_t) = k_{jt} + (-\beta\Delta_t + \nu_t)$$

where l_{jt} and k_{jt} represent, respectively, the logarithm of L_{jt} and K_{jt} and where, by simplification, we consider that the random shocks are perfectly correlated across banks[11]. Developing this expression:

$$\Delta^*_{jt} = (\alpha - \beta)^{-1}(l_{jt} - k_{jt} + \mu_t - \nu_t) \qquad (2.4)$$

Figure 1 shows the two demand functions of bank *j*. Above and below Δ^*_{jt} in the vertical line, the demand for the reserves of bank *j* is represented by the line on the right. Thus, at some level of reserve balances, there is a switching between the binding types of reserve-related

[11] If the shocks affect each bank individually and differently, the results of the model do not change. Note that different behavior by different banks, thus balancing each other, have no effects on the market interest rate.

demand. The switching point is the critical value deviation of interest rates, and this is a *switching-model*.

According to this switching-model, if the required reserves regime changes in the direction of a lower required-related demand, that is l_{jt}, and the critical deviation Δ^*_{jt} decreases, the range of market interest rate values in which the daily clearing related demand is binding increases. The same will happen if a shock to the demand to avoid overdrafts has the effect of increasing it[12].

The aggregation of effective individual demand for reserve balances of all banks gives the aggregate effective demand for reserves:

$$D_t = \sum_{j=1}^{n} D_{jt} = \sum_{j=1}^{n} \max(R_{jt}, O_{jt}) \tag{2.5}$$

The supply of reserves is settled by the central bank:

$$S_t = A + \omega_t \tag{2.6}$$

where A is the central bank's intended supply through open market operations and ω_t is a random shock on day *t*.

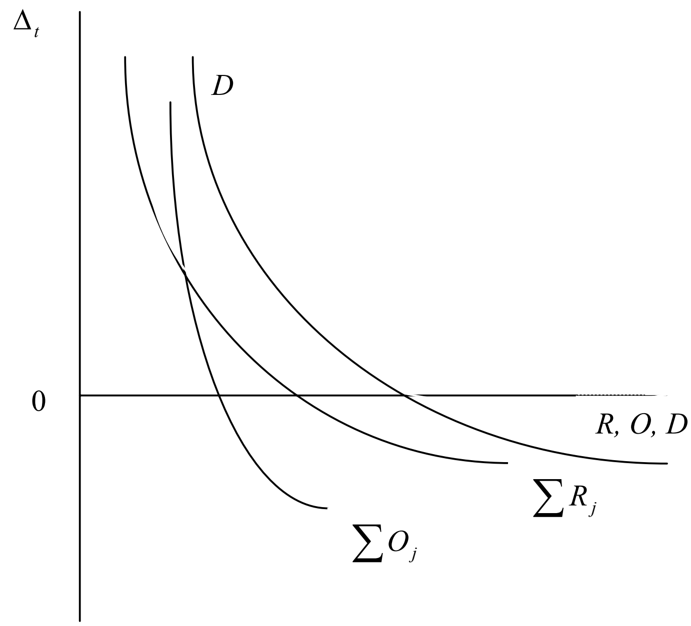
Equilibrium in the funds market requires equal aggregated demand and supply:

$$\sum_{j=1}^{n} \max\left(L_j e^{(-\alpha\Delta_t + \mu_{jt})}, K_j e^{(-\beta\Delta_t + \nu_{jt})}\right) = A + \omega_t \tag{2.7}$$

The bigger the deviation Δ_t, the greater will be the number of banks whose demand is determined by the risk of overdraft. As a result, the aggregate demand converges to the sum of the individual's precautionary demands. The inverse occurs for very low deviations. For intermediate values of Δ_t, there will be banks in the two different situations, which results in a smooth aggregate demand, without a switching point unlike the bank's individual demand. Figure 2 shows aggregate demand. In this figure the reserves supply would be a vertical line.

[12] Clouse and Elmendorf (1997) recognized the limitation of using a constant semi-elasticity of demand, which implies that banks are willing to hold very large quantities of reserves balances as the funds rate falls.

Figure 2: Aggregate demand for reserves



A decrease in the required ratio would have the effect of moving the required-related demand to the left and the aggregated demand to the left, too, because a large number of banks would see their demand for reserves depending on the precautionary demand. This means an increase in overnight interest rate volatility. A shock to the precautionary demand that moves the demand $\sum O_j$ to the right would have the same effect. As an example, a Treasury auction could have this effect in the sense that it increases the volume of interbank transactions and raises the uncertainty about end-of-day balances.

Clouse and Elmendorf (1997) estimated the parameters of the model, using data for a large number of banks and money market data. These parameters are then used to simulate the effects of changes in required reserves. Continued falls in required reserves volume have the effect of increasing the standard deviation of the difference between the market interest rate and the target rate. This increase is non-linear because continued drops in required balances mean that there are more banks whose reserves demand is determined by overdraft risk, and so an acceleration in funds rate volatility occurs. However, the improvement by banks of their reserves management skills, including the ability of forecasting end-of-day balances, reduces the uncertainty, dampening the increase in interest rate volatility[13].

The analysis of the effects of lower required reserves on interest rate volatility, and the consequent reduced monetary policy effectiveness, is also the aim of VanHoose and Humphrey (2001) model. For these authors, improving the predictability of reserve demand does nothing to reduce uncertainty in daily payment flows. They present a model of intraday bank reserve management[14] and interest rate determination, with the aim of identifying the effects of the decrease in required reserves volume on short-term interest rate volatility. The model considers a single day where the bank aims to maximize its expected profit through the management of its earning assets. The bank experiences shocks that affect their balances and enters the overnight market funds. The funds are supplied by the central bank with the intention that the end-of-day funds rate is equal to the target value[15,16]. If the market is already closed and the bank needs funds, it pays a penalty to the central bank[17].

The overnight interest rate is market-determined, and VanHoose and Humphrey (2001) show the solution to its variance, represented by:

$$Var(i) = f\left[(\varepsilon_2 - E(\varepsilon_2)), (D_2 - E(D_2)), \overline{R}, \rho, W\right] \tag{2.8}$$

where i is the overnight interest rate, $(\varepsilon_2 - E(\varepsilon_2))$ is the unexpected shock late in the day, that is, near the close of the funds market[18], $(D_2 - E(D_2))$ represent unexpected deposit changes, that also occur late in the day, $\overline{R}$ is the required reserves, ρ is the overdraft cost and W is a vector of balance sheet adjustment costs (non-negatives).

A reduction in required reserves (in reserves ratio or due to sweep accounts) has an ambiguous effect on interest rate variance. The reason for this ambiguity is that a reserve-requirement reduction has two opposing effects:

[13] For Clouse and Elmendorf (1997), this is one of the features that explains the low interest rate volatility (compared with that in 1990) in the USA, after the introduction of Retail Sweep Programs in 1994.

[14] Reserve management models have been developed for several decades by, for example Orr and Melon (1961) and Poole (1968). A survey of this area can be found in Baltensperger (1980) and in Santomero (1984). For recent work see, for instance, Nautz (1998) and Clouse and Dow Jr. (1999).

[15] Naturally, the supply of liquidity fits the central bank forecasts of demand for reserves by banks.

[16] The central bank conducts open market operations and lends 24 hours funds (paid the next day) and intraday funds (paid the same day). In this work the intraday rate is set by central bank and all intraday credit is available. In VanHoose (1991) the intraday rate depends on the market. The author also analyses the relation between this rate and other maturity rates.

[17] The penalty can be the marginal lending interest rate (higher than market interest rate) or another charged fixed by the central bank.

[18] This shock occurs after central bank intervention.

1) A reduction in required reserves makes the demand for reserves less sensitive to interest rate changes, leading to greater potential funds rate volatility.

2) A reduction in required reserves frees liquid funds. These funds have an opportunity cost. However, the banks can retain some of them in order to cover unexpected shocks. This reduces the interest rate volatility[19].

The theoretical conclusion of this model is that falls in required reserves demand have an ambiguous effect on overnight interest rate volatility.

The empirical analysis by VanHoose and Humphrey (2001) set out to test two hypotheses: 1) a fall in reserve requirements leads to increased federal funds rate volatility (relative to its target), and 2) the increase in federal funds rate volatility leads to increased short-term interest rates volatility.

The estimations were divided in two periods: before (May 1991-January 1994) and after (March 1994-August 1996) the improvement of public announcement of funds rate target. A relationship between a decrease in reserve requirements and an increase in overnight volatility was identified for the first period[20], but not for the second period considered. The implementation of sweep accounts did not affect the central bank's ability to implement monetary policy. The answer to the second question is the same: volatility transmission existed, but not in the second period where the target value for funds rate is announced. In this period, funds rate volatility appears as noise, rather then conveying information about changes in monetary policy.

The result of Bartolini, Bertola and Prati's (2002) empirical investigation is similar. They conclude that the Fed's transparency policy adopted after 1994 had an effect of "smoothing" funds rate volatility across maintenance periods. It can be said that, with announced monetary policy, funds rate volatility appears as noise, rather then conveying uncertainty about future monetary policy.

In conclusion, the Clouse and Elmendorf (1997) and VanHoose and Humphrey (2001) theoretical models, yield the same result: the effect of a fall in reserve requirements on funds rate volatility is ambiguous. This ambiguity arises from the fact that demand for reserves could be business-needs determined. Reserves needed for business with clients are not specified in

[19] This effect can be criticized: if the required reserves are specified in terms of an average level over a maintenance period, they are always a buffer against unexpected shocks. The exceptions are the last days of maintenance periods when funds rate volatility is higher.

[20] The identification (or not) of this relationship was achieved through non-linear estimations between the logarithm of the deviation (between the actual interest rate and the target rate) and the logarithm of required reserves volume.

terms of an average level over a maintenance period, thereby giving rise to a higher potential volatility. This ambiguity is identified theoretically and empirically. It depends on several factors, such as the ability to forecast and manage reserves, monetary policy implementation and the impact of continued changes in required reserve system.

3. The Portuguese Interbank Money Market and the requirement reserves faced by Portuguese banks

The institutional features of the reserve requirements faced by Portuguese banks changed with the coming of the EMU. The reserve ratio remained constant, with a value of 2%, the reserve base maintained its main characteristics and the required reserves are also specified in terms of an average level over a maintenance period. However, two important distinctions were introduced by the minimum reserve system of single monetary policy[21]. Until 1998 Portuguese banks faced a shorter reserve period of 7-8 days length. The minimum reserve system of the single monetary policy has a maintenance period of one month. The other difference is that, until 1998, the system was semi-lagged, that is, the calculation period partly overlapped the maintenance period, whereas later the system became lagged, meaning that the calculation period precedes the maintenance period. That is, until 1998, each calendar month had four periods of calculation and four periods of maintenance. The calculation periods were days 1-8, 9-15, 16-22 and 23-last day of month, and the reserves were calculated by applying the reserve ratio to average end-of day sheet balances. The maintenance periods begin 3 days after the calculation period, that is, they were, respectively, 4-11, 12-18, 19-25 and 26-3 of following month.

According to minimum reserve system of single monetary policy, it is the balance sheet data referring to the end of the calendar month that are used to determine the reserve base. The maintenance period starts on the 23rd day of the following month.

Note that a transition period was established so that the Portuguese banks could adapt to the new rules: between 4 November 1998 and 31 December 1998, two maintenance periods were settled, the first one between 4 and 23 November, the second between 24 November and 31 December. The reserve base was calculated on 31 October 1998.

[21] The detailed description of Single Monetary Policy instruments can be found in European Central Bank (2002).

The features of the Portuguese reserve system before EMU were much less flexible for the management of reserves by banks. The maintenance period was shorter and, in its first part (3 days), the banks were uncertain about the minimum balance level to hold.

According to the Clouse and Elmendorf's (1997) model, we can say that these changes in minimum reserves system have the following effects:

1) The increase in the length of maintenance period raises the degree of substitutability between the balances from different days, because banks have more days to balance the amounts of reserve accounts. This means that the elasticity of requirement-related demand increases and the demand curve rotates anti-clockwise (leaving the value of L_j unchanged). The critical deviation of an individual bank decreases and we should expect volatility to rise because business needs have become more binding.
2) The change from a semi-lagged reserve system to a lagged reserve system means that uncertainty about minimum reserves to hold disappears. Therefore, minimum reserve management becomes easier and banks can use a bigger amount of their (minimum) balances to avoid overdrafts. This causes a shift to the left in the demand to avoid overdrafts (K_j decreases) and the critical deviation of an individual bank increases. This effect is similar to that of an improvement of reserve management skills by banks.

These two factors have an opposite effect on the short-term interest rate volatility. Thus, there is an ambiguity in the effect of the changes of Portuguese minimum reserve system over interest rate volatility that must be empirical studied.

The reserves are lent and borrowed between banks in the Portuguese domestic interbank market, known as the Mercado Monetário Interbancário- MMI. The MMI 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[22].

The central bank money 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[23]. The

[22] The creation and evolution of the MMI are described in Sol (1996).
[23] The spot segment is the most important in the market.

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[24], an electronic 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[25].

4. Empirical Estimation

4.1. Data

We use the daily data on the MMI's overnight interest rate. The data covers the period from April 1995 to January 2003. We also use data on interest rate facilities, fixed by the Banco de Portugal until 1998 and by the ECB since then. The data were collected from the Banco de Portugal's site and from the ECB's site.

Using the selected data, we calculated the mid-point of the two marginal facilities rates, equal to $(i_t^l + i_t^d)/2$ where i_t^l is the rate of marginal lending facility and i_t^d is the rate of marginal deposit facility. Next we calculated the daily spread between the overnight interest rate and this average. Doing this, we are supposing that the target rate is equal to the mid-point of the interest facilities corridor. In support of this hypothesis is the fact that, from January 1999 until June 2002[26] the fixed rate for the MRO was equal to this mid-point, and after June 2002, the minimum MRO rate is equal to the mid-point of the corridor. Despite the fact that the MRO's rates have a different maturity from the overnight rate, they have the role of signalling the stance of monetary policy.

Thus, the spread series allows the study of volatility dynamics, on the basis of the short-term monetary policy objective. VanHoose and Humphrey (2001) analyze the behavior of the same variable (deviation of federal funds rate relatively to the target) to test the effects of changes in required reserves and changes on the central bank's procedures[27].

[24] The SITEME features are described in Banco de Portugal (2000).
[25] The interest is calculated according to the formula: Effective Number of Days/360.
[26] With the exception of a small time period (22 January to 14 April 1999).
[27] Bartolini, Bertola and Prati (2002), with similar objectives, use the series of federal funds rate, which they model as an E-GARCH.

4.2. Characterization of spread series

Figure A.1, Annex 1, illustrates the evolution of the spread between the overnight rate and the mid-point of the corridor of interest rate facilities. Figure A.2 shows the correlogram of the series, where the correlation coefficients decrease smoothly to zero.

First, we tested the stationary of the spread series by applying the Augmented-Dickey-Fuller test[28]: This test is based on autoregressive processes:

$$1)\ \Delta y_t = \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \tag{4.1}$$

$$2)\ \Delta y_t = a_0 + \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \tag{4.2}$$

$$3)\ \Delta y_t = a_0 + a_1 t + \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \tag{4.3}$$

where the second regression is different from the first one by the presence of a constant and the third regression is different from the second by the presence of a trend. To accept the stationary of the series, we must reject the hypothesis of γ being equal to zero.

The results are showed in table 1[29]:

[28] The calculation of statistics, along with the estimations and tests presented in this work, has used RATS, version 5.

[29] The "Augmented Dickey-Fuller" test was carried out through the URADF procedure of RATS. This procedure performs the t-test and z-test considering the selected number of lags (number of lags is selected through one of 5 criteria: AIC, BIC, Ljung-Box test, LM test or reducing the order of the lags until the last one is significant) and tests joint hypotheses on the coefficients.

Table1: ADF Test

Equation (1)	
Augmented Dickey-Fuller t-test with 8 lags:	-2.2363
1% 5% 10%	
-2.58 -1.95 -1.62	
Augmented Dickey-Fuller Z-test with 8 lags:	-9.1474
1% 5% 10%	
-13.8 -8.1 -5.7	
Equation (2)	
Augmented Dickey-Fuller t-test with 8 lags:	-2.6260
1% 5% 10%	
-3.43 -2.86 -2.57	
Augmented Dickey-Fuller Z-test with 8 lags:	-14.1122
1% 5% 10%	
-20.7 -14.1 -11.3	
Coefficient and T-Statistic on the Constant:	-0.00524 (-1.4169)
Joint test of a unit root and no constant:	
1% 5% 10%	3.5058
6.43 4.59 3.78	
Equation (3)	
Augmented Dickey-Fuller t-test with 8 lags:	-5.2544
1% 5% 10%	
-3.96 -3.41 -3.12	
Augmented Dickey-Fuller Z-test with 8 lags:	-62.1443
1% 5% 10%	
-29.5 -21.8 -18.3	
Coefficient and T-Statistic on the Constant:	-0.06926 (-4.7560)
Coefficient and T-Statistic on the Linear Trend:	0.00005 (4.5435)
Joint test of a unit root and no linear trend	
1% 5% 10%	13.8051
8.27 6.25 5.34	

From the analysis of table 1 we see that results for equation (3) are high, that is, we can reject the unit root hypothesis[30] and the trend is sufficient to explain the non-stationary. However, the results are less definitive for the other equations. Thus, we tested next for the presence of a structural change, which appears to happen (a “jump” in November 1998) if we look the figure A.1.

[30] According to Enders (1995), it is possible to reject the existence of a unit root only with the result of the test on equation (3) because it is the least restrictive of the models and the one which has the lower power to reject the null hypothesis of a unit root.

In accordance with Perron (1997), we tested three models[31]. The first one, called the *innovational outlier model*, tests the existence of a change in the intercept of trend function:

$$1)\ y_t = \mu + \theta DU_t + \beta t + \delta D(T_b)_t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \qquad (4.4)$$

where T_b denotes the time at which the change occurs and DU_t is a dummy that represents the change in the intercept resulting in the innovation at time T_b thus, DU_t=1 if $t > T_b$. $D(T_b)$ is also a dummy, which equals 1 if $t = T_b + 1$ and 0 if not.

Under the second model, a change in both the intercept and the slope are allowed at time T_b:

$$2)\ y_t = \mu + \theta DU_t + \beta t + \gamma DT_t + \delta D(T_b)_t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \qquad (4.5)$$

where DT_t is the change in the slope.

Under the third model, a change in the slope is allowed but both segments of the trend function are joined at T_b.

Table 2 gives the results of the application of tests for structural breaks[32] to the spread series, for the two models presented.

The results show that spread series is stationary with a structural change in 24 November 1998. This is the day that follows the first one of the reserves maintenance period in the period of transition to EMU. Thus, there is a structural change in the series that divides it into two: before and after EMU (the change is located at the middle of transition period). The structural change is the result of a significant and positive change in the intercept (see, also figure A.1). The second model results show a structural break on 16 December 1998, also in the middle of the transition period. Value of *DT* is not significant. The estimated coefficients are similar in both models.

In conclusion, we accept the stationary of the spread series with a structural change in 24 November 1998. Thus, we eliminate the data for the transition period (4 November-31 December 1998) where the Portuguese banks are adapting to the new procedures and we study the two parts of the series separately: before (April 1995-November 1998) and after EMU (January 1999-January 2003).

[31] The test for structural change was performed by the procedure PERRON97 of RATS, which endogenously determines the moment of the change.

[32] According to this procedure, the method that selects the time of the change is the one that minimizes the t-statistic for testing $\alpha = 1$.

Table 2: Structural change test

Model 1							
break date TB = 24/11/1998			statistic t(alpha=1) =				-9.34052
critical values (for infinite sample) at							
1%	5%	10%	50%	90%	95%	99%	
-5.41	-4.80	-4.58	-3.75	-2.99	-2.77	-2.32	
number of lag retained : 8							
explained variable : i_t-1/2(l_t+d_t)							
	coefficient	student					
CONSTANT	-0.16148	-8.64704					
DU	0.13355	7.71911					
D(Tb)	-0.14094	-1.13878					
TIME	2.38534e-05	2.26877					
ONT {1}	0.82220	43.192851					
Model 2							
break date TB = 16/12/1998			statistic t(alpha=1) =				-9.41150
critical values (for infinite sample) at							
1%	5%	10%	50%	90%	95%	99%	
-5.57	-5.08	-4.82	-3.98	-3.25	-3.06	-2.72	
number of lag retained : 8							
explained variable : i_t-1/2(l_t+d_t)							
	coefficient	student					
CONSTANT	-0.18035	-8.70271					
DU	0.16792	6.35929					
D(Tb)	-0.04457	-0.36067					
TIME	4.24468e-05	2.66657					
DT	-2.85636e-05	-1.40818					
ONT {1}	0.80889	39.83378					

4.3. Method of volatility analysis

The aim of this work is to study the effects of changes in the Portuguese reserve requirement system on interest rate volatility.

In the literature dealing with studies short term interest rate behavior, it is usual to consider the martingale hypothesis – that reserves held on any day are perfect substitutes within maintenance periods – from which derives that the changes in interest rate along maintenance periods are unpredictable. However, the empirical evidence shows a predictable pattern in overnight interest rate changes, for the different days of maintenance periods in the American money market[33]. After the introduction of the Single Monetary Policy, the martingale hypothesis

[33] See, for instance, Hamilton (1996).

can not be rejected for the European money market[34]. That said, there is also empirical evidence, for the American and the European markets that the overnight interest rate volatility increases as the settlement day approaches.

Thus, like Bartolini and Prati (2003), we studied the series of spread changes in order to identify a volatility pattern along the maintenance period. Bartolini and Prati (2003) compare the behavior of the short-term interest rate in two economic areas, according to the regulations imposed in each of them[35]. They use GARCH models applied to the series of spread changes.

We have therefore modeled the volatility of the series of spread changes through GARCH models. The statistics of the spread changes series are given in table 3. Both series show a high degree of kurtosis (leptokurtic) and are right skewed. The Jarque-Bera test of normality shows a high value, confirming the non-normality of the two series. The fact that the series do 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 analysed the auto-correlation function (ACF) and the partial autocorrelation function (PACF) of squared spread changes.

Table 3: Statistics for the series of the spread changes

3 April 1995- 3 November 1998			
Sample Mean	0.00039237668	Variance	0.015454
Standard Error	0.12431308303	SE of Sample Mean	0.004162
t-Statistic	0.09427	Signif Level (Mean=0)	0.92491669
Skewness	1.94807	Signif Level (Sk=0)	0.00000000
Kurtosis	11.63423	Signif Level (Ku=0)	0.00000000
Jarque-Bera	5594.89140	Signif Level (JB=0)	0.00000000
4 January 1999- 31 January 2003			
Sample Mean	-0.0001936445	Variance	0.020905
Standard Error	0.1445855434	SE of Sample Mean	0.004556
t-Statistic	-0.04250	Signif Level (Mean=0)	0.96610807
Skewness	0.62184	Signif Level (Sk=0)	0.00000000
Kurtosis	12.45653	Signif Level (Ku=0)	0.00000000
Jarque-Bera	6575.36692	Signif Level (JB=0)	0.00000000

Table 4 presents the values of the autocorrelation functions and statistic-Q.

[34] See, for instance, Quiróz and Mendizábal (2001).
[35] Cyree, Griffiths and Winters (2003) analyze the interest rate spread changes *spreads* in order to identify patterns in short-term interest rate volatility. Their final objective is to study the pervasive effects of American settlement regulations over the English short term rate.

Table 4: Autocorrelation function (ACF) and partial autocorrelation function (PACF) of squared spread changes

	3/4/1995 - 3/11/1998				4/1/1999 – 31/1/2003			
	ACF	PACF	Q-Stat	P-value	ACF	PACF	Q-Stat	P-value
1	0.1127	0.1127	11.3591	0.0008	0.1364	0.1364	18.8013	0.0000
2	0.0832	0.0714	17.5578	0.0002	0.1307	0.1143	36.0823	0.0000
3	0.1019	0.0868	26.8879	0.0000	0.0052	-0.0270	36.1096	0.0000
4	0.1182	0.0956	39.4287	0.0000	0.0578	0.0470	39.4899	0.0000
5	0.1443	0.1146	58.1434	0.0000	-0.0211	-0.0321	39.9423	0.0000
10	0.0971	0.0135	199.0850	0.0000	-0.0492	-0.0312	50.4011	0.0000
15	0.0224	-0.0404	258.9326	0.0000	-0.0104	-0.0119	54.2548	0.0000
20	0.0429	-0.0824	277.0483	0.0000	0.1491	0.1319	85.7773	0.0000
25	0.0043	-0.0071	283.1374	0.0000	-0.031	-0.0763	169.8905	0.0000

These autocorrelations are always significant and give p-values of zero. They continue to decrease with the increase in the number of lags. These autocorrelations show that the series of spread changes are characterised by *clustering*, that is, significant spread changes are followed by significant spread changes. This is a feature of heteroskedastic series[36].

Finally, we used GARCH[37] models to estimate the process followed by the spread and its variance. The estimated equations are:

$$y_t = a_0 + \sum_{i=1}^{p} a_i y_{t-1} + \sum_{i=1}^{q} b_i v_{t-1} + \varepsilon_t \tag{4.6}$$

where y_t represents the spread changes series, which is modeled as an ARMA(*p,q*) process and ε_t is described as a process

$$\varepsilon_t = z_t \sigma_t$$

where $z_t \approx i.i.d.(0,1)$ and σ_t is a function conditional on information available at moment *t-1*, that follows a GARCH (*p,q*) process:

GARCH (*p,q*): $$\sigma_t^2 = \omega + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i \sigma_{t-i}^2 \qquad \text{where } \alpha_i \geq 0 \text{ and } \beta_i \geq 0 \tag{4.7}$$

The estimation of GARCH (1,1) models was found to be correct for the two periods considered, and the test does not permit the rejection of the inexistence of additional ARCH effects. However, for the period before EMU, we always verified the rejection of the inexistence

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

[37] About ARCH/GARCH models and their extensions, see, for instance, the surveys by Bollerslev, Chou and Kroner (1992) and Bollerslev, Engle and Nelson, Handbook of Econometrics, Vol. IV, Chapter 49.

of signal effects. We therefore estimate, for this period, asymmetrical models of the type EGARCH and GJR:

EGARCH (*p,q*): $$\log\sigma_t^2 = \omega + \sum_{i=1}^{q}\alpha_i\left[\phi z_{t-i} + \gamma\left(\left|z_{t-i}\right| - E\left|z_{t-i}\right|\right)\right] + \sum_{i=1}^{p}\beta_i \log\sigma_{t-i}^2 \qquad (4.8)$$

where $z_{t-i} = \varepsilon_{t-1} / \sigma_{t-i}$ and there are no restrictions on parameters α_i and β_i

GJR: $$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 + \lambda\varepsilon_{t-1}^2 I_{t-1}^- \qquad (4.9)$$

where I_{t-1}^- is a dummy variable, where $I_{t-1}^- = 1$ if $\varepsilon_{t-1} < 0$

In the EGARCH model introduced by Nelson (1991), the conditional variance depends on both the size and the sign of lagged residuals.

An alternative to the EGARCH model was proposed by Glosten, Jagannathan and Runkle (1993)[38]. GJR is an asymmetric model that incorporates the sign of lagged residuals into the GARCH model. The GJR presented in equation (4.9) is based on GARCH(1,1). The GJR model is a version of a threshold GARCH, or TARCH, that allows the volatility to react differently to news of different signs[39].

For our series, the GJR showed better results, in terms of the tests performed, than the EGARCH model[40].

In each of these models a vector of exogenous variables, which help to explain the volatility, can be also take in account. We included some exogenous variables:

-the maintenance periods, before and after EMU, were divided into an equal number of parts. Until 1998 each of these parts corresponds to one day; after January 1999 each of these parts corresponds to several days, because maintenance periods are longer. A dummy variable was assigned to each of these parts. Thus we can compare the behavior of the spread across the maintenance periods.

- We considered the central bank's regular and occasional operations, and assigned a dummy variable to each of them. Until 1998 the Banco de Portugal provided liquidity to the

[38] The GJR model has been widely used in overnight interest rate modeling and overnight spread modeling. See, for instance, the recent works of Cyree, Griffiths and Winters (2003) and Lee (2002).
[39] Engle and Ng (1993) analyse comparatively several assymetric models including the EGARCH model and the GJR model.
[40] The GARCH and EGARCH estimations were carried out by procedure Garch.src of RATS-Version 5, which uses the MLE-Maximum Likelihood Estimates method and performs several tests. The GJR estimations were achieved through the writing of an adequate procedure.

banks through regular operations performed on the first day of the maintenance periods. When necessary it absorbs liquidity. After January 1999 we considered the regular MRO (for which we considered a dummy for the announcement day and another for the settlement day) and occasional Fine-Tuning Operations[41]. All of these operations were realized through an auction procedure.

- a dummy variable that takes value one on days where there is a change in interest rate standing facilities, and also on preceding days.

- finally, we introduced the exogenous variable change into the volume of the MMI's loans.

4.4. Results

The results are given in table 5:

[41] We did not take into account the Longer-term refinancing operations because they affect the banking sector liquidity for long periods.

Table 5: Model estimation

	3/4/1995 - 3/11/1998		4/1/1999 – 31/1/2003	
Mean				
Constant	-0.000406 (0.000377)		-0.000175 (0.000059)	**
AR1	0.6583 (0.0429)	**	0.7584 (0.0140)	**
MA1	-0.8332 (0.0316)	**	-0.9242 (0.007934)	**
Variance				
constant	0.001108 (0.000492)	**	0.003647 (0.000327)	**
α	0.008858 (0.0179)		0.7011 (0.0468)	**
β	0.3928 (0.04118)	**	0.1455 (0.0148)	**
λ	0.8533 (0.1351)	**	-	
1st part of MP	0.000509 (0.000809)		-	
2nd parte of MP	-		-0.003442 (0.000327)	**
3rd part of MP	0.002199 (0.000565)	**	-0.003496 (0.000329)	**
4rd part of MP	0.000414 (0.000399)		0.003659 (0.000371)	**
Last part of MP	0.005492 (0.000635)	**	0.0370 (0.000463)	**
Change in interest rates standing facilities	0.006567 (0.001384)	**	0.0258 (0.005675)	**
Regular liquidity absorption	0.001399 (0.001760)		-	
MRO announcement	-		-0.000109 (0.000038)	**
MRO settlement	-		0.000193 (0.000063)	**
Occasional liquidity lending	-0.000777 (0.000434)		-	
Fine-Tuning Operations	-		0.00382 (0.001699)	*
Change in loan volume	-0.0000019 (0.0000009)		-0.0000002 (0.00000008)	*

Standard error estimates are given in parentheses
* Significant at 5% level
** Significant at 1% level

The main difference found in the estimations for the two periods considered is the issue of asymmetry in the way that volatility reacts to news of a different sign. After EMU, no sign effects on volatility were detected. However, they were always present in the period before EMU. Thus, the models that best fitted the data were an asymmetric GARCH(1,1), or GJR model in the period that precedes EMU, and a GARCH(1,1) for the EMU period. This can be interpreted on the basis of maintenance period length. Before EMU, "bad news" represented an important risk in the holding of minimum required balances. After EMU, with its longer maintenance period, one single day with lower balances is not significant[42]. It is important to note that there is asymmetry in required reserve holdings: excess reserves represent an opportunity cost, but the shortage of minimum balances means a penalty[43]. The less the time remaining until the end of maintenance period, the lower the capacity to invert a bad position, as Spindt and Hoffmeister (1988) say. Thus, before EMU, when the length of maintenance period was 7/8 days, the volatility reaction to bad news is positive ($\lambda = 0{,}85$); after EMU the reaction is the same to bad and good news.

The GARCH effect, that is, the shock persistence, is higher before EMU.

The estimated coefficients for the different parts of the maintenance period[44], are all positive before EMU, and two of them (including the one for the last day) are significant. After EMU all of them are significant and two of them are negative. Therefore, before EMU there is not a strong pattern in volatility across the reserve maintenance periods, and volatility tends to rise across it. After January 1999, with a longer period, the spread volatility falls and then rises on the last two parts considered. The estimated coefficient for the last part of the maintenance periods, after EMU, is the bigger one: with a longer maintenance period, the pressure to hold minimum reserves is "pushed" to the last days of the periods.

These conclusions are supported by the estimated coefficients of monetary policy operations. Before EMU, only the coefficient of the standing facilities' interest rates changes is significant, and it is smaller than the same estimated coefficient for the period after EMU: before EMU the interest rate change expectations are less important due to the difficulty in holding minimum reserves.

[42] This is even more important due to the uncertainty in the minimum balances: until 1998 the calculation period ended 3 days after the beginning of maintenance period.

[43] Cyree, Griffiths and Winters (2003) noted the asymmetry in reserve balances, but this was in the case of carryover (excess or deficit) availability for the following period. In this case, a shortage means funds borrowed from Federal Reserve at zero interest rate.

[44] Before EMU, we included in the estimation, the dummy for the first day of the maintenance period. This is the day when the central bank carried out regular operations to provide liquidity. After EMU we do not include the dummy for the first part of the maintenance periods, so the estimated coefficients for the other parts are interpreted by reference to this one.

The estimated coefficients for open market variables are significant only in the period after January 1999. The coefficient of the MRO announcement is negative: the announcement has the effect of decreasing uncertainty about banking sector liquidity conditions. The coefficient of the MRO settlement is positive: after the banks take possession of the funds, they proceed to redistribute them. The dummy for Fine-Tuning Operations has a positive coefficient: the need of this kind of operation is a signal that the banking liquidity is not balanced.

Finally, the exogenous variable change in the volume, too, is significant only in the period after EMU. Its estimated coefficient is negative: a higher volume of loans in the money market means a clearer liquidity situation (excess or shortage).

In conclusion, the change in the reserve requirement system, which took place in Portugal with the 3rd stage of EMU, has the effect of changing the behavior of the spread between the overnight interest rate and the target rate. This change was identified through the application of structural change tests. Here, the two series are modeled by GARCH models: the models that best fitted the data are a GJR(1,1) in the period before EMU, and a GARCH(1,1) in the period after EMU. The asymmetric model applied to the data that precedes the 3rd stage of EMU shows that the spread reacts strongly to bad news.

Furthermore, the estimated coefficients for the several parts of maintenance periods demonstrate that, until 1998, the spread volatility is stable across maintenance periods, with a tendency to increase. After January 1999, the volatility shows a U-pattern. The dummies for monetary policy operations are significant only after January 1999: before that period, the banks do not react to them because their behavior is determined by the risk present in accomplishing the required reserves.

It may be said that the change in the reserve requirement system brought more flexible conditions for the maintenance of minimum reserves to the Portuguese banking sector. The spread's conditional volatility is no longer sensitive to bad news: it vanishes in a longer maintenance period. The length of the maintenance periods allows the volatility to decrease during the course of them, and it increases only at the end, when the banks are under the pressure to hold minimum reserves.

5. Concluding Remarks

The aim of this work is to characterise the effects of the introduction of Single Monetary Policy, specifically, its required reserve system, on Portuguese money market interest rate volatility.

The literature reviewed identifies certain ambiguous effects of reserve requirement regime changes on short-term interest rate volatility.

The introduction of the Single Monetary Policy reserve regime may be said to have contributed to the easing of reserve management by Portuguese credit institutions, in comparison with the former regime. The evidence shows that, before EMU, the banks' reaction to "bad news" was different from its reaction to "good news", in the sense that the reserve management was much more difficult with a shorter reserve maintenance period, and uncertainty in the relation to the minimum reserves they had to hold. The estimated coefficients for the dummy variables included (days of maintenance periods and monetary policy actions) also indicate greater difficulty for reserve management before 1999. After January 1999, the pressure to hold minimum reserves is only felt in the last two days of the maintenance period, when the exact requirement must be met. Thus, before EMU, volatility was more stable across the reserves maintenance period. Since EMU volatility it has been pushed to last days of the maintenance period.

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Annex 1

Figure A.1

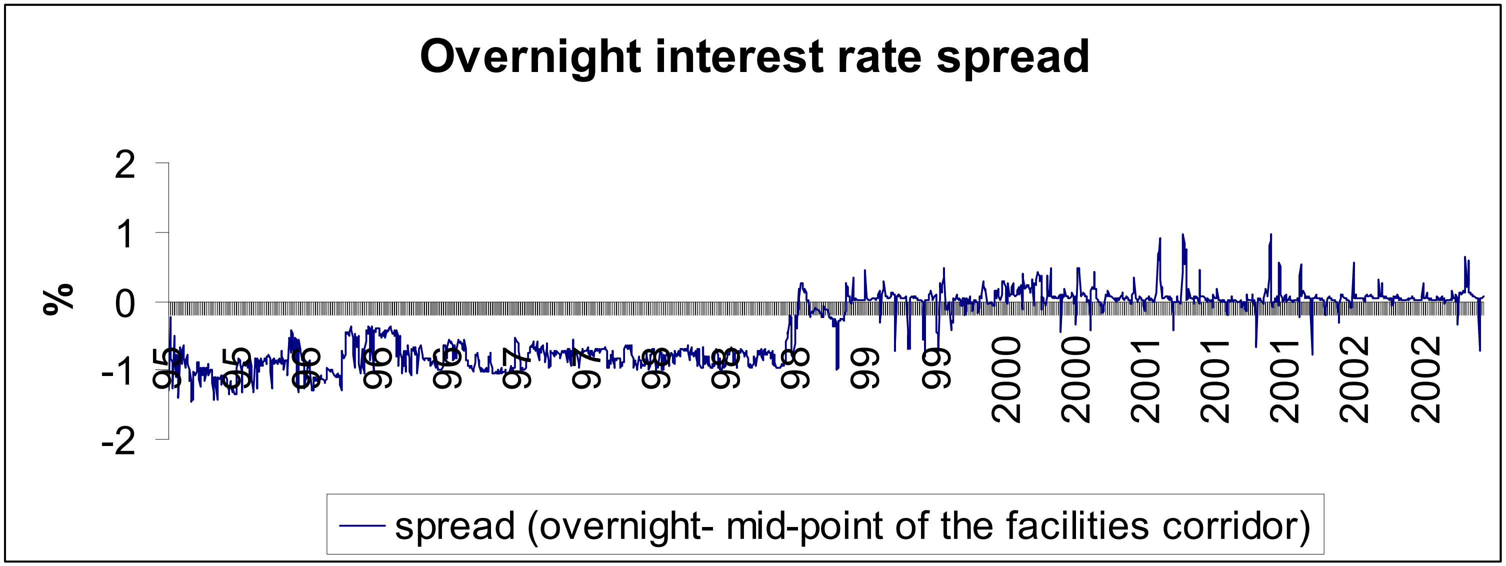

Figure A.2

Correlogram of the spread series (overnight interest rate – mid-point of the corridor of interest rate facilities)